LUT
Lappeenranta
University of Technology

LAPPEENRANTA UNIVERSITY OF TECHNOLOGY
LUT School of Energy Systems
Master's Degree Programme in Energy Technology

Master's thesis

Jere Nylund

LOCAL ENERGY MARKETS: OPPORTUNITIES AND CHALLENGES

Examiners: Professor Samuli Honkapuro
D.Sc. Ahti Jaatinen-Värri

Supervisors: D.Sc. Salla Annala
Ph.D. Gonçalo Mendes

ABSTRACT

Lappeenranta University of Technology
LUT School of Energy Systems
Master's Degree Programme in Energy Technology

Jere Nylund

Local energy markets: opportunities and challenges

Master's Thesis
2018
106 pages, 13 figures and 4 tables

Examiners: Prof. Samuli Honkapuro
D.Sc. Ahti Jaatinen-Värri
Supervisors: D.Sc. Salla Annala
Ph.D. Gonçalo Mendes

Keywords: local energy markets, peer-to-peer trading, prosumers, aggregators, distributed energy resources, local energy community, microgrid

The integration of distributed energy resources and a transformation of consumers into prosumers bring new opportunities and challenges to the power systems. A local energy market is a marketplace that aims to maximize the utilization of local energy assets by optimizing the use of end-users' flexible resources. A peer-to-peer energy trading platforms enable end-users to trade and share energy with other participants of the local energy marketplace. Services related to demand response, aggregation and grid management are other essential aspects in local energy markets.

The objective of this master's thesis is to review the opportunities and challenges of local energy markets. Alternative local market models are introduced, and stakeholders' roles and interactions are investigated. The findings of the study showed that local energy markets can bring benefits to customers and the network operators at several levels. The benefits are, for instance, reduced energy costs of customers, improved security of supply, effective use of local resources, cleaner energy generation and increased flexibility of the network. In addition, local markets provide an opportunity for service providers to develop innovative customer-centric energy services.

However, the concept of local energy markets is still new and under development, thus there are many barriers that hinder its development. The challenges are, for instance, the technical and economic maturity of distributed energy resources, various regulatory barriers, societal barriers and ensuring a secure data handling.

The development of local energy markets require clear regulatory framework, which determines the rights and responsibilities of the market actors. The stakeholder co-operation is necessary in order to develop novel market models and to achieve well-functioning local energy marketplaces.

TIIVISTELMÄ

Lappeenrannan teknillinen yliopisto
LUT School of Energy Systems
Energiatekniikan koulutusohjelma

Jere Nylund

Paikalliset energiamarkkinat: mahdollisuudet ja haasteet

Diplomityö
2018
106 sivua, 13 kuvaa ja 4 taulukkoa

Työn tarkastajat: Prof. Samuli Honkapuro
TkT Ahti Jaatinen-Värri
Työn ohjaajat: TkT Salla Annala
FT Gonçalo Mendes

Hakusanat: paikalliset energiamarkkinat, aggregaattorit, hajautetut energiaresurssit, paikallinen energiayhteisö, mikroverkko

Hajautetut energiaresurssit ja kuluttajien muutos sähköntuottajiksi tuo uusia mahdollisuuksia ja haasteita sähköjärjestelmiin. Paikallinen energiamarkkina on markkinapaikka, jonka tavoitteena on maksimoida paikallisten energiavarojen hyödyntäminen optimoimalla loppukäyttäjien joustavien resurssien käyttöä. Uudet kaupankäyntialustat mahdollistavat loppukäyttäjien myydä ja jakaa energiaa paikallisen markkinapaikan muiden jäsenten kesken. Muita keskeisiä paikallisiin energiamarkkinoihin liittyviä asioita ovat kysyntäjoustoon, aggregointiin ja verkonhallintaan liittyvät palvelut.

Tämän diplomityön tavoitteena on tarkastella paikallisten energiamarkkinoiden mahdollisuuksia ja haasteita. Vaihtoehtoisia markkinamalleja esitellään ja tutkitaan sidosryhmien rooleja ja vuorovaikusta paikallisella markkinapaikalla. Työn tulokset osoittivat paikallisten energiamarkkinoiden tuovan hyötyä asiakkaille ja verkkoyhtiöille useilla eri tasoilla. Hyötyjä ovat esimerkiksi asiakkaiden pienentyneet energiakulut, parantunut toimitusvarmuus, paikallisten energiaresurssien tehokas käyttö, puhtaampi tuotanto ja joustavampi sähköverkko. Lisäksi paikalliset markkinapaikat tarjoavat palveluntarjoajille tilaisuuden innovatiivisten ja asiakaskeskeisten energiapalveluiden kehittämiselle.

Paikallisten energiamarkkinoiden konsepti on kuitenkin uusi ja kehittyvä, joten on vielä monia esteitä, jotka haittaavat sen kehitystä. Haasteita ovat esimerkiksi hajautettujen energiaresurssien teknillinen ja taloudellinen kypsyys, useat regulaatioesteet, yhteiskunnalliset esteet sekä datan tietoturvallisen käsittelyn varmistaminen.

Paikallisten energiamarkkinoiden kehitykseen tarvitaan selkeä sääntelykehys, jossa määritellään toimijoiden oikeudet ja velvollisuudet. Sidosryhmien yhteistyö on välttämätöntä uusien markkinamallien kehittämiseksi ja tehokkaasti toimivien markkinapaikkojen saavuttamiseksi.

ACKNOWLEDGEMENTS

This thesis was written at The Laboratory of Electricity Market and Power Systems in Lappeenranta University of Technology within the DOMINOES project funded by the European Commission (Horizon 2020 Programme, Grant No. 771066).

I would like to thank LUT Energy Systems for providing the opportunity to take part in the DOMINOES project. I want to express my gratitude to my instructors Samuli Honkapuro, Ahti Jaatinen-Värri, Salla Annala and Gonçalo Mendes for their guidance and help during the research process.

I would also like to thank my family and friends for supporting me in my studies and in my personal life as well.

Lappeenranta, 30.7.2018
Jere Nylund

TABLE OF CONTENTS

NOMENCLATURE

ADS	Active Demand and Supply
BRO	Balance Resource Owner
BRP	Balance Responsibility Party
BSP	Balancing Service Provider
CDS	Closed Distribution System
CHP	Combined Heat and Power
DA	Day-ahead
DER	Distributed Energy Resources
DSM	Demand Side Management
DSO	Distribution System Operator
ECSP	Energy Community Service Provider
ESCO	Energy Service Company
EU	European Union
EV	Electric Vehicle
FCR	Frequency Containment Reserves
FCR-D	Frequency Containment Reserve for Disturbances
FCR-N	Frequency Containment Reserve for Normal Operation
HVAC	Heating, Ventilation and Air Conditioning
ICT	Information and Communication Technology
PV	Photovoltaic
TSO	Transmission System Operator
USEF	Universal Smart Energy Framework
VoLL	Value of Lost Load
VPP	Virtual Power Plant

1 INTRODUCTION

The increasing amount of renewable energy generation has brought new opportunities and challenges to the electricity markets and power systems. Most of this new renewable energy generation, such as wind and solar energy, has intermittent nature, and that unpredictability is causing challenges to traditional energy systems. Local energy markets enable customers to utilize the full potential of distributed energy resources (DER). A local energy market is a marketplace where end-users can share and trade self-generated energy locally among each other. More broadly, local market can be a platform where end-users trade energy with other members of a marketplace without geographical limitations (Kilkki et al., 2018). For instance, virtual power plants provide opportunity to aggregate customers' flexible capacity from multiple sources. Local markets can also be connected to the wholesale electricity markets and ancillary service markets which can provide more opportunities for customers to gain revenues from their flexible resources.

Prosumers are consumers who also produce electricity and they are going to have an essential role in a future energy systems. For instance, according to Koirala et al. (2016), end-users will participate in the electricity markets much more actively than before and the use of a local resources are optimized efficiently because of micro-generation, demand response and energy storage systems. Closer connection between the wholesale and retail markets are required and that is also one of the objectives in the European Union Commission's Clean Energy package (European Commission, 2016a). The price fluctuation of the wholesale market should be passed through the retail market up to the customer. Local markets facilitate a local energy balance of supply and demand, increase flexibility of the energy system and provide efficient ways to manage peak power of the networks. Self-generated electricity can be consumed within a local community and that can improve the security of supply in distribution networks and provide new business opportunities for local industry and enterprises. Profits from electricity trading will stay within end-users' own community providing incentives for new renewable generation investments.

Smart grid solutions are an important aspect of the concept of local energy markets. Highly developed information exchange, trading and metering solutions are required to enable local trading and to enable interconnection with other marketplaces (Holtschulte et al., 2017).

These solutions should be transparent, promote competition and strengthen customers’ role on the markets.

Balance responsibility is another important feature in energy systems. Thus clear definitions of market players’ rights and requirements in local energy markets have to be established. Active information exchange between market participants is required for maintaining the balance of the network and to ensure effective overall operation of the energy system. Market participants’ electricity consumption/sales have to be equal to their generation/purchase continually. In practice, individual market actors’ demand and supply are not perfectly in balance but at system level the balance must be maintained all the time. These imbalances are caused because market actors’ hourly load and generation forecasts do not match perfectly with actual load and generation. After operating hours, these imbalances are settled financially by imbalance settlement. At the moment there are different imbalance settlement periods used in Europe but the goal is to have 15 minutes imbalance settlement period in all European Union member states (European Commission, 2016b).

1.1 Background of local energy markets

The European Commission set goals in the 2030 Energy Strategy (European Commission, 2017) to increase the share of renewable energy, reduce greenhouse gas emissions and improve energy efficiency in EU countries. Specific targets for 2030 are to achieve at least 27 % share of renewable energy consumption, 40 % reduction in greenhouse gas emissions compared to 1990 levels, and improve energy efficiency at least 27 % compared to business as usual scenario. With these targets EU is aiming at achieving a more competitive, secure and sustainable energy system. Targets are also helping to reach EU’s long-term 2050 greenhouse gas reductions target. The European Commission’s Energy Strategy guides the markets to develop in cleaner direction, since it encourages investors to invest in sustainable and low-carbon technology.

It is possible that the share of the renewable energy resources in EU countries’ electricity consumption can be high as 50 % by 2030, and significant part of that share is from intermittent energy sources (European Commission, 2016c). Resources’ intermittent nature sets some challenges for system operators to ensure the network balance and the security of supply at system level (Koirala et al., 2016). In addition to big energy utilities, also household level customers are interested in investing in their own energy generation and storage units. In the future, consumers/prosumers will actively participate in the energy markets and their role will be essential. The consumers' transformation into prosumers provides new business opportunities, for instance, to service and technology providers. The customers' active involvement opens up new possibilities for innovative market structures, and that has led to the discussion on local energy communities and local energy markets. Local energy markets enable efficient utilization of DER and help to overcome some challenges that intermittent renewable generation is setting. Customers will interact and exchange energy and flexibility with each other and with other market actors, such as Distribution System Operator (DSO), aggregators, retailers and other consumers (Mengelkamp et al., 2017a).

The DSOs have well-defined role in current energy systems i.e. to ensure reliable operation and management of the electric distribution system and to develop distribution networks. The distribution network receives electricity from the Transmission System Operator (TSO) in high voltage levels and transfers it to lower voltage levels to supply it to medium and small-size end-users. Both the customers' active participation in local energy systems and the distributed generation will cause significant impact on the DSOs' role and responsibilities in the system. The DSOs and TSOs can utilize local energy markets for demand response services and that will facilitate customers' participation in demand response activities. Controllable loads, distributed generation and energy storages are providing many opportunities to network operators to manage grids' flexibility (Timmerman, 2017). Demand side management allows to operate distribution grid more effectively since it makes possible to shave the peaks in the demand and relieve congestions in the grid.

In some cases, local marketplaces might be able to offer their flexible capacity to the ancillary service markets, hence helping the TSOs to maintain the balance of the network. Local market solutions might also help the DSOs to avoid expensive network expansions due to efficient usage of local distributed energy resources (DER). In Sweco's final report (Sweco, 2015) to the European Commission, on the effective integration of DER for providing flexibility to the electricity system, DER is defined as "small- to medium- scale resources that are connected mainly to the lower voltage levels (distribution grids) of the system or near the end-users". DER's definitions varies in different sources but in this master's thesis DER consist of distributed generation and energy storage. Distributed generation is power generation in distribution grids in or near the customer premises. It consists of multiple different generation technologies, such as wind and solar generation, co-generation units and biogas production. Energy storage technologies include, for instance batteries, flywheels, and other technologies which are able to store energy and supply it later when electricity is needed.

Smart grid operations are the foundation which enable the effective management in local energy markets. Smart meter solutions enable service providers to develop innovative and user-friendly services for customers. In addition, smart metering is important for market settlement procedures, since it improves quality of balance settlement by providing more accurate data. Energy flows in the local markets are bi-directional, since end-users are producing electricity and also feeding it into the distribution grid. Data from smart meters is valuable for different market stakeholders and enables efficient market operations. Smart grid development has generated many promising technologies which will facilitate the growth of the local markets. Virtual Power Plants (VPPs) are one example of a concept which has great potential to be utilized in the local energy markets. A VPP is a virtual entity which consists of several energy producers and consumers, thus it can be seen as a platform which bundles multiple resources. In electricity markets, VPPs act as single operating entities and are often referred to as aggregators. (Koirala et al., 2016)

According to Mengelkamp et al. (2017a), microgrids are main building blocks of local energy markets and provide the opportunity for peer-to-peer energy trading. A microgrid is a geographically limited group of multiple distributed generation units and loads operating as a self-coordinated system. Microgrids are often connected to the distribution grid at a point of common coupling, thus they can operate parallel with the distribution grid or in island mode (Lo Prete & Hobbs, 2016). Interconnected microgrids can enhance the balance of supply and demand and strengthen markets' effectiveness. The Brooklyn microgrid in New York is an excellent example of local energy market which is using the microgrid structure. Community members can trade self-generated energy peer-to-peer with each other through a blockchain-based trading platform. The physical microgrid is built in addition to the distribution grid, enabling island mode operations and ensuring the security of supply during power outages in the main grid.

Implementation of local energy markets requires innovations in several different fields. The innovation areas can be divided in customer applications, market services and control services. This thesis focuses mostly on market services which include topics, such as market mechanisms, transactions valuation, resource modelling, settlement models, regulation models and connection to the wholesale markets. There are different possibilities for trading mechanisms and for example pricing and billing can be done in various ways. One promising technology that can be utilized in local energy markets is blockchain and it is already in use in the Brooklyn microgrid and new blockchain-based projects have been launched (Mengelkamp et al., 2017a).

There are several options for local markets' structures and possibilities for operating the market, thus challenges and opportunities vary according to the different marketplaces. Stakeholders' roles will change in different market scenarios and new market actors such as aggregators will enter the markets. Local markets can be connected to the wholesale market, balancing and reserve markets. Interconnection between different markets requires active information exchange between market participants to ensure well-organized utilization of resources. Markets' transparency is essential, since it ensures non-discriminatory local market operation and participation of all market stakeholders. Interaction between local, wholesale and retail markets is shown in Figure 1.

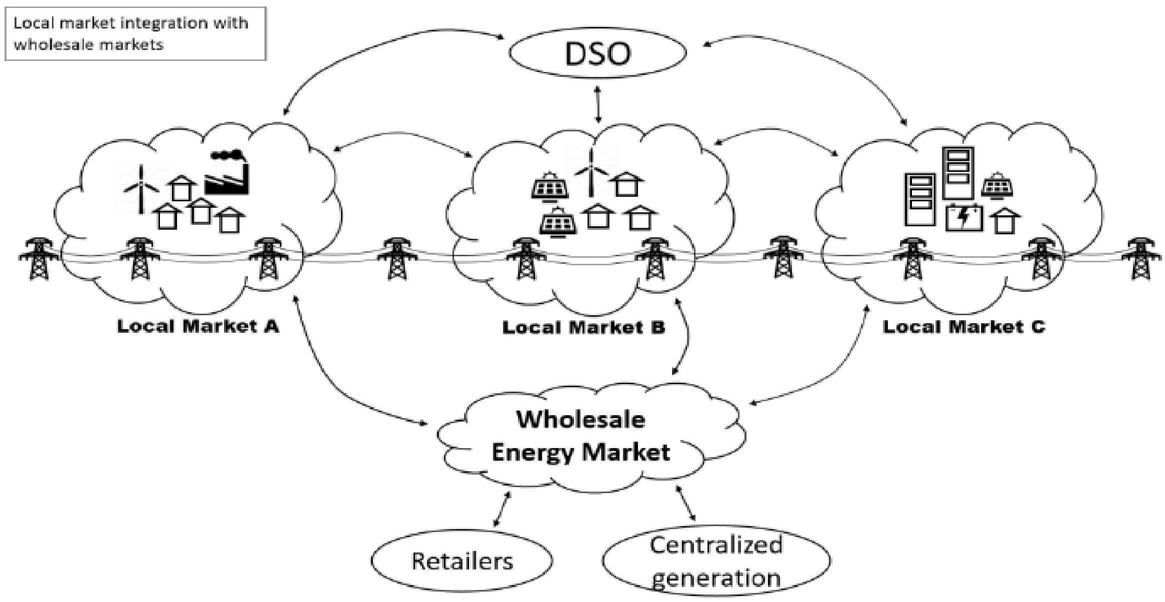

Figure 1. Interaction between local, wholesale and retail markets. (Kilkki et al., 2018)

1.2 Research objectives and methods

This master's thesis is written as part of the DOMINOES project, which is a European research project funded by the Horizon 2020 Programme. The DOMINOES project aims to enable the discovery and development of new demand response, aggregation, grid management and peer-to-peer trading services by designing, developing and validating a transparent and scalable local energy market solution. The DOMINOES concept is explained more deeply in Chapter 2.1.

The objective of this master's thesis is to review opportunities, benefits and barriers of local energy markets. The definition of the local energy market varies in the literature, thus different market structures and categories are investigated and introduced. In this thesis, the local energy markets have been divided into three categories: 1) "Microgrids", 2) "Energy communities" and 3) "Aggregating services and Virtual power plants". Under each category, there are multiple market variations and structures, thus this thesis aims to provide a basic overview of the various possibilities. Even though these categories have different market structures, they still have many similar features, which link the categories together as local energy markets.

This thesis aims to provide answers to four main research questions:

1. What are the prerequisites, benefits and barriers of local energy markets?
2. What are the possible local market models and structures?
3. How are different stakeholders interacting and what are the roles of the market actors in local energy markets?
4. How are local energy markets facilitating the development of new services and innovations?

The research methods of this thesis were the literature review and interviews of the selected market stakeholders. The concept of local energy markets is still new and under development, thus the definitions of local energy markets varies in the literature. The goal of the literature review is to provide answers to the research questions by investigating different standpoints and results from various projects, research papers and reports. The market stakeholder interviews deliver valuable information from the markets and widen the perspective of the study.

The regulatory framework sets prerequisites for local energy markets, thus the European Commission's Clean Energy Package proposal's (European Commission, 2016a) definition of local energy communities is studied and reviewed in this thesis. For instance, taxation, grid connection and metering systems are dependent on the national legislations hence the challenges may vary in different countries. In this thesis, the focus is mainly in Finland's legal conditions, but other countries' circumstances have been taken into account, especially in the analysis of identified benefits and barriers in Chapter 5.

In this thesis, the benefits and barriers of local energy markets are investigated in various levels considering the different perspectives of the market actors. The identified benefits are categorized into 1) "Customer level", 2) "Network operator level", 3) "Service, technology and energy provider level", and 4) "Society level". As mentioned earlier, the concept of local energy markets is still new, and even though it has potential to provide great opportunities and benefits, there are some obstacles that might slow down their implementation. For example, gaps in the current regulations might hamper the utilization of full potential of the local markets. To overcome these obstacles it is important to ensure that the regulatory frameworks consider how local energy resources can be utilized effectively and that new regulations will not hinder the development of novel business models. Compared to benefits' categorisation, a different approach has been used to categorise barriers, hence identified barriers have been allocated into 1) “Technical”, 2) “Policy & legislation”, 3) “Economic & market” and 4) “Societal barriers”.

The roles of market stakeholders are introduced and it is discussed how these roles can change in different local market scenarios. This thesis includes stakeholder interviews gathering their opinions on the local market solutions’ current situation and future. To get the transmission and distribution system operators’ viewpoints of the local energy markets, their future roles and how to empower customers’ market participation, representatives from the Finnish TSO Fingrid Oyj and from Helsinki area’s DSO Helen Electricity Network Ltd were interviewed. From Fingrid, Electricity Market Specialists Risto Lindroos, Laura Ihamäki and Heidi Uimonen participated into interview and from Helen Electricity Network Ltd Customer Management Manager Jouni Lehtinen was interviewed. From suppliers and service providers’ side, Helen Ltd’s Business Development Manager Markus Logren was interviewed. The goal of the interviews was to provide standpoints of the market actors and compare the results to the literature review. The interviews provide the latest information from the market actors and may introduce new research questions for future studies.

1.3 Outline of the thesis

The first chapter is the introduction of the study, which describes the background of local energy markets and the key drivers for their development. The research objectives and methods are introduced with four main key research questions. Also, the outline of the thesis is presented.

The second chapter introduces the different local market models and provides an overview of the DOMINOES project. This chapter aims to explain the concept of local energy markets by presenting different market models and by investigating existing literature on the topic. Local energy markets are allocated into 1) “Microgrids”, 2) “Energy communities” and 3) “Aggregating services and Virtual power plants”. These three categories are explained and different market structures under each category are studied. The prerequisites of introduced models are investigated, thus for instance the European Commission’s definition of local energy markets is reviewed. In addition, there are presented an example cases of already implemented local marketplaces.

The third chapter presents the components that are needed to establish well-functioning local marketplaces. These components include local DER, microgrid setup and connection, information exchange and electricity metering system, market and pricing mechanism, energy management system and regulatory framework. Metering systems in Finland are presented and requirements of the next-generation smart meters are discussed.

The fourth chapter discusses the roles and responsibilities of the stakeholders involved in local energy markets. The roles are dependent on the structure of the local marketplace, hereby there are many possible scenarios as to what would be the role of a certain market actor. The end-users' change from passive consumers to active prosumers is the key aspect, since it is the feature which drives the local market development. The roles of the system operators, prosumer, producers, consumers, suppliers, balance responsibility parties and aggregators are discussed.

The fifth chapter presents the identified benefits and barriers of local energy markets. Benefits are divided into 1) "Customer level", 2) "Network operator level", 3) Service, technology and energy provider level", and 4) "Society level". Barriers and challenges are categorised into 1) "Technical", 2) "Policy & legislation", 3) "Economic & market" and 4) "Societal barriers".

The sixth chapter provides the concluding remarks of the thesis. The main research findings are gathered and the need for the future research is discussed.

2 LOCAL ENERGY MARKET MODELS

In this chapter, different market models and categories of local energy markets are introduced. There are various names for local market models, even though the basic technical structure and objectives of most of the options are not that different. For example "Microgrid Energy Markets", "Local Energy Communities" and "Virtual Power Plants" are used in the literature. In this thesis, the name Local Energy Markets is used and it gathers all the different models and structures together. The local energy market is a marketplace where prosumers and consumers can trade electricity among each other and utilize local energy resources effectively. Local energy markets do not necessarily have to be geographically contained, since virtual market platforms can aggregate loads from customers in different locations and offer the capacity to the wholesale and balancing markets (Koirala et al., 2016). Nevertheless, the main goals are similar in all local market structures: to optimize the use of renewable local energy resources, allow local energy trading, provide new services and strengthen customers' role on the energy markets.

The Universal Smart Energy Framework (USEF, 2015) provides common standards on which to build new smart energy services and products. The USEF model is a good reference framework when designing local energy markets. Figure 2 presents the interactions between various market players and services they are providing. Flexibility is the key factor in local markets and in the USEF model in which the energy supply chain and the flexibility supply chain are separated. Physical transport of energy combines these two chains. In normal circumstances, the DSO provides grid connection for prosumers according to the terms and condition determined in the connection contract. The supply side of the USEF model is similar to the liberalized energy market structure in Europe. Energy suppliers have established purchase and supply contracts with end-users and balance agreements with a Balance Responsible Parties (BRP). The suppliers forecast their customers' load profile and the BRPs are responsible for imbalance settlement of all suppliers which have established balance agreements with them. Imbalance settlement determines the electricity deliveries between the parties operating in the electricity market. The BRP has energy purchase contracts with energy producers to serve the energy demand of its suppliers' customers. The BRP has a balance service agreement with the TSO which is the open supplier of the BRP. In addition, the BRPs can balance their portfolio by arranging energy trading deals in different markets, such as spot market, intraday market and over-the-counter market. Energy service companies (ESCOs) can provide optional auxiliary services to the end-users. For instance, an in-home optimization and automation services are related to energy supply chain. (USEF, 2015)

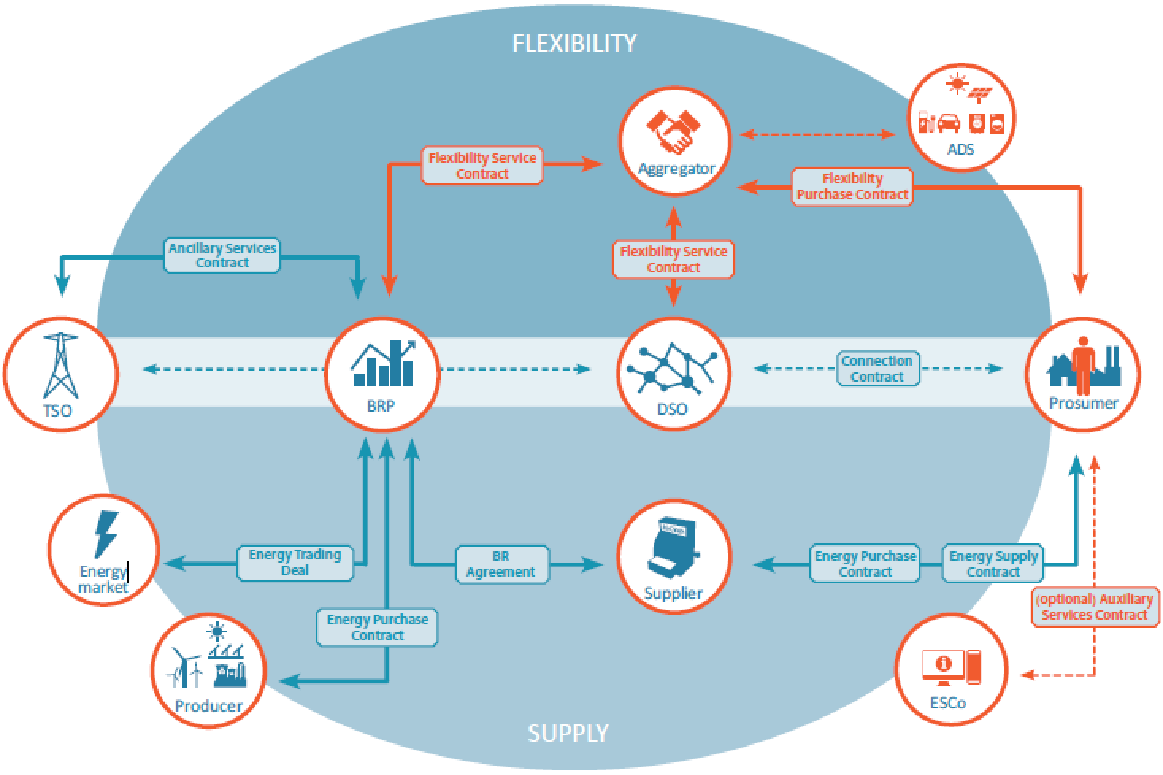

Figure 2. Stakeholder interaction model in smart energy systems. (USEF, 2015)

The objective of the USEF flexibility supply chain is to exploit the value of Active Demand and Supply (ADS) flexibility. Aggregators are essential market players in the flexibility supply chain. Aggregators and prosumers establish contracts that define the terms and conditions when prosumers flexibility assets can be utilized by aggregator. Aggregator establish flexibility service contracts with participating prosumers' BRPs, since flexibility trading affects the BRP's imbalance settlement. The BRP can use flexibility to optimize its own portfolio, trade it on the markets, or provide ancillary services to the TSO. Another value stream for aggregators comes from providing flexibility to the DSOs. By purchasing flexibility, the DSO can optimize network operation and enhance reliability of supply. (USEF, 2015)

2.1 Local market concept in the DOMINOES project

DOMINOES project is a European research project funded by the Horizon 2020 Programme. The DOMINOES project members are Empower (coordinator – Finland), EDP Distribuição – (Portugal), EDP Centre for New Energy Technologies – CNET (Portugal), Instituto Superior de Engenharia do Porto – ISEP/GECAD (Portugal), Lappeenranta University of Technology – LUT (Finland), University of Leicester (UK) and University of Seville (Spain). The project aims at enabling the discovery and development of new demand response, aggregation, grid management and peer-to-peer trading services by designing, developing and validating a transparent and scalable local energy market solution.

The local market concept in the DOMINOES project will be designed in a way that it will enable:

- local sharing and effective generation of renewable energy in distribution level
- empowering prosumers and maximize the value of their energy resources
- facilitating demand response service provision
- creating relevant and liquid flexibility for innovative distribution management
- easy wholesale market uptake of DER
- support to liberalized energy markets
- compatibility with the ongoing policy development

The above mentioned key requirements are the overall targets which will be followed during a development process of the project. DOMINOES should be compatible with European Commissions' guidelines for the energy market development and take into account the growing penetration of DER at the distribution network level. In addition, upgraded energy ICT (information and communication technology) infrastructure will be considered in the development process. For instance, smart metering and datahubs are reforming the electricity markets and providing new business opportunities. The goal of the project is to provide benefits at multiple levels to different market actors.

Local markets open up new business opportunities and its development drives innovations. Innovation is especially needed in market service, customer application and control service areas. Topics such as market mechanism, transaction valuation, regulation models and settlement models are included in the market services. The end-users' interaction with other market actors is essential in order to achieve well-functioning customer applications. Transparency is another important aspect for customer services and for a whole local market concept. Smart metering is enabling market actors to develop innovative customer services and to monitor end-users' energy consumption behaviours. The DSOs or other market actors who act as the operators of the local marketplaces should be able to manage grid loads dynamically. Various stakeholders can take the role of marketplace operator, thus this role is dependent on the structure of the local market. The main innovation areas of the local energy markets in the DOMINOES project are presented in Figure 3.

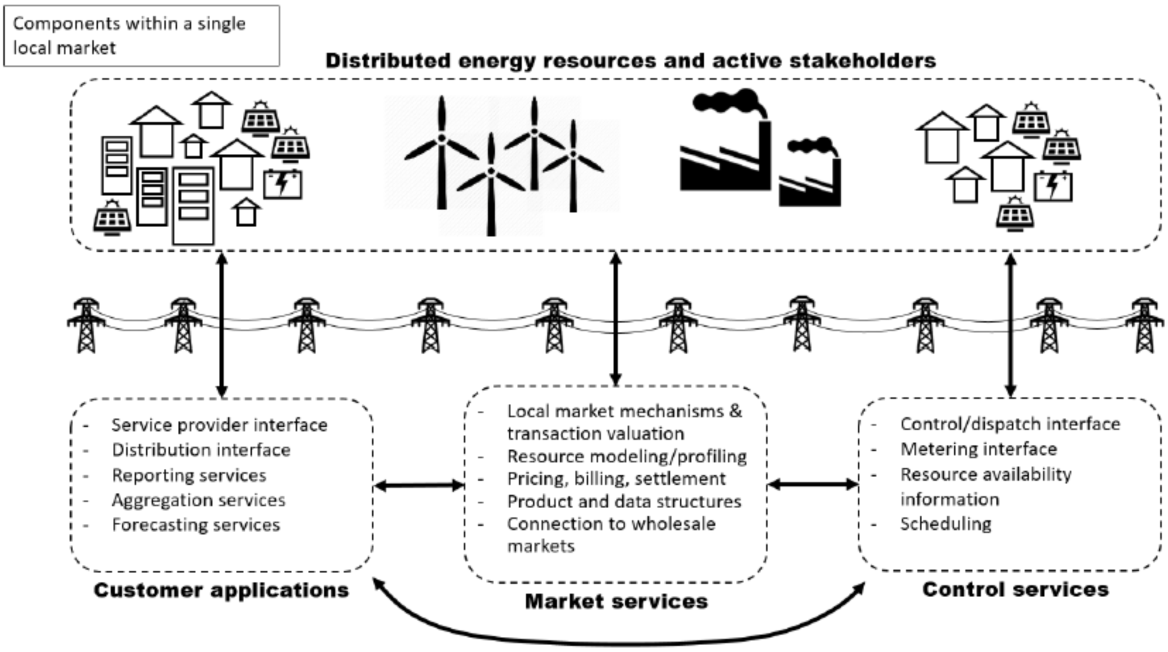

Figure 3. Three innovation areas of local energy markets addressed in the DOMINOES project.

Figure 4 shows an overview of the local energy market structure and stakeholders' interactions in the DOMINOES concept. The blue circles represent market stakeholders, while the red circle represents the Energy Community Service Provider (ECSP) which facilitate the local market platform. The role of the ECSP can be taken by different stakeholders depending on the market architecture. For instance, a DSO or retailer can operate as an ECSP, or it is possible that some new market actor will provide ECSP services and will be responsible for operating and managing a local market. Market actors provide their services to the end-users and other market players, and ECSP can act as a third-party intermediary between service providers and customers. The connection between other local markets and wholesale market is possible, hence providing more opportunities to the customers. The BRPs have to be defined clearly and information exchange must be ensured in all market scenarios.

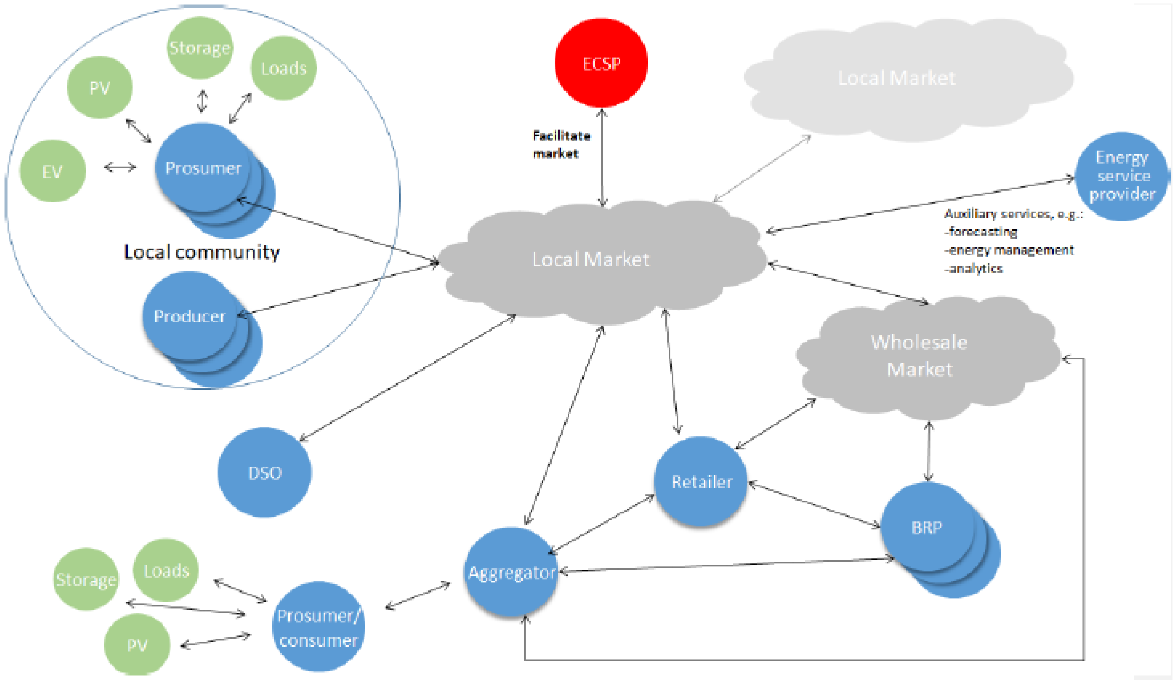

Figure 4. The basic structure of local energy market and stakeholders' interaction in the DOMINOES concept. (Kilkki et al., 2018)

2.2 Microgrids

There is not only one specific definition for a microgrid because its functions, architecture and size can vary widely. A microgrid is an extension of a low voltage or a medium voltage distribution network that exploits local energy resources. Microgrids consist of interconnected renewable and traditional energy sources, and often have storage systems for enabling efficient utilization of intermittent renewable generation and supporting island mode operation (Soshinskaya et al., 2014). For instance, Stadler et al. (2016) defines the microgrid concept as a *"cluster of small sources, storage systems, and loads, which presents itself to the main grid as a single, flexible, and controllable entity"*. The U.S. Department of Energy Microgrid Exchange Group (The U.S. DOE, 2012) states: *"A microgrid is a group of interconnected loads and DER devices within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and* *disconnect from the grid to enable it to operate in both grid-connected or island-mode. A remote microgrid is a variation of a microgrid that operates in islanded conditions."*

According to Stadler et al. (2016), interconnected microgrids can form local energy market, enabling end-users to trade electricity also with end-users in other microgrids, rather than just trading within their own microgrid or feeding electricity to the distribution grid. This type of structure empowers optimized use of DER and facilitates the integration of intermittent renewable generation to the energy system. Local energy markets can restrain the market power of traditional power utilities, particularly when the local market is formed from customer owned microgrids. Interconnected microgrids produce value streams to market participants by lowering the energy costs and by promoting the use of local energy resources. Single microgrid can be considered as a local energy market also. Benefits of the local energy markets, including microgrid cases, are presented more specifically in Chapter 5.1.

Smart energy management systems are typically used in microgrids for operating energy storage systems and managing energy consumption in smart buildings. Microgrids facilitate increasing distributed renewable generation and reducing losses in the electricity distribution. Local prosumers can cover some or all of their electricity consumption by their own power generation. Microgrids are usually connected to the distribution grid at a point of common coupling, and can isolate for example during grid outages, hence improving the security of supply. To be able to operate microgrid effectively and to maintain network's reliability in islanded mode, microgrid need to have enough distributed generation capacity and storage units. (Soshinskaya et al., 2014)

The basic function of a microgrid is to aggregate and integrate local energy resources, storages and loads, and by that way to optimize energy consumption and efficiency of the system. Microgrids are using smart energy management from the supply and demand-side to achieve the balance between power supply and demand efficiently. Distributed storage options are essential for reaching network balance, since it is challenging to match perfectly the microgrid's power generation to its load. The level of peak demand, reliability requirements and desirable flexibility level determine the needed capacity of the storage. Batteries, electric vehicles (EV), flywheels, energy capacitors, pumped hydroelectric storage and compressed air are examples of these storage options. Especially EVs are seen as promising technology facilitating consumers' active participation in flexibility management in the future energy systems. From the perspective of the DSOs, the microgrid is seen as one entity with aggregated load and generation. Active interconnection and information exchange between the distribution grid and the microgrid is essential. Other electric system requirements such as voltage quality, flexibility and electrical safety have to be taken into account when microgrids are designed. Microgrids can be interconnected with multiple microgrids and that kind of network structure is one possible option to be utilized in the further developed local energy markets. (Soshinskaya et al., 2014)

Soshinskaya et al. (2014) divided microgrid's ownership options into three different designs: "DSO monopoly microgrid", "Prosumer consortium microgrid" and "Free market microgrid". The DSO monopoly microgrid is operated and owned by the distributed system operator. In that ownership design, the DSO is responsible for the costs and benefits linked to the microgrid. Single or multiple end-users are owners of the DER in the Prosumer consortium microgrid model. In the Free market microgrid model, a central controller is needed to operate the microgrid. Since this type of microgrid is driven by many different stakeholders, also the possible benefits are shared between these stakeholders (DSOs, prosumers, consumers etc.).

Microgrid types can be divided in low voltage and medium voltage microgrids. Low voltage microgrids are formed by groups of low voltage network customers and the electricity production is based on the small-scale generation, as for instance households' solar panels. The low voltage microgrid can cover the whole low voltage network or it can be formed by only some consumption points of the network. Medium voltage microgrids are typically formed by many larger consumption points/loads and also bigger production units, such as wind farms, can be a part of the microgrid. (Soshinskaya et al., 2014)

2.2.1 Value streams of microgrids

For example, Stadler et al. (2016) identified four key value streams of microgrids: "Participation in demand response programs", "Export of on-site generation to the electricity grid", "Reduced costs due to added resiliency against outages and lost loads" and "Participation in local microgrid electricity markets". Microgrids suit well for demand response programs, since they utilize local DER and have well-functioning control systems. Demand response means that end-users make changes in their electricity usage from their normal consumption habits in response to changes in the price of electricity or other incentives. End-users may lower their electricity consumption during times while wholesale market price is high or when network system's reliability is endangered. Services related to demand response facilitate effective use of the energy system by increasing flexibility and reliability of the network. There are various load management strategies, such as peak shaving or consumption shift to different time period. Load management can be done by either managing customers' load directly or by exploiting distributed generation and storage options. Benefits of the demand response occur to system operators and customers, and indirectly to wider scale. With various generation and storage resources, microgrids can successfully capture the value streams of peak shaving and load levelling, hence improving microgrids' overall economic performance. (Stadler et al., 2016)

In addition of ability to consume and trade self-generated electricity within the microgrid, revenues from the exported electricity to the distribution grid can be significant source of income for customers. Net-metering and feed-in tariffs can be used for determining the value of electricity fed to the main grid. Bi-directional meter is used for measuring customers' consumption and production in the net-metering scheme. Meter runs backwards if self-generation exceeds microgrids' overall consumption in pre-defined time period (for instance, imbalance settlement period). In turn, with feed-in tariffs, customers receive pre-defined payments for the exported electricity. The regulatory framework affects significantly to the net-metering and feed-in tariff schemes, and due to that the metering and feed-in tariff procedures differ in different countries. Net-metering or feed-in tariffs are not the only options, and often more market based approaches are appreciated. Microgrids can be interconnected with each other, improving grid autonomous features and bringing additional value to the microgrid concept. (Stadler et al., 2016)

With distributed generation and storage resources microgrids increase the security of supply, hence mitigating economic losses in case of power outages in the main grid. Increased reliability is significant advantage of microgrid concept, even though the value of reliability is difficult to quantify. One method for calculating this value is the method of Value of Lost Load (VoLL) which estimates the cost to customers per unit electricity not delivered, or the price that customers are willing to pay to avoid disruptions in the power supply. Customer type and the nature of their operation affect the VoLL. Also many external factors, such as timing and duration of outage, location, season, and if the outage is planned or unplanned are affecting the results. Due to that, VoLL is higher if the outage take place at the afternoon compared to the outage during the night time. Lost production, additional cost incurred to ramping up/down, and lost goods are included when estimating the VoLL for industrial customers. Lost leisure time and loss of goods are taken into account for residential customers. In every situation, VoLL is always higher than the price of the undelivered electricity. (Stadler et al., 2016)

2.2.2 The challenges of microgrids

Depending on distributed generation resources, components, share of the renewable energy and optimization goals, microgrid structures vary significantly, which causes different kinds of challenges and barriers. Most typical challenges in microgrids are related to technical, regulatory, financial and stakeholders' aspects.

Technical barriers include challenges with technology components, switching from grid-connected to island mode, protection and power quality problems and control issues. Dual-mode operation, which means the possibility to transfer from grid-connected operation to island mode, is one of the key factors of the microgrid concept. During the transition to island mode and during the outage, energy reliability needs to be maintained. When reconnecting back to the distribution grid, synchronizing these two grids requires right timing to close the switch. Also, improved voltage and frequency controls in microgrid might be required, since transitions cause imbalances between generation and load. The power and frequency control problems are typically at component level caused by intermittent renewable generation, such as wind and photovoltaics, or by frequent load shifting. (Soshinskaya et al., 2014)

Interconnection rules of distribution grid and microgrid, issues with bi-directional power flow and local energy trading are causing the main regulatory barriers in microgrid systems. Well-designed regulatory frameworks are essential for facilitating microgrids' implementation, providing guidance, integration and interconnection rules to the distribution network. Additionally, the fact that legislation is country-specific can causes challenges for microgrid design and its economic attractiveness. Regulation issues about bi-directional power flows are causing problems for prosumers' ability to feed surplus power to the main grid, and that necessarily hinders the development of local energy markets. (Soshinskaya et al., 2014)

The main financial challenges faced by microgrids are high upfront costs and expensive technology, such as DER and energy management systems. Lower production costs of microgrid's technical components would increase economic attractiveness of the microgrid solutions. In recent years, prices of many DER technologies have decreased, thus promoting microgrids deployments. Even though the prices have decreased, for example storage technology is still quite expensive and further development is needed to make it more cost-effective. Some renewable energy technologies are dependent on support schemes and that can distort the development of the market. Support mechanisms are facilitating and boosting the development of renewable energy but in the long run technologies must be cost-effective without any incentives. Financial support focuses mostly on renewable technology but market support also for high-tech control systems and energy management systems would help the commercialization of the microgrid concept. (Soshinskaya et al., 2014)

Stakeholder barriers are related to self-interest problems, consumer engagement and trust. To achieve successful microgrid deployment, local residents must be convinced that microgrids can bring benefits to them and to the whole community. Understanding the different levels of financial and environmental benefits of microgrids can be challenging for local consumers and getting the social acceptance by local residents might in some projects need more effort than developers expect. To gain social acceptance and trust from the community, it is important to explain and clarify the concept of microgrids to the local customers and provide them with the appropriate guidance about the benefits that can be achieved. The energy suppliers and the DSOs are slightly sceptical about local trading because it could reduce suppliers' daily income and might reduce electricity transfer payments charged by the DSOs. In turn, local energy markets can open up new business possibilities for all of the market stakeholders. (Soshinskaya et al., 2014)

2.2.3 Brooklyn microgrid

In Brooklyn New York, LO3 Energy and Siemens have implemented a pilot microgrid using blockchain technology. The project started in early 2015 and the first energy transactions occurred in April 2016. The pilot represents the first local energy marketplace in the world where end-users can trade self-generated electricity with their neighbours in a blockchain-based peer-to-peer transactions. The blockchain technology provides an opportunity to execute trading without a third-party intermediaries. (Mengelkamp et al., 2017)

According to Mengelkamp et al. (2017a), the project consist of the physical microgrid and the virtual community energy market platform. The physical microgrid is built in addition to the existing distribution grid. It provides opportunity to operate in island mode and it ensures the security of supply during power outages in the distribution grid. Microgrid involves end-users from three different distribution network areas in Brooklyn, thus the physical microgrid is only a part of the grid infrastructure that the microgrid is using. The physical microgrid reduce the impact of grid problems and facilitate a control of electricity supply within the microgrid area. The blockchain-based trading platform provides the infrastructure to develop local marketplace. Platform is using Tendermint protocol and the TransActive Grid smart meters are implemented.

Smart meters send the consumption and production data to end-users' blockchain accounts where buy and ask orders are created. The orders are sent to the market platform, which takes care of matching the orders and confirming the payments. The trading is done automatically according to end-users' pre-defined preferences, for instance, about energy sources and price limits. When the matching is completed, payments are carried out and new blocks, that contain all the required market information, are added to the blockchain. The market mechanism in the Brooklyn microgrid is a closed order book with a time discrete double auction in 15 minute time intervals. The last matched bid represents the market clearing price of the time interval. (Mengelkamp et al., 2017)

2.3 Energy communities

In community energy projects the citizens are usually the owners of DER and participate in the energy generation. Generated electricity is traditionally sold to the local energy utilities and the profits are divided among project participants. In energy communities, the generated electricity could also be consumed by participating prosumers, providing valuable economic benefit of local energy generation. To establish community energy projects, private households or communities usually form a legal assembly to finance and manage project collectively. These projects can use the bottom-up or the top-down approach. In bottom-up approach, the end-users have greater impact on the project management and they own the generation units, whereas in top-down approach, the end-users are only partly involved. In top-down approach, citizens participate to energy projects by buying shares of the projects which are developed and managed by other actors, for instance energy utilities. Projects can be co-owned by citizens and companies, and this co-operation might enable to develop larger-scale projects. End-users are important renewable energy producers and public acceptance of renewable energy projects have increased in recent years due to community owned projects. (Fruhmann & Knittel, 2016)

In Europe, community energy projects have become more common and the projects are helping in decarbonisation and in achieving a cleaner energy system. There are differences in national legislations in EU-member states and in some cases legislation may hamper the execution of the community energy projects. Wind and solar energy technologies are the most typical technologies in community energy projects and the support schemes for each technology varies depending on the national legislations. The main support mechanisms include feed-in tariffs, feed-in premiums, quota obligations with tradable green certificates, loan guarantees, soft loans, investment grants, tax incentives and tendering schemes (Fruhmann & Tuerk, 2016).

Denmark and Germany are the trailblazers in community owned energy generation in Europe and good experience has been gained from projects in these countries. In Denmark, communities have invested in wind energy for many years already, resulting that by 2013, 70-80 % of installed wind turbines was owned by communities (Fruhmann & Knittel, 2016). Danish energy policy promotes implementing community-owned energy projects by for instance grid connection arrangement which defines that project owners have to take care of connection costs only to the closest technically feasible connection point of the grid. If grid expansions are needed, energy utilities are required to take care of the cost incurred. Furthermore, since 2009 the Danish Renewable Energy Act has required that all new wind energy projects have to be owned by at least 20 % by local people. (Fruhmann & Knittel, 2016)

Germany is not focusing only on wind projects, since it has a lot of solar community projects as well. In 2014 half of the Germany's renewable generation was community owned. Energy policy in Germany is very supportive for renewable energy, thus end-users are willing to participate in community energy projects. Examples of Germany's energy policy are that grid operators are obliged to purchase renewable electricity, remunerative support schemes, grid connections for renewable energy installations are ensured and grid extensions are adapted according to renewable generations' requirements. (Fruhmann & Knittel, 2016)

Energy communities increase customers' possibilities to participate more actively in the electricity markets and to invest in own electricity generation. Customers can gain economic benefits and value-related benefits. Value-related benefits arise for instance from customers' improved possibilities to choose the technology that they want to use in their electricity generation and by that way being able to promote cleaner technology and renewable energy. Economic benefits come from being able to consume self-generated electricity or sharing/trading it with other members of the community. Energy communities enable customers to participate in larger scale investments than individual customers would be able to do. These large-scale investments, such as solar and wind power plants or big storage systems, have lower unit costs and usually better efficiency compared to smaller units. (TEM, 2017)

In this thesis, three categories of energy communities are introduced: 1) "Local energy community within the boundaries of real estate", 2) "Local energy community crossing the boundaries of real estate" and 3) "Distributed energy community". Since legislation and regulations differ in different countries, these three types that are studied in this thesis are mainly focusing on Finland's conditions. When policy makers introduce definitions and rules concerning energy communities, they have to ensure that customers who are not participating in local energy communities are not disadvantaged. It is important to avoid discrimination between members of the local energy communities and other users of the energy system in terms of regulated network charges, policy costs and electricity taxes.

Interviewed Fingrid’s specialists stated that energy communities may offer flexible capacity to the reserve and balancing markets through aggregators, or community can be considered as an aggregator itself. They believe that more energy communities will enter into the markets in the future, but at the same time they mentioned that balance responsibility have to be taken into account also in case of local energy markets. Some energy communities aim to reduce network service fees by being independent and operating in island mode. However, with current technology and storage prices, complete energy self-sufficiency is very challenging to achieve. It would be questionable if energy communities would have lower network service fees in cases when they are part of the time connected to the distribution grid. Distribution network would be used in electricity delivery in situation when community’s self-generation cannot cover its consumption, and by that way ensure community’s security of supply. By maintaining connection to the distribution grid, energy communities have access to the conventional electricity markets which may offer wider opportunities for revenues. For instance, energy community can participate into the balancing markets, when it is connected to the distribution network. Power-based tariffs could facilitate energy communities’ development, since those would encourage end-users to optimize their electricity consumption and participate in demand response services. All interviewed stakeholders pointed out that energy communities should provide lower energy costs and reliable security of supply in order to get end-users’ involvement. Monetary benefits are usually customers’ main incentive. (Stakeholder interviews, 2018)

Jouni Lehtinen from Helen Electricity Network Ltd stated in his interview that energy communities are not a threat for the DSOs. He believes that most of the energy communities will maintain connection with distribution network, since there are many risks involved to be completely disconnected from the main grid. The similarities of energy community’s operators and the DSOs’ roles was discussed. Electricity distribution is a regulated business and it should be considered what are the legal rights and responsibilities of the party responsible for distribution inside the community’s network. Especially an energy community which crosses the boundaries of the real estate is questionable, since there would be need to build new distribution lines if the DSO’s network would not be used. Lehtinen also pointed out the electrical safety aspect when some other party than the DSO is responsible for the network operations. The DSOs have lot of know-how that could be utilized in energy communities, but that kind of service development and seeking new market opportunities is out of a scope of the DSOs' regulated business. For the greatest challenge for energy communities Lehtinen stated that generation and storage technology need more development and prices of those technologies should decrease. End-users' micro-generation increases quickly, but that is not a challenge or a risk for the DSOs. Self-generation only lightly decreases the load of the network. If storage systems increases significantly, that would have a major impact for distribution networks' loads. According to Lehtinen, energy communities and micro-generation do not affect the network's planning and reinforcements, since other factors are more dominant and security of supply cannot be dependent on the availability of flexible resources. (Stakeholder interviews, 2018)

2.3.1 European Commission's directive proposal's definition for local energy communities

At the moment, there is no clear definition of a local energy community and what are the rights and obligations of these communities. Due to the absence of a clear definition, the practices and principles of energy communities have wide variety and the interpretation of legislation is rather difficult. Topic is under discussion in a field of energy business and for instance the European Commission have started to make first attempts to clarify this new concept. In the Clean Energy Package directive proposal (European Commission, 2016a) on common rules for the internal market in electricity, the commission has defined a local energy community as "an association, a cooperative, a partnership, a non-profit organisation or other legal entity which is effectively controlled by local shareholders or members, generally value rather than profit-driven, involved in distributed generation and in performing activities of a distribution system operator, supplier or aggregator at local level, including across borders". In Article 16.1, proposal sets out the basic principles which are stating that local energy communities:

a) *are entitled to own, establish, or lease community networks and to autonomously manage them;*
b) *can access all organised markets either directly or through aggregators or suppliers in a non-discriminatory manner;*
c) *benefit from a non-discriminatory treatment with regard to their activities, rights and obligations as final customers, generators, distribution system operators or aggregators;*

d) *are subject to fair, proportionate and transparent procedures and cost reflective charges;*
e) *where relevant, may conclude agreements with the distribution system operator to which their network is connected on the operation of the community network*

The above description thus states that local energy communities may own and operate distribution networks and can make agreements on its operation with the DSOs the communities are connected to. The overlapping of responsibilities between a local energy community operators and DSOs might be the main challenge when trying to establish a clear definition of local energy communities. Access to the energy markets in a non-discriminatory manner is an important aspect that facilitates the capture of new revenue streams by its members/shareholders. The proposal states that the local energy communities' procedures should be fair and transparent and charges should be cost-reflective, but there is not any specific definition of the charges that communities can apply to the end-users that are connected to their network. The equal treatment of customers is another essential aspect, thus the party who is operating the community's energy system needs to ensure that. European Distribution System Operators' Association for Smart Grids (EDSO) reviewed in its position paper (EDSO, 2017) the Clean Energy Package's statements about local energy communities. EDSO states that energy communities should benefit from a non-discriminatory treatment with regard to their activities, rights and obligations as other actors but some rights and obligations could possibly be discordant or incompatible between different market actors. In some situations the right of one actor is an obligation for another actor, or the other way round, thus it can be difficult to ensure the benefits of all actors in some cases.

Proposal's Article 16.2. states that Member States shall provide an enabling regulatory framework that ensures that:

a) *participation in a local energy community is voluntary;*
b) *shareholders or members of a local energy community shall not lose their rights as household customers or active customers;*
c) *shareholders or members are allowed to leave a local energy community; in such cases Article 12 shall apply;*

d) *Article 8 paragraph 3 applies to generating capacity installed by local energy communities as long as such capacity can be considered small decentralised or distributed generation;*
e) *provisions of Chapter IV apply to local energy communities that perform activities of a distribution system operator;*
f) *where relevant, a local energy community may conclude an agreement with a distribution system operator to which their network is connected on the operation of the local energy community's network;*
g) *where relevant system users that are not shareholders or members of the local energy community connected to the distribution network operated by a local energy community shall be subject to fair and cost-reflective network charges. If such system users and local energy communities cannot reach an agreement on network charges, both parties may request the regulatory authority to determine the level of network charges in a relevant decision;*
h) *where relevant local energy communities are subject to appropriate network charges at the connection points between the community network and the distribution network outside the energy community. Such network charges shall account separately for the electricity fed into distribution network and the electricity consumed from the distribution network outside the local energy community in line with Article 59 paragraph 8.*

Article's paragraphs a), b) and c) are ensuring that customers in local energy communities have same rights as customers who do not participate into the community. It is important that participation is voluntary and customers are able to resign from the community if they want to do so. Community members should be able to choose and change their electricity supplier in a same way as before. That discards the possibility that local energy communities would operate as Closed Distribution Systems (CDS), since customers inside CDS are not able to choose their supplier. CDS is defined in the proposal's Article 38 as *"a system which distributes electricity within a geographically confined industrial, commercial or shared services site and does not, without prejudice to paragraph 4, supply household customers, as a closed distribution system"*. Above mentioned paragraph 4 states that exceptions can be in a case of *"incidental use by a small number of households with employment or similar associations with the owner of the distribution system and located within the area served by* *a closed distribution system"*. The CDS will either have its operations or the production process of the users of the system integrated for specific or technical reasons or distribute electricity primarily to the owner or operator of the CDS or their related undertakings. If local energy communities could be considered a CDS, the DSO would treat it as one big customer with its internal private customers. The distribution and network operation inside the CDS would not be in the DSO's responsibility. End-users connected to the CDS would not directly be the DSO's customers but the CDS itself would be a customer. Owner of the CDS would pay the network charges to the DSO and end-users inside the community would have private arrangements about the charges with the CDS owner. Local energy community which would have the CDS-structure would have one mutual electricity supplier and that would remove customers' rights to choose and change their supplier. Quality of service within the CDS would be its operator/owner's sole responsibility. If local energy communities would have the CDS-structure, there is a need to clarify and define the obligations of the community's operator and quality requirements that its services must meet.

Article 16.2. paragraph e) states that provisions of proposal's Chapter IV, which discusses the DSOs' role in the energy systems, apply to local energy communities that perform activities of a DSO. In some cases, it might be difficult to evaluate if a local energy community is performing a DSO activities, and thus paragraph e) can be applied. Because of that, clear definitions of energy communities' activities are needed, as it is clarification of which activities define that they can be considered as ordinary DSO. In paragraph f) it is stated that communities may conclude an agreement with the local DSO on the community's network operation. In that case the DSO would be the operator of the energy community and it remains unclear if the same distribution network regulations applicable to elsewhere in the distribution network would be applicable also within the community boundaries.

The article's paragraph d) states that the proposal's Article 8.3. applies to community's generating capacity when it can be considered as a small decentralised or distributed generation. The above mentioned Article 8.3. discusses about authorisation procedure for new capacity. Members States need to have specific authorisation procedures for small decentralised and distributed generation, and these procedures should take into account the limited size and potential impact of this generation on the energy system. Member States can set the guidelines for these authorisation procedures by themselves, and national regulatory authorities or other valid authorities review the guidelines and may recommend changes if needed.

Paragraphs g) and h) discuss the network charges and some questions may arise, as the charges for community members are not clear. In the proposal, it is not specified how community members’ charges are constructed, what members exactly pay, and how to guarantee fair charges and an acceptable split of costs between community members and non-members. It is not explained how community members’ charges include other costs than energy, such as policy costs, taxes and others. That needs to be clarified to avoid discrimination between community members and other customers. Also, there is not any mention about rules and obligations concerning the metering, connection, information exchange and billing arrangements of the customers that are connected to the local energy community. These issues are essential for enabling the implementation of local energy communities, thus these need to be clarified.

In order to guarantee customers’ rights and quality of service, local energy communities that act as a DSO, probably should have the same responsibilities and obligations as conventional DSOs. These responsibilities and obligations affect many aspects such as network planning and development, operation and maintenance, metering and billing, quality of service, customer service, connections, switching arrangements, and information and data exchange with suppliers and other stakeholders. Some of these tasks could be delegated or outsourced to some other actors, but the community operator is responsible for the community’s services quality and delivery, thus the operator has to ensure that all of these above mentioned areas are covered. To ensure customer interest and efficient network developments, an adequate regulatory supervision needs to be established. National regulatory authorities could be responsible for controlling and supervising local energy communities’ implementation and development.

2.3.2 Local energy community within the boundaries of real estate

End-users living in a building with multiple households (for instance a block of flats) are interested in installing solar panels on the building rooftop and form an energy community. For instance, they might co-invest in a photovoltaic system and share the generated energy among themselves. Local energy community within the boundaries of real estate means that all generation, consumption, storage units and other possible energy resources are located inside the area of the real estate. Typically this type of energy community can be formed, for example, by residents of blocks of flats or terraced house condominium. (TEM, 2017)

Electricity metering schemes pose barriers that hinder the economic viability of self-generation in condominiums. In detached houses, small-scale production is installed behind the meter, thus self-generated electricity does not go through the DSO’s meter and due to that, the DSOs cannot charge network service fees for self-generation. In condominiums, it is not possible to install generation units behind the meter, thus setting barriers to the customers’ ability to utilize self-generation in an economic way. When electricity goes through the electricity meter of individual customer, the DSO will charge the network service fees and customer have to pay taxes for measured electricity, even though self-generated electricity would not be transferred through DSO-owned distribution grid. There is need to change the metering procedure of self-generated electricity in apartment houses to enable end-users to achieve full financial benefits of small-scale production. If self-generated electricity is consumed within the boundaries of the real estate and distribution network is not used to transfer electricity, end-users should not be obliged to pay network service fees for that part of their electricity consumption. If distribution network is used for transfer electricity to the consumption point, then the DSO would be allowed charge network service fees. Electricity taxes need to be paid in accordance with general practice. (TEM, 2017)

Figure 5 shows the basic structure of a local energy community within the boundaries of real estate. Self-generated electricity goes from solar panels to the electric control centre of the building where it is shared among the members of the community and end-users’ electricity consumption is measured by each apartment’s separate electricity meter. Part of generated electricity goes to condominium’s common areas through the electricity meter of the apartment house company (condominium owners’ association).

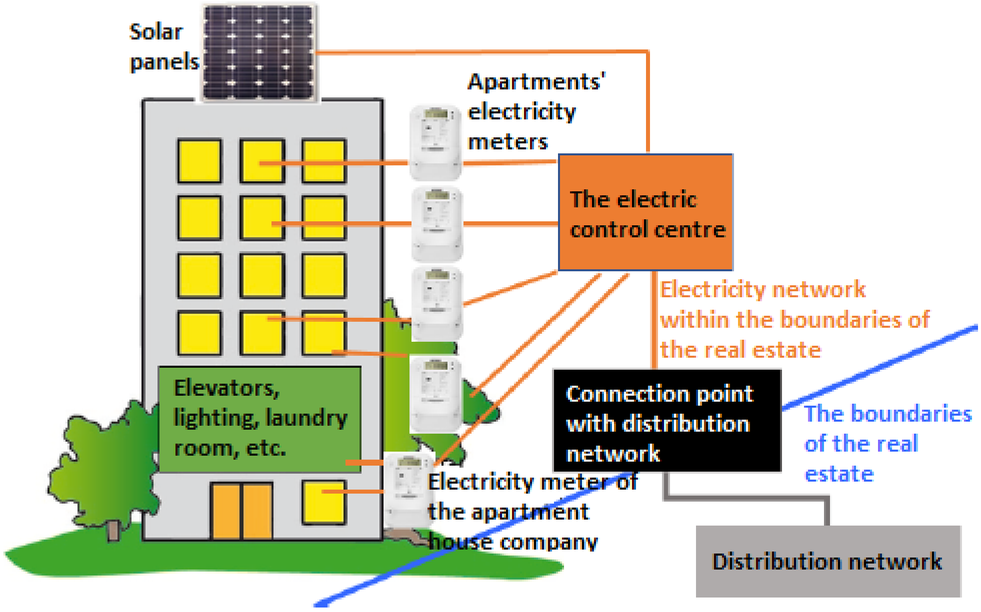

Figure 5. Basic structure of a local energy community within the boundaries of real estate. Adapted from FinSolar, 2017.

End-users must be able to resign from the community by taking into account the relevant legislation and agreements concluded. In order to allow energy community members to easily resign from the community (for example in the situation of moving out), the electricity metering inside the real estate borders should be the energy community's responsibility, not the DSO's. The community can arrange its members' electricity metering by themselves or it can order metering services from the DSO. Energy community service provider is operating this type of local energy market and it is responsible for sharing the self-generated electricity to the community members. The energy community's metering system must be able to separate the electricity taken from the distribution grid and the self-generated electricity. The changes in the metering regulation could enable net-metering within imbalance settlement period. In the future, the metering data will be collected into the datahub which will facilitate implementing net-metering services in energy communities. (TEM, 2017)

The datahub is a platform which will speed-up, simplify and improve processes related to information exchange in electricity markets (Fingrid, 2018c). Centralized information platform provides equal and simultaneous access to the information for all the market players who are entitled to the data. The utilization of the datahub was discussed also in the stakeholder interviews. The shared view was that the datahub will offer many services which can be utilized in energy communities' operations and it will facilitate the development of the local energy market concept. Electricity market specialists from Fingrid stated that the datahub will make suppliers' operations easier and may provide opportunities to develop new services and new types of supply contracts. They also pointed out that easier access to the customer data will enhance the competition, leading to improved quality of products and services.

The energy community should not impose restrictions on its members in selecting an energy supplier. Members of the community should be able to choose their own energy supplier, in the same way end-users who are not members of the community do. On the other hand, if one supplier would take care of the electricity supply for the whole community and the community would have one mutual network service contract, it would not be needed to separate individual customers in suppliers' calculations and billing. The energy community could make an agreement on how economic benefits and costs incurred are divided between its members. That division could be the responsibility of community's operator. The supplier would perceive the community as one individual customer. (TEM, 2017)

The FinSolar pilot project lead by the Aalto University is an example case of local energy community within the boundaries of real estate. The pilot partner is a limited liability housing company at Haapalahdenkatu 11 in Helsinki and it has 24 apartments with 56 residents in two buildings. In 2017 the housing company made an investment in a solar PV system. The size of the PV system is 8,7 kWp and the it is paid and owned by the residents of the buildings in proportion to their amount of shares in the housing company. The pilot tests smart metering IT-service that distributes the hourly solar electricity production to the apartments according to an algorithm that take into account the percentage of shares that residents own. Part of produced electricity goes to buildings common areas, thus the housing company had made savings in its energy costs and residents have gained savings in their individual electric bills. (FinSolar, 2017)

2.3.3 Local energy community crossing the boundaries of real estate

Local energy community which crosses the boundaries of real estate can be seen as one form of community-scale microgrid. In many cases, the best place for small-scale production is not inside the borders of the real estate, where electricity is consumed. In this type of energy community, members build an electricity network between their consumption points and make co-investments in the small-scale generation, such as PV-system, that will be installed to the place where its production can be maximized. If community would have only one coupling point with the distribution grid, the community could have one mutual network service contract and community members would gain savings with lower network fees, as predicted in the European Commission directive. (TEM, 2017)

Building electricity networks and delivering electricity over the boundaries of real estate are businesses that are subject to authorisation, and its specific regulations are defined in the Electricity Market Act (588/2013). Without regulation and authorisation any party would be allowed to build electricity networks and that would lead to building parallel grids, which would not be economically sensible. Local energy communities that cross the boundaries of real estate would be much easier to establish in new residential areas where electricity network is not built yet by the DSO, compared to establishing it in already existing residential areas. Also, in rural areas, establishing energy communities could lead to utilizing full potential of local DER, and to facilitating the improvement of security of supply. For local energy communities to be established, there is the need to set regulations about who has the legal rights to build the respective distribution networks, set its maximum physical size, and define what qualitative and functional requirements it must meet. The total cost-effectiveness and quality of the grid service must be considered, if some other party than the DSO will be allowed to build the electricity network. (TEM, 2017)

Also in this type of energy community, the members must be allowed to resign. The DSO is obliged to connect the end-users to the distribution grid in its operational area and to develop and expand the network when it is needed. That means that the DSO is responsible to offer grid connection also to those end-users who are not participating in the energy community or are resigning from it. (TEM, 2017)

The Finnish Energy Authority has written a report (Finnish Energy Authority, 2017) about the local energy communities' legal conditions in a view of EU and national electricity network regulation. According to the report, connecting generation units to the real estate's network by building a connection line, is not subject to license. However, permission from the local DSO is required before building. Local energy communities can cause so called “free rider problem”. The problem can emerge when the local energy community resigns from the distribution network and all of the community’s electricity supply comes directly from the generation unit which is connected by a separate connection line. In this situation members of the community do not have to pay grid service fees for the local DSO and taxes of consumed electricity. That could increase other customers’ grid service fees served by the same local distribution network (especially in rural areas), because the DSO is required to use distance-independent pricing in its electricity distribution. Energy communities might also set some challenges in security of supply, because the DSO would not responsible for developing and maintaining the network of the energy community. The responsibility over the community network’s technical solutions, operations and maintenance would lie exclusively with the energy community service provider.

2.3.4 Distributed energy community

In distributed energy communities, the location of the generation units, storage units and consumption loads is distributed and existing transmission and distribution networks are used for delivering electricity to the community members. Distributed energy communities enable customers to utilize self-generated electricity, even if the conditions in the customers’ consumption points would not allow the installation of their own energy resources. The restrictions and limitations can be, for instance, a tight building permission requirements or poor generation conditions in a particular location. Distributed energy communities could allow larger generation unit power capacities, which would make investments relatively cheaper for individual community members because of lower unit costs. There is a need to define applicable practices and framework conditions for forming distributed energy communities. Unbiased and clear regulations have to be established and suitable information and communication technology solutions have to be investigated in order to enable consumers forming distributed energy communities, and by that way utilize the full potential of DER. (TEM, 2017)

One example of distributed energy community is a case where the customer owns two or more apartments and he wants to utilize self-generated electricity in a different consumption point from the place where the generation unit is located. Typical scenario is the situation where the customer has installed solar panels in his leisure apartment and he wants to utilize generated electricity in his permanent home. Another typical example of distributed energy community is a case where several customers want to co-invest in a larger-scale generation unit, such as solar or wind power plant, and share the generated electricity between the shareholders. There are some advantages of this type of energy communities and investments compared to other energy community options. For instance, generation units can be installed in a place where operation conditions are optimal, since units do not have to be located near to community members. Compared to other energy community cases, large-scale investments might be easier to implement in this type of communities and that would lower the unit costs which would make investments more profitable. In the distributed energy community case, end-users are able to participate in several energy communities. In addition, the implementation of the required information systems should be easy, since in the future most of the operations and calculations could be done in the datahub. (TEM, 2017)

Customer fairness and freedom of choice are the basis of distributed energy community practices. Each community member can choose independently their electricity supplier, who will also be their open supplier. The suppliers have to be informed about the energy community's operating principles and the factors that determine the community members' electricity sharing. The principles for sharing the generated electricity between community members must be clear for balance settlement procedures before a delivery moment. The metering data should be delivered to the datahub, where collected data is available to the energy community service provider and to the community members. The party approved by the datahub is responsible for sharing the right amount of electricity between the community members within the timeframes of the balance settlement schedule. One business opportunity the datahub promotes, is to provide electricity imbalance netting-services for energy communities. According to Fingrid interview, the first version of the upcoming datahub does not have electricity netting opportunities, but when energy communities become legally defined, these netting features and other calculation opportunities will most probably be developed. Figure 6 presents the basic concept of distributed energy community considered in this master's thesis. (TEM, 2017)

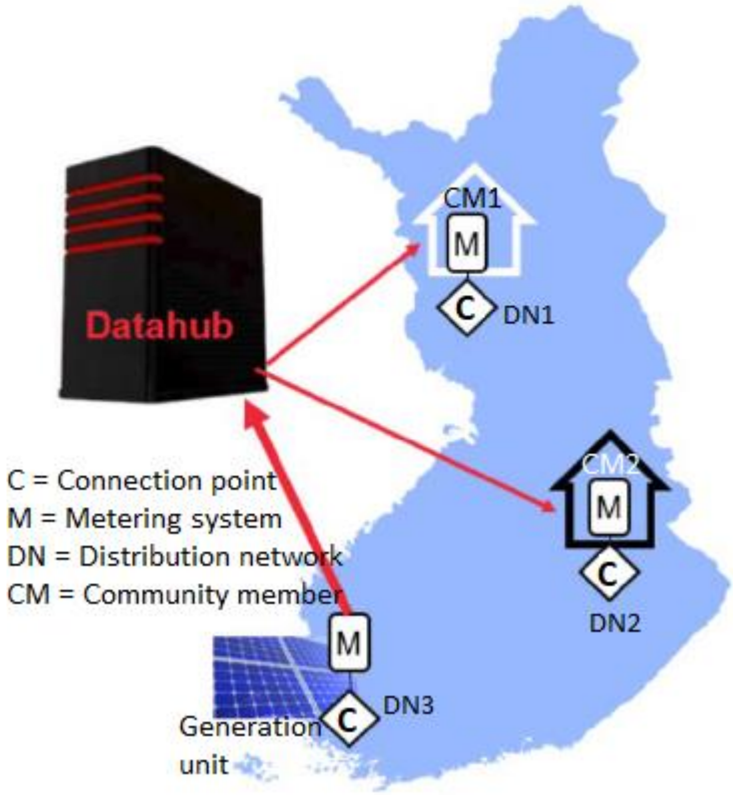

Figure 6. Basic structure of distributed energy community. Adapted from TEM, 2017.

Distributed energy community's consumption points can be located in different DSOs' operating areas. Due to that, every member or consumption/production point have to make an individual network service contract with the local DSO. The distribution fees and taxes are paid in accordance with general principles, based on the metering data of the consumption points. It would not be equal treatment of customers if distributed energy communities would have different policies for distribution fees and taxes. That would lead to the situation where system costs would increase and end-users who are not participating into the energy community, would have to bear most of these costs. The DSOs' pricing for electricity distribution is regulated and varies between a different DSOs. Due to that, it would be hard to implement equal distribution fees for each member of the distributed energy community, since consumption points are located in different distribution network areas. (TEM, 2017)

The sonnenCommunity in Germany is an example of distributed energy community. It is developed by sonnenBatterie, which is an energy storage manufacturer. The community consists of sonnenBatterie owners which are able to share self-produced energy with other members of the community. As a result, the community members may not need a conventional energy suppliers anymore. With PV system and battery, the members can cover their energy consumption on a sunny days and often generate more energy than is their own consumption. The surplus is fed into a virtual energy pool that serves other members in times when they cannot produce enough energy due to bad weather conditions. The community members are linked and monitored with a central software that balances the energy supply and demand. To participate in the sonnenCommunity, members need to have sonnenBatteries and they are obliged to pay a monthly membership fee. The company promises to community members a low-priced electricity tariff, which is cheaper than electricity tariffs from traditional market. The members receive financial compensation for sharing their electricity and the compensation is promised to be above the level of compensation offered by traditional electricity suppliers. (The sonnenBatterie, 2018)

2.4 Aggregating services and virtual power plants

Constantly developing electricity markets require more flexibility, due to increasing capacity of intermittent DER. One way to increase flexibility is to develop aggregating services and enable market actors to aggregate resources more freely than it is possible at the moment. Individual small resources, such as households and singular units, cannot provide enough flexibility to the system unless some market actor bundles them and provides their combined flexibility to the market. Market actors who do this bundling are called aggregators. Another name that is often used is Virtual power plant, which can be seen as a platform for aggregated resources. Conventional market actors such as the suppliers and the BRPs can start operating as aggregators and it is possible that new market players emerge as providers of aggregation services. A third-party aggregator is a Balancing Service Provider (BSP) which comes outside of the conventional energy supply chain as presented in Figure 7. (Nordic TSOs, 2017)

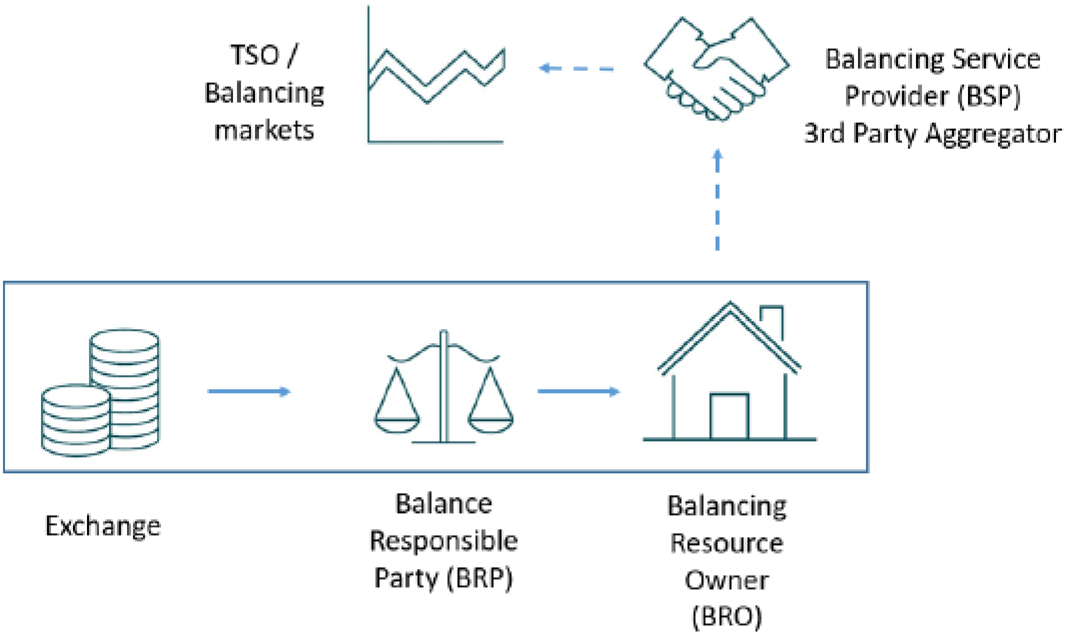

Figure 7. Third-party aggregator comes outside of the conventional supply chain. (Nordic TSOs, 2017)

A third-party aggregator can be implemented by an independent or dependent model. Independent aggregator is a third-party aggregator who is not affiliated to a supplier or any other market participant and does not need a permission from a BRP in order to operate in the balancing markets. Independent aggregators do not have a conventional role on the electricity markets. They can control customers' consumption, production and storage and offer that flexibility to the markets. Dependent model aggregators need a permission or a contract with a suppliers and a BRPs to be allowed to control customers' loads. In both, the dependent and independent aggregation models, the permission to control the customer load is required from the balance resource owner (BRO). Enabling market entry of independent aggregators can facilitate customers' involvement in demand response and would give more choices to customers. However, the rights, responsibilities and obligations of independent aggregators need to be defined, in order to ensure that their operations are well-organized and do not disturb other electricity market activities. The challenge with independent aggregators is that their actions affect other market actors' imbalance settlement procedures. That will affect, for instance, the customer's BRP, because actual consumption will not match with predicted consumption when aggregators are controlling the loads. Other challenges are related to information exchange between the market parties and the requirements for developing data systems. The BRPs should possess the knowledge about customers who have concluded a service agreement with aggregators, in which case this could be taken into account in their operations. (Nordic TSOs, 2017)

Aggregators should have good understanding of the characteristics of the technologies that are providing flexibility, and know well their end-users' behaviour, so to be able to find the right source of flexibility on a right service at the right time. Aggregators can collect flexibility from several sources. For instance, controllable loads, local generation, storage and electric vehicles are optimal sources of flexibility. These flexibility sources are listed, along with examples, in Table 1. (USEF, 2015)

Table 1. Aggregators' flexibility sources with examples. Adapted from USEF, 2015.

Type	Flexibility	Examples
Controllable load	Load shifting, on/off switching, variable power	Heat pumps, air conditioning, electric heating, HVAC systems, cold stores, heating or cooling processes, industrial production processes
Local generation	Controllable, variable power generation	Solar PV, wind turbines, CHP and micro-CHP systems, fuel cells, gas turbines, etc…
Storage	Charge and discharge. The main task is to provide flexibility to the system	Residential storage units (e.g. batteries), district storage
Electric vehicles	Smart charging and discharging with ability to move to another location	Cars, trucks, forklifts, work machines, watercraft

However, there are barriers hindering the utilization of aggregating services. High bid thresholds are one example. Lower minimum bid sizes would allow smaller resources to participate more easily in the markets. In most of the marketplaces, it is not allowed to aggregate load and generation in the same bid, even though the same BRP would be responsible for both of these. By allowing the combination of generation and consumption in the same balancing bid, aggregators would be able to utilize larger variety of their portfolios. In Finland, this combining opportunity is already implemented. For instance, a 10 MW Manual Frequency Restoration Reserve (mFRR) bid can consist of 5 MW load and 5 MW generation under the same BRP. Single balance model where consumption and generation portfolios would not be separate could facilitate aggregating services. (Nordic TSOs, 2017)

The delivery verification procedure must be agreed and the suitable measurement time resolution has to be decided. The verification of aggregation was mentioned as a challenge also during the stakeholder interviews. Fingrid's electricity market specialists stated that there have been strict requirements for measurements and third-party aggregation increase the verification requirements, but it has to be kept in mind that the premise for aggregation is to provide market access for smaller resources and increase reserve capacity. Therefore, it has to be ensured that the verification procedure is appropriate, so that too strict requirements will not set unnecessary barriers for aggregation. In Fingrid's previous aggregation pilots, projects challenges have been identified in the verification of load control actions in cases where only the aggregated consumption data has been available. In order to facilitate the verification process, the metering data should also be available separately from aggregated resources. Different markets have different requirements for information exchange, thus it has to be considered where and when, for instance, real-time data is needed. Currently, flexible resources that are participating in the reserve and balancing markets provide minute-level metering data, and control commands can be executed in seconds. Online metering on small resource level is a challenge for the aggregating services, since metering equipment is relatively expensive and the amount of flexibility and possible revenues from smaller resources are relatively low. (Stakeholder interviews, 2018)

According to a Fingrid interview, the prices of the Frequency Containment Reserve for Normal Operation and for Disturbances (FCR-N and FCR-D) have decreased after aggregated reserves were allowed to participate in the markets. Finland's own reserve capacity has not been sufficient in every situation. Thus, aggregation has brought new capacity to the markets and improved Fingrid's ability to control the balance of the system, for instance, during heavy rainfall events, when the hydro asset's ability to participate in the reserve and balancing markets is limited. In FCR-D markets, flexible consumption capacity has increased during last years, covering now about 70 % of the total capacity. This is a significant difference compared to the situation a few years ago, when flexible production covered most of the reserve capacity and flexible consumption's share was not higher than 10 %. Increasing wind power capacity may sometimes cause situations when there is more power generation than was predicted, which results in the network having too much generation compared to the consumption. It would be valuable for the TSOs if wind power generators would start participating in the balancing markets, since that would provide more flexibility to the network balancing. (Stakeholder interviews, 2018)

For Fingrid more flexibility also in the day-ahead and intraday markets would be welcome. That would reduce the need for activating flexibility from the reserve and balancing markets. Upcoming transition to 15 minute balance settlement period should improve day-ahead and intraday markets' flexibility. This transition requires changes in information exchange systems, but concurrently it should help the TSOs in network balancing. From Fingrid's point of view, it is essential to implement this transition simultaneously with other countries of the Nord Pool Spot markets. At the same time, products in balancing markets will change to 15 minute time-periods and that might facilitate household level consumers' market access. (Stakeholder interviews, 2018)

Currently, aggregated household-level end-users are involved only in FCR-N markets. This resource will soon become available in balancing energy markets, when a new Fingrid pilot reaches operation phase. This new pilot will be introduced in the next chapter. At the moment, the main focus of demand response services is on reserve markets, since these provide the best opportunities for gaining monetary benefits. (Stakeholder interviews, 2018)

Markus Logren from Helen Ltd mentioned financial benefits for customers, increase of balancing capacity, environmental aspect and optimized use of DER as the most important benefits of aggregating services and virtual power plants. Aggregation decreases prices in balancing markets, which will ultimately be reflected on the customers as cheaper electricity prices. Sufficient balancing capacity enables the increase of DER without jeopardizing network's stability. In addition, Logren stated that the aggregation services provide business opportunities for retailers and it is easier to provide additional services to customers, since many new services can be combined into a single service package. The package solutions are easier to market and combined service packages may improve the customers' commitment and stability in retailer's point of view.

As to challenges, Logren mentioned customer limited knowledge of services related to demand response. Household level customers do not need to have deep understanding of demand response services, thus service providers should develop services and products, which are easy in customers' daily use, and easy to market in service providers' point of views. Customers want services that are simple to use and that provide effective savings in their electric bills. Logren stated that there is no major regulatory barrier for slowing down the development of demand response services, but some improvements can be done in the online metering regulatory framework.

2.4.1 Fingrid pilot project for independent aggregators in the balancing energy markets

In late 2017, the Finnish TSO Fingrid started a pilot project where independent aggregators can participate in the balancing power market (mFRR) by aggregating resources from multiple BRPs' balances. Helen Oy and Voltalis S.A were chosen as project partners and the pilot was separated into two different cases. Helen is a Finnish energy retailer and producer. Voltalis is French company that specialize in demand response services. It has been operating as an aggregator in France since 2008 and today more than 100 000 French households are participating in their residential demand response programs (Voltalis, 2018).

In the pilot, Helen intends to aggregate real estates' reserve power generators, such as diesel engines. Voltalis is expected to focus on aggregation of end-users' flexibility at a household level. The pilot is using the reimbursement model which ensures the BRPs' neutral positions when third-party aggregation is allowed in reserve products. In reserve products, such as mFRR-markets, the amounts of activated energy are prominent. Thus the aggregator operations would be affecting the BRPs' imbalances if the reimbursement would not take place. The reimbursement model enables third-party aggregation from multiple BRPs' portfolios, adds more flexibility to the balancing markets and provides fair conditions to all market actors (Nordic TSOs, 2017). An example of the reimbursement model in the up-regulation situation is presented in Figure 8.

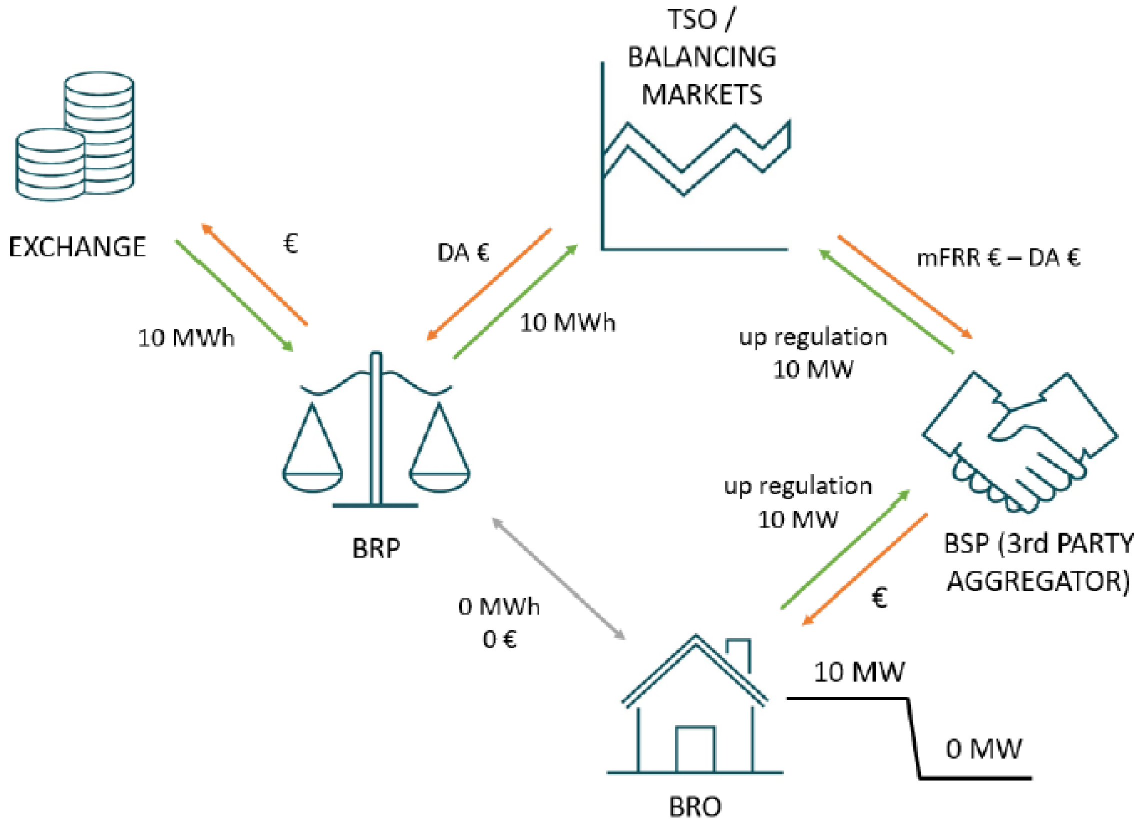

Figure 8. Third-party aggregation, reimbursement model, used in Fingrid mFRR aggregation pilot. Example of up-regulation situation. Orange arrows represent monetary flows and green arrows power and energy flows. The Balancing Service Provider (BSP) aggregate the Balance Resource Owners' (BRO) flexibility and offers that to the balancing markets, operated by the TSO. The BSP's income is the difference of an up-regulation price and a day-ahead (DA) price. The TSO buys the undelivered energy from the BRO's Balance Responsible Party (BRP) at DA price. (Nordic TSOs, 2017)

The TSO pays the difference of the mFRR price and the day-ahead price as compensation to the aggregator for the balancing services. The reimbursement is a compensation for activated energy between the TSO and the BRP. The TSO do imbalance adjustment to the BRP's imbalance according to verified delivery of activated energy between the TSO and the BRP. The TSO bases its calculations for each BRPs' delivery and imbalances on the verified measurements and on a case specific baseline model. The TSO removes the BRPs' calculated imbalances with a trade which is priced according to an activation hour's day-ahead market price. The aggregator has to inform the BRPs about their customers balancing market participation and bid activations but it does not need the BRPs permission for load controlling (Stakeholder interviews, 2018). Aggregator has bilateral contracts about load management and payments with balance resource owners. Aggregators can adjust the terms of the contract separately with different customers to serve better the customers' will.

Usually BROs receive monetary compensation from aggregator for allowing to control their flexible resources or aggregator can offer some other compensation method, for instance additional services which should improve the BROs' energy efficiency or bring some other benefits to the BROs. This aggregation model requires information exchange between TSO and BSP, BSP and BRP and BSP and BRO. (Nordic TSOs, 2017)

Without reimbursement, the aggregators' actions would affect negatively or positively the BRPs' positions, depending on particular circumstances. For instance, if the consumption participates in up-regulation, that would affect negatively the BRP's imbalances. In this situation, the BRP cannot sell the electricity bought in advance to the BRO, because the BRO is reducing its consumption. Instead, the electricity would be transferred to the TSO at price zero. Thus, the BRP would face financial losses because of undelivered energy. The BRP would get positive impact, in the case the consumption participates in down-regulation. The BRP would be selling extra energy to the BRO, who is increasing its consumption. The BRP would get that extra energy from the TSO with price zero, instead of buying it from the market in advance. In an up-regulation situation, the independent third-party aggregator would gain more profit, when compared to the BSP (who is also a BRP), because the third-party aggregator has not bought the electricity but would get paid for it when its resources' flexibility is activated upon the TSO's request. In turn, down-regulation with positive prices would be unprofitable for the aggregators. The reimbursement model is unbiased for all market actors in both up-regulation and down-regulation cases, thus it can solve the above mentioned problems, which occur if the reimbursement is not used. (Nordic TSOs, 2017)

According to expert from both Fingrid and Helen, the pilot has faced some challenges and is behind schedule. In May 2018, when stakeholder interviews of this master's thesis were done, the installation of the resources' control systems was still in progress. Thus, neither Helen nor Voltalis have been able to offer aggregated capacity to the markets yet. Some of the challenges reported included difficulty to establish sufficient revenue streams, finding suitable customers, disagreements of terms of the contracts and technical challenges of control systems' installations (Stakeholder interviews, 2018).

3 COMPONENTS OF LOCAL ENERGY MARKETS

In order to achieve well-functioning local energy markets, several individual components have to be integrated to operate together. Mengelkamp et al. (2017a) mentioned seven components of local energy markets: 1) "Microgrid setup", 2) "Grid connection", 3) "Information system", 4) "Market mechanism", 5) "Pricing mechanism", 6) "Energy management trading system", and 7) "Regulation". There are various opportunities to organize and operate each of these components in different market models. These components should be designed in a way that those would improve the efficiency of a local marketplace. Same market model is not the best option in all cases, and due to that the structure and design of the markets varies in different cases. Each of these seven components must be considered when trying to achieve well-functioning local energy markets. These seven previously mentioned components are presented in the following chapters. Additionally, DER technologies and smart metering systems are included in local market components in this master's thesis.

3.1 DER technologies

Koirala et al. (2016) state that available DER technologies and technical standards adopted affect to the structure and operation of the local energy market. Recently, decentralized technologies, such as photovoltaic systems, wind turbines and energy storage have become more common, thus driving community level engagement. Local DER assets can improve optimization of end-users' energy usage, since end-users are able to cover part of their energy demand with self-generation.

A large part of the distributed generation is from intermittent sources, such as wind and solar. It can be difficult to do accurate production forecasts from these intermittent generation technologies, and due to that energy systems should not be depending only on those generation sources. Energy storage and demand side management are helping to keep the energy system in balance and ensure the security of supply in the situations when there is not enough energy from the wind and solar units. Households' energy storage, flexible appliances and electric vehicles can be programmed to match the local consumption profiles in a way that customers can achieve monetary benefits, whereas the DSOs might be able to utilize that flexibility in the network's congestions management. (Koirala et al., 2016)

End-users are interested in owning generation capacity, and solar photovoltaic (PV) technology is the most typical technology that end-users are investing in. The prices of the PV systems have decreased whereas efficiency has improved, thus annual capacity additions have increased. Figure 9 presents the global solar PV capacity and annual additions over the last ten years. Global capacity has increased from 8 GW to 402 GW between years 2007-2017.

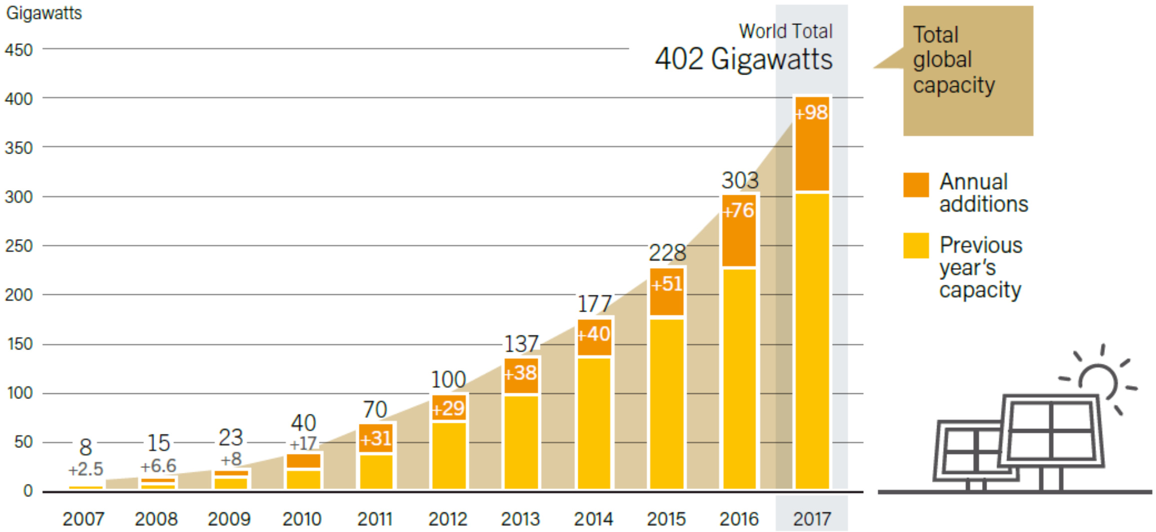

Figure 9. Solar PV global capacity and annual additions over the years 2007-2017. (REN21, 2018)

Finnish Energy Authority have collected the data concerning small-scale generation in Finland. Small-scale generation in this context means generation units which power capacity is less than one megawatt. Total small-scale generation capacity in Finland was 177,7 MW at the end of 2017 (Finnish Energy Authority, 2018). Production capacity was divided into PV, wind, bio, hydro, diesel and other generation technologies and their proportional shares are presented in Table 2. Especially PV generation capacity increased strongly, since PV capacity was 27,2 MW at the end of 2016, and at the end of 2017 installed capacity was 66,2 MW. Increase of PV and other small-scale generation was raised to the discussion also in stakeholder interviews. Helen Electricity Network's Customer Management Manager Jouni Lehtinen confirmed that micro-generation almost doubled in Helen's network during 2017 and most of that new generation is from solar PV. He stated that capacity additions will probably accelerate and be bigger during upcoming years. Even though end-users' generation capacity will increase, these new units do not affect to the network operation or cause any problems to network management.

Table 2. Small-scale generation capacity and their proportional shares in Finland at the end of years 2017 and 2016. (Finnish Energy Authority, 2018)

Technology	Capacity [MW] 2017	Capacity [MW] 2016
PV	66,2 (37 %)	27,2 (21 %)
Wind	17,5 (10 %)	15,5 (12 %)
Bio	16,3 (9 %)	15,3 (12 %)
Hydro	36,2 (20 %)	34,2 (26 %)
Diesel	38,2 (22 %)	37,4 (28 %)
Other	3,3 (2 %)	2,8 (2 %)
Total	**177,7 (100 %)**	**132,4 (100 %)**

Figure 10 represents the DER technologies which can be utilized in the local energy markets. DER consist of distributed generation and energy storage systems. Distributed generation have been divided into renewables and non-renewables. Energy storage options have been divided into kinetic, thermal, chemical, electrochemical and electrical technologies. The used technologies varies in each local market cases, since available technologies and conditions varies in different locations.

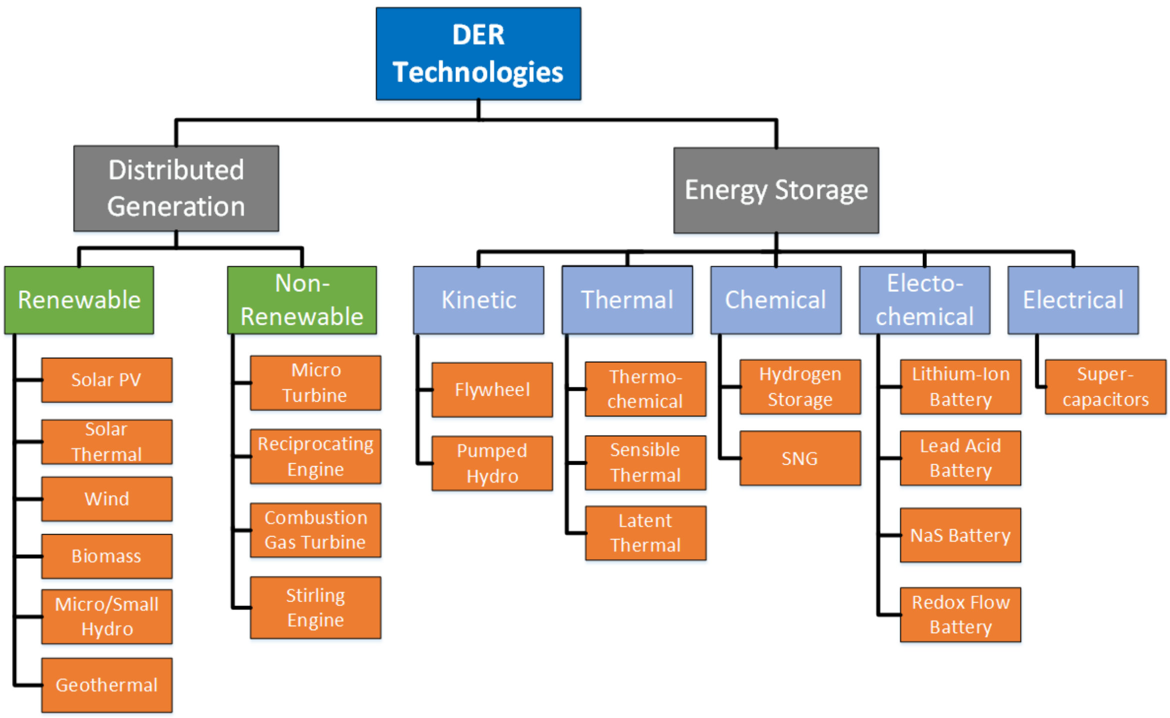

Figure 10. DER technologies available in local energy markets. Adapted from Paliwal et al. (2014).

3.2 Microgrid setup and connection

The microgrid setup needs to define objectives, market participants and form of energy that is traded. Microgrid implementations can have many objectives but usually microgrids are designed to increase security of supply and to maximize the usage of local renewable energy sources. In local markets, some of the end-users have to be prosumers who are producing electricity with, for example photovoltaic system. Prosumers are providing energy that can be traded with other prosumers or consumers on the markets. It has to be defined which parties can have market access and if heat is also traded, in addition to electricity. It has to be decided if physical microgrid is built or if the already existing distribution grid is used for energy transfer. Local energy market can consist of various microgrids or combination of physical microgrid and distribution grid. (Mengelkamp et al., 2017a)

Connection between a microgrid and distribution grid must be organized with one or many connection points. That enables superordinate grid to help for balancing supply and demand within a microgrid. Physical microgrid can be decoupled from the distribution grid and operate in island mode, for example during power outages. One type of the microgrid is a virtual microgrid (similar to VPP) which means that it does not have its own separate network for electricity distribution. Since virtual microgrids are using the DSO’s network for electricity distribution, virtual microgrids cannot be operated in island mode. To ensure security of supply when operated in island mode, microgrids need to have enough of their own energy generation capacity and flexibility. Grid congestions need to be taken into account when operating microgrid. Demand response services and storage systems are providing flexibility to the grid. (Mengelkamp et al., 2017a)

3.3 Information exchange and electricity metering system

According to Mengelkamp et al. (2017a), the foundation of the market platform is an active information exchange system. It connects all market stakeholders, monitors market operations and provides market access. Information and communication technology (ICT) enables market stakeholders to develop new energy services and to operate effectively. To promote transparency, every market participant has to have equal access to the system. Blockchain is promising technology that can be utilized in information exchange in energy systems. According to Mengelkamp et al. (2017) blockchain protocol can be seen as “a shared global infrastructure for decentralized applications that enables the implementation of full-scale software applications (smart contracts) without a central platform". Smart electricity metering and a secure data handling are the key aspects in the active information exchange system. Because of smart metering, the microgrid operator receives useful information on the status of the network, and consumers are able to observe their energy consumption and generation on real-time. Smart metering data enables market actors to provide new services such as smart applications and load controlling devices to customers.

Standardisation should be used to ensure that various components of the local markets can be interconnected and interoperated (Timmerman, 2017). On the local energy markets, communication structure can be divided into centralized, distributed or unidirectional communication (Morstyn et al., 2018). Central operator communicates with all prosumers in centralized communication system, whereas in distributed communication prosumers communicate bilaterally with each other. In unidirectional communication, prosumers receive broadcasts from communicator and make decisions according to these broadcasts.

Smart metering systems are helping the DSOs in network operation. Metering data is providing important information that can be used by local market operator to optimize its operation. In addition to the network operators' benefits, efficient network operation can bring cost savings to the customers. The DSOs can use metering systems, for example in electricity quality measurements, to improve customer communications, in outage management and generally monitoring the status of the network in real-time. (Energiateollisuus, 2017)

The smart meters enable to develop innovative services related to demand response, thus smart meters' features affect to the possibilities that local energy markets might offer. The stage of the smart meters' roll-out differs significantly in different countries. Figure 11 shows the differences in the progress of implementation stage, and legal and regulatory status of smart meters in EU-member countries. It can be seen that Finland is a forerunner in smart meter implementation.

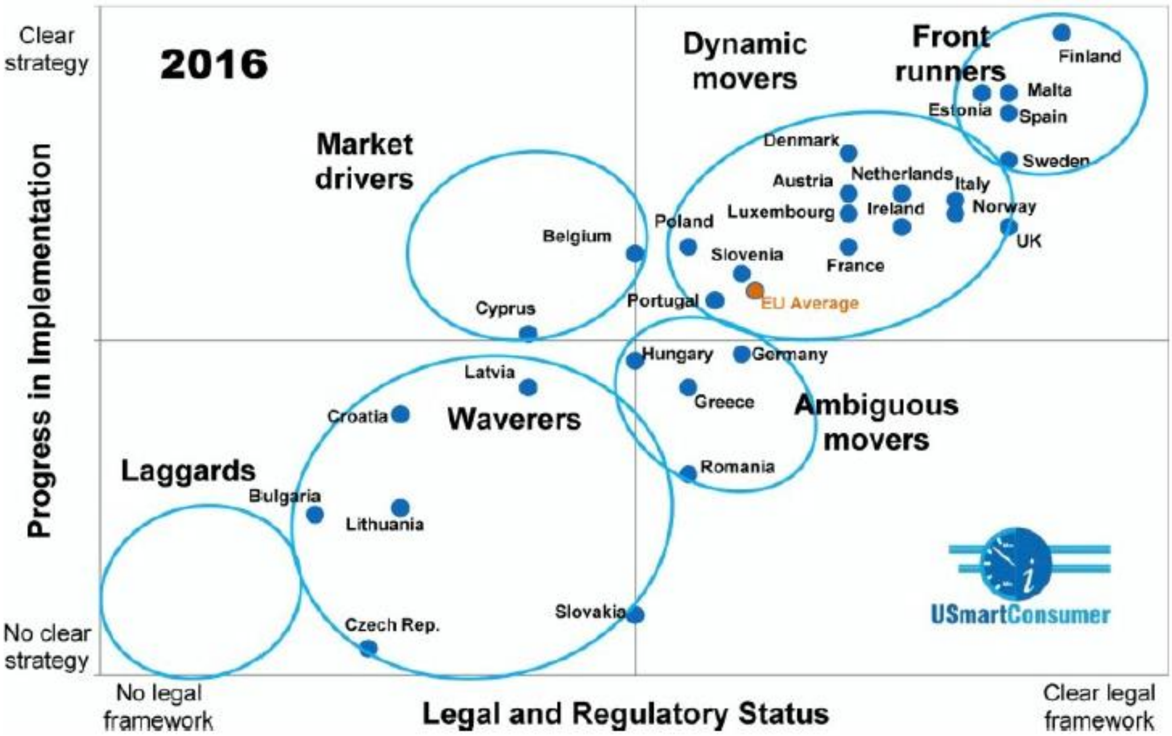

Figure 11. Stage of the smart meter roll out in EU-member countries 2016. (The USmartConsumer Project, 2017)

3.3.1 Metering systems in Finland and requirements for the next-generation smart meters

In Finland, current legislation determines that the metering of electricity consumption and small-scale electricity production must be based on hourly metering and remote reading of the metering equipment. Decree of the Council of State concerning balance settlement and measurement 66/2009 determines in Chapter 6 some minimum requirements that hourly metering equipment and the DSOs' data systems need to fulfil (VNa 66/2009). The metering equipment must be remote readable, thus the recorded information must be available to be read from the equipment's memory via communications network. The metering equipment needs to register the starting and ending times of more than three minutes voltage-free periods. It also must be capable to receive and to implement or forward load control commands. The hourly metering data must be stored in the DSO's data systems at least for six years and information on the voltage-free periods at least for two years. The data of the metering equipment and the DSO's data systems must be protected in an appropriate way. The changes to the metering systems were required to be implemented by the end of 2013, thus today, first-generation remote metering systems have been installed almost in every household in Finland. The installations of these first-generation remote metering systems were done mostly during 2008–2013 and costed around 800 million euros (YLE, 2018). Since the technical lifetime of these meters is about 15 years, there is need to replace the meters by new ones between the years 2023–2028. Because of that renewal process, there is now a debate what the requirements of the next-generation remote metering systems should be.

Pöyry Management Consulting Oy did a comprehensive report (Pöyry, 2017) about next-generation smart meters minimum functionality requirements. The report describes the legal and other prerequisites for next-generation smart meters' implementation in Finland, it presents the metering requirements set by EU, analyses the needs of the stakeholders and reviews the business opportunities provided by next-generation smart meters. The report presents quality and cost-benefit analyses about meters' load control functionalities and real-time data exchange. With these analyses they are able to evaluate if there is a need to require load control and real-time data exchange functionalities. The report suggests that next-generation smart meters should meet the following minimum functionality requirements:

- The measurement frequency must be based on the balance settlement period, which can be 3–15 minutes in the future
- Measure and register energy, active and reactive power in each phase
- Measurement of instantaneous values: active and reactive power, voltage, current and frequency
- Metering of power input and output to/from a network separately in each phase (no inter-phase net metering on the meter)
- The metering equipment must record the starting and ending times of a voltage free periods, even if that period would last less than three minutes
- The software of the meters should be possible to update remotely
- Functionality for remotely cutting off and connecting power to the metering point
- Local unidirectional physical data exchange channel, which update rate is less than five seconds

Finnish Energy (Energiateollisuus ry) has written a position paper (Energiateollisuus, 2017) on the features of next-generation electricity meters. The basic overview and requirement suggestions are quite similar as in Pöyry's report. Finnish Energy recommends that current metering requirements (determined in VNa 2009/66) will be applied to the next-generation equipment and metering systems. Nonetheless, some requirements need to be specified and improved to better serve the customer needs and electricity markets in general. The minimum metering period of the equipment should be based on the balance settlement period and trading period which is 60 minutes in Finland currently. However, this will probably change to 15 minutes according to proposed European Commissions' regulations. To implement new equipment cost-efficiently and to ensure adequate transition period, the change will probably happen at the earliest in 2025. Due to possible changes in the balance settlement period, future meters should be capable to measure the electricity consumption and production at least in 15 minute time-periods. It is also reasonable to require the capability of measuring and registering momentary power because there have been discussion if the pricing structure in distribution should be changed to be based on the power more than current pricing structure does.

Finnish Energy suggests that the next-generation electricity meters, excluding current transform meters, should be capable of remotely cutting off and connecting power to the metering point. This is already possible in 60 % of already installed meters in Finland, thus the percentage can be improved. The remote operations improve customer services and enable harmonising operational processes, for example in a case when customer is moving to new apartment. The operational costs of disconnections and connections will also reduce in a debt collection situations, due to possibility of remotely cutting off. The remote updating of the meters' features must be enabled in new meters. In this manner, new meters can be modified according to market changes, thus improving meters' operational efficiency. Only the realistic needs of the markets should be considered when the minimum criteria of the meters are defined. Costs and risk of faults increase with excessive technical requirements of the meters. Reliable metering of electricity consumption and production, remote operations and requirements mentioned above are the priority features of the next-generation electricity meters.

In Finnish Energy's position paper it is stated that on the customer's separate request, the DSOs must provide a standardized connection that permits customer monitoring electricity consumption in real-time. In European Commission's Directive proposal "Clean Energy Package" (European Commission, 2016a) in Article 20 it is defined that "information shall be made easily available and visualised to final customers at no additional cost and at near-real time in order to support automated energy efficiency programmes, demand response and other services." It is not defined what Commission means for example by the concept of "visualised", hence more specific definitions are expected later in the Directive process. The Directive will set a guidelines for requirements of the next-generation meters and this will naturally be affecting the investment and implementing decisions, hence it is important to have clear definitions.

3.3.2 Data sharing

The data from the electricity meter is available by two different ways. The unvalidated real-time consumption data directly from the meter or validated data from the DSO via information exchange system. The metering data validated by the DSO is read, processed and provided for the use of balance settlement, customers and other market stakeholders one day after consumption. Currently, customers can view their data information from the DSOs' online services and the DSO sends the validated data directly to the other market stakeholders via operators. (Energiateollisuus, 2017)

The Finnish TSO Fingrid is working on the Datahub project and planned deployment for the Datahub is at 2020. All the measured information will be collected centrally to the Datahub and stakeholders have an access to the data that they have legal rights. Easy and equal access to consumer data will improve retail markets' transparency and facilitate consumers to make efficient and reasoned decisions based on increased amount of available data. Datahub can bring opportunities for suppliers and third-party intermediaries to develop innovative services for customers. The main reason for implementing the Datahub is to intensify information exchange, and it has been calculated that cost incurred because of information exchange will be decreased by 7 %. The flow of the metering data is presented in Figure 12. (Stakeholder interviews, 2018)

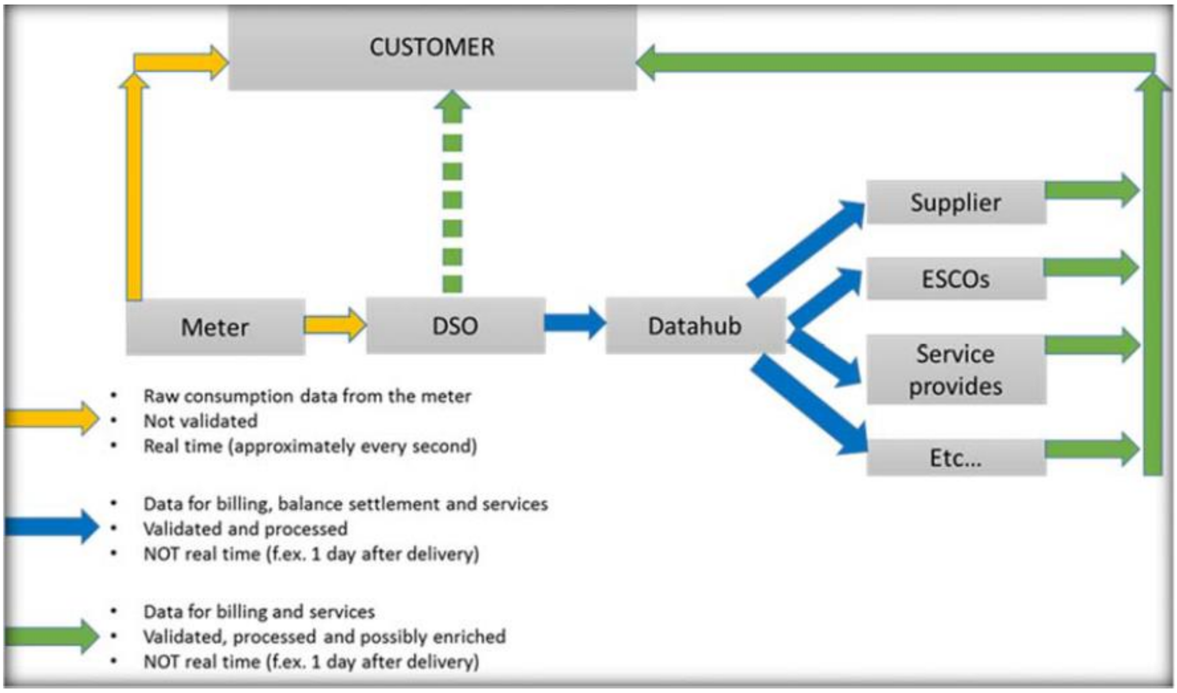

Figure 12. Two routes of the metering data to the customer. (Energiateollisuus, 2017)

Nordic TSOs Energinet, Fingrid, Statnett and Svenska kraftnät presented a report (Nordic TSOs, 2018) on common solutions for the future Nordic power system in March 2018. In the report there is a discussion about linking the Nordic datahubs together, which could allow easier data exchange over the national borders and could facilitate integrating retail markets in Nordic countries. An integrated market would intensify competition of new and old market actors, resulting to better services for Nordic customers.

Pöyry's report (Pöyry, 2017) and Finnish Energy's position paper (Energiateollisuus, 2017) both state that data reading technology and systems should be designed to be modifiable easily to more frequent reading interval than at present with reasonable costs. From the standpoint of electricity suppliers and balance settlement, validated data is needed quickly but not in real-time. It is enough if the validated data for the balance settlement period is available on the day after electricity supply, thus there is no need to require the DSOs to provide validated data faster than they are providing it at the moment. Although, if the real-time customer billing becomes more common, situation would change and the data should be read and validated faster. Before setting new statutory requirements in the metering systems, it is important to ensure that the benefits achieved will be greater than costs incurred.

3.3.3 Role of metering systems in services related to demand response

Next-generation meters should provide unvalidated real-time consumption data for market parties more effectively and extensively than at present. Electricity suppliers and energy service providers are developing new services based on real-time consumption data to serve better the customer needs. These services include control systems, various home automation solutions, home displays and possibly demand response verification for the reserve markets. At present, it is not defined clearly enough what requirements will be set in the future for aggregated regulatory and reserve sales' verification. The entire metering system should support verification process if the DSOs' meters will be used for verifying these demand response sales. It is important to ensure that all the operators are following the same procedures. Figure 13 presents new and constantly developing requirements, which should be considered when designing the next-generation smart metering systems. (Energiateollisuus, 2017)

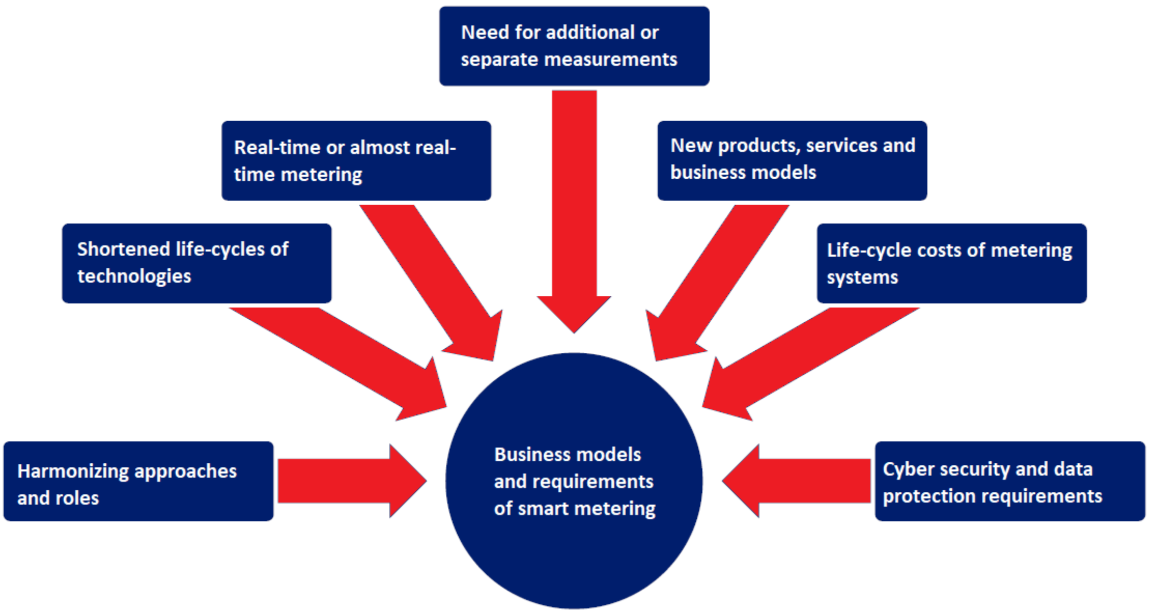

Figure 13. Developing business models and requirements of smart metering systems. Adapted from Pöyry 2017.

New demand response services and solutions are developed constantly and those can be applied in different markets. There are several types of services with different features, such as response times, the reliability of execution and verification of response implementation. The metering system should be capable to receive, implement and forward load control commands from the communication network. There are lot of electric heating load that could be controlled via metering system. To be able to utilize electricity meters in that kind of load controlling, that would require standardization on data exchange, response times and procedures. Currently, response times varies because of the different reading technologies, and there are challenges to fully ensure that control commands have been delivered. (Energiateollisuus, 2017)

Currently, it is not usual for common household to use demand response controls, even though service developers are constantly developing new solutions for that. Smart meters might enable, for instance, spot-price dependent controlling of electric heating loads or using the scheduled control determined by the supplier. Measurement interval based on the imbalance settlement period enable suppliers to offer contracts which are based on the electricity spot prices. For instance, Helen Ltd base most of their products and services, which are related to demand respond, to the market-priced exchange electricity contract which is following Nord Pool Spot price trend by the hour (Stakeholder interviews, 2018). Government Decree on Determination of Electricity Supply and Metering (VNa 2009/66) states that metering equipment must be capable of receiving and implementing or forwarding load control commands sent via communication network. Hence, it should be possible to utilize metering systems in customers' load management, but there are some challenges which complicates its implementation in practice.

Pöyry's report (Pöyry, 2017) states that based on the quality and cost-benefit analyses, there is no need to include load control relays in the next-generation smart meters' minimum functionality requirements. In the same report it is stated that suppliers' and service providers' opinion is that the load control relays should not be required, since their smart energy management systems can do the load controlling better. They stated that controls done by load control relays are not accurate enough and response times are too long. The view of the service providers in the report was that load controlling should be implemented in principle through commercial needs and service production. Thus, if customers are willing to participate in the demand response services, it would be reasonable that they have to invest in additional metering equipment. The next-generation smart meter should have interfaces for external devices, such as home automation systems, which could utilize the data from the meters.

Finnish Energy's position paper (Energiateollisuus, 2017) states that the volatility and available load capacity will enable forming a market-based demand response market, since meter-controlled loads are offered for utilisation by the market actors. The control interface that is forwarding control commands must be standardised and adopted by all DSOs. Data exchange, interfaces and response times should be standardised as well, to make controls feasible. Meter controlled demand response operation supports the deployment of other demand response controlling systems, such as home automation systems. Optimization of customers' energy usage, flexibility and energy costs will be increasingly based on controlling internal energy flows of the households and energy management will be based on the electricity market price.

Since PV-systems, EVs and electricity storage systems are becoming more common, in addition to smart electric meters, some other smart control systems are required to respond to the increasing need for customer energy management automation. Quick response times of controls and two-way monitoring in real-time are necessary features for implementing these automation services. In the future, various types of control solutions are needed. Shorter response times will increase flexibility management options and in some cases real-time or almost real-time control operations are required. (Energiateollisuus, 2017)

3.4 Market and pricing mechanism

The market mechanism defines market's allocation and rules. Bidding language and format have to be defined. The efficient market mechanism is aiming to match market participants' buy and sell orders. Due to microgrids' prosumers' generation constraints, minimum and maximum allocations of energy should exist. The market mechanism should be designed in a view of different stage of the electricity markets, such as day-ahead and intraday markets. Day-ahead market requires accurate forecasting of prosumers' electricity production and consumption. Therefore, shorter trading horizon enables more efficient coordination of DER because, for example, PV generation and end-users' consumption can be difficult to forecast a day before. In short trading horizon, there is less imbalance between predicted consumption and actual consumption, thus imbalance settlement is more stable. To achieve optimized use of the local DER, balancing mechanism and pricing mechanism have to be combined when designing the market mechanism. If the imbalances cannot be met in the local market, then distribution grid can be used to achieve balance and the imbalance settlement system is used to define financial imbalances. Local marketplaces can have different market mechanism but the mutual goal is to utilize prosumers' surplus electricity efficiently. (Mengelkamp et al., 2017a; Ampatzis et al., 2014)

The function of the pricing mechanism is to set an electricity price which is in economic equilibrium. Double-sided auctions are often used as a pricing mechanism in energy markets and the clearing price can be determined by uniform or discriminatory pricing. In uniform pricing, the clearing price is the equilibrium of supply and demand bids, thus the clearing price is equal for all transactions. In discriminatory pricing, the clearing price will be individual for each transaction according to matched supply and demand bids. Markets should be able to send price signals to the market participants about energy scarcity or surplus. According to basic market law of demand and supply, local market price should be low when there is surplus of energy and price should rise when there is lack of energy. If socio-economic reasons are excluded the local markets are profitable for consumers and prosumers when the local market price is lower than energy from the wholesale markets. Lower energy costs is one of the objectives of local energy markets' and reduced costs will increase customers' interest and commitment towards the local energy market development. (Mengelkamp et al., 2017a; Ampatzis et al., 2014)

The order book market design is using double-sided auction market where the buy and sell orders have to be submitted to a public order book. The orders are matched continuously or at specific closing times. If there is a uniform clearing price, the lowest bid price that can be served determines the clearing price. All consumers whom buy orders are at least the clearing price are going to receive energy from the local markets. The clearing price is the market price that end-users who are successful on the auction market are paying for sellers. If consumers cannot cover their whole electricity demand from local markets, they have to purchase electricity also from the retail market. Prosumers have to feed surplus electricity to the distribution grid if they are not able to sell it on the local markets or cannot reserve it to a storage. Prosumers should sell their surplus electricity on a local market if the local market price is higher than the price that they can get from the electricity fed into the distribution grid. The order book market design needs a central unit or a platform that receives the bids and determines the clearing price. (Mengelkamp et al., 2017b)

According to Mengelkamp et al. (2017b) on the peer-to-peer markets, energy is traded bilaterally between prosumers and consumers on a pay-as-bid method. Buying consumers are randomly paired in every time slot with selling prosumers until consumers have successfully covered their electricity demand. Consumers are matched with prosumers when their bid price is equal or higher than prosumers asking price. Consumers are paying the price they bid for the electricity and the matching energy amount is determined by buy and sell orders minimum capacity. On the peer-to-peer market every buyer is paying a different price for the electricity in contrast to the order book market where all the successful buyers are paying the market clearing price.

3.5 Energy management systems and smart applications

Customers' energy management and smart applications are important factors to make local market profitable and to ensure optimized usage of local DER. (Koirala et al., 2016). The automatic energy management trading system is trying to find an efficient bidding strategy and securing the energy supply to a customer. The development of customer's bidding strategy is based on the forecasted consumption and generation data. The service provider of the energy management system will do the energy trading on the market platform and manages customer's demand response resources according to variable market prices. Market participants are aiming to minimize the price that they are paying for energy and maximise their revenues by selling energy as a high price as possible. Automatic management and trading is important since typical customer is not willing to take responsibility for energy trading and prefer it to be automated. Easy and efficient energy management can improve customers' attitudes towards the local energy markets. Socio-economic factors can affect customers' willingness to pay and in this manner to their bidding strategy. The energy trading is done according to predefined settings of customer's bidding strategy. (Mengelkamp et al., 2017a)

Eid et al. (2016) studied market integration of local energy systems and local energy management. They defined electric flexibility as "a power adjustment with a specific size and direction, sustained at a given moment for a given duration from a specific location within the network". Flexibility enables to manage network congestions, optimize suppliers' portfolios and integrate renewable energy resources into the network. In their study, they have defined local energy management as "a coordination of decentralized energy supply, storage, transport, conversion and consumption within a specific local geographical area, combined with automated control system and demand-side management strategies".

There are different strategies to manage and activate customers' flexibility. The flexibility activation can be done by direct control, semi-direct control or according to indirect signals (price signals). Direct control enables system operator or third-party intermediaries such as aggregators, to control customers' consumption and energy management system directly. Customers and load control operator party have to establish a contract where it is defined the devices which flexibility are allowed to be controlled by operator. End-users have various appliances that have different technical abilities to provide capacity for flexibility services. Such appliances are for instance electrical heaters, washing machines, EVs or generating units like PV-systems and CHP units. Direct control is easy for customers, since some other party is taking care of the energy management and customers do not have to activate the flexibility controls manually. Operator actor is provided with guaranteed access to the flexibility capacity within specific time and location, determined in the contract. (Eid et al., 2016)

Indirect signals mean that customers' flexibility is activated according to the electricity market price. Customers are willing to make changes in their electricity usage from their normal consumption behaviours during hours when electricity market price is high. Compared to direct control, in indirect control end-users have more freedom to decide of their participation in provision of the flexibility services. Indirect control does not necessarily guarantee the expected capacity of flexibility to the operator actor. (Eid et al., 2016)

Semi-direct control gives customers more control to define how the flexibility is managed compared to the direct control. Customers predefine timeframes and market price limits which will set the boundaries for the controlling party. Semi-direct control is often used for automated flexibility activation in predefined devices according to the price signals. (Eid et al., 2016)

Markus Logren from Helen Ltd stated that energy management and services related to demand response are providing significant business opportunities for the retailers. Helen is providing new kind of operating model combined with “the Exchange Electricity Optimum” electricity product, which provides opportunity for customers to take part in the network balancing and reduce their electric bill at the same time. Helen is co-operating with OptiWatti which is a company that designs smart control systems for households. Exchange Electricity Optimum is electricity contract where prices varies according to hourly changing electricity market price, and unlike similar electricity products, Exchange Electricity Optimum does not have separate margin charge added in top of the market price. Electric heating customers can gain monetary benefits when combining Exchange Electricity Optimum contract with OptiWatti control system. Smart control system optimizes domestic heating by arranging the heating for the most favourable priced moments of the day. Automation will ensure that indoor temperature stays at the preferred level. Currently, only heating loads of the households are controlled but in the future storage systems and EVs are supposed to provide more flexibility to be controlled. Households’ flexibility can be aggregated together and form virtual power plant. Helen’s virtual power plant is a platform which combines Helen’s customers’ DERs. Virtual power plant can be utilized in network’s balancing and customers receive compensation for that in the electricity contract price. (Stakeholder interviews, 2018)

3.6 Regulation

The regulation set the boundaries for local markets and affects significantly to the structure of the marketplace and a designing process. Taxation and other fees are dependent on the legislative rules, affecting the profitability of the local energy markets. Legislation also determines how local markets can be integrated to the wholesale markets and for example how microgrids are connected to distribution grid. The regulation is one of the key factors for facilitating local energy markets’ development. The regulation is setting various barriers for local energy markets and due to that it is important to design new regulations and rules in the way that those are not hindering the local markets’ development. The barriers related to regulation is discussed more specifically in Chapter 5.2.

4 STAKEHOLDER ROLES IN LOCAL ENERGY MARKETS

This chapter elaborates on the stakeholders of the local energy markets. Their future roles and responsibilities in different local market models are investigated. Development and changes in the electricity markets will challenge the traditional business models and also the stakeholders' roles might change. National governments and policy makers in the national and local level play an important role in facilitating the market entry of innovative market solutions, such as energy communities and microgrids (Koirala et al., 2016). The stakeholder interviews, which were done during the research process, are providing supplementary information about stakeholders' viewpoints of the local energy market development and market players' future roles. The topics of the interviews were related to the future of the electricity markets, energy communities, aggregating services, demand response, customer empowerment and generally to all the themes that are discussed in this master's thesis.

4.1 TSO and DSO

The grid operators have an important role in the transitions process towards a cleaner energy systems by facilitating efficient DER utilization and promoting the development of the local energy markets. The main responsibilities of the grid operators are to guarantee the stable and secure physical infrastructure, and by avoiding grid congestions, ensure that sufficient network capacity is constantly available. That means that the DSOs are responsible to ensure security of supply by providing free flow of energy in the network, and by that way guarantee that suppliers are able to deliver energy to the end-users. Transmission and distribution grids are one of the most essential and stable infrastructure in our society and their designing standards are based on the reliability and safety. When designing and implementing new market structures, such as local energy markets, it is essential to ensure that changes do not endanger the networks' stability and security of supply. New services and functionalities should be enhancing networks' reliability even further. (USEF, 2015)

The development of the local energy markets is not affecting to the role of the TSO. The main role is to transport energy from the centralized producers to the industrial customers and the DSOs by using its high-voltage transmission network (USEF, 2015). The TSO is responsible for maintaining the balance of the energy system by organising regulating capacity, reserve capacity and incidental emergency capacity. When it is needed, the TSO will take corrective actions to restore the network balance by procuring flexible power from the market. Aggregating services in local energy markets can offer new flexible capacity to the balancing energy markets, and by that way the TSO is interacting with local energy markets.

Compared to the TSO, the local energy markets can affect to the DSO's role significantly more. The basic role and responsibilities of the DSOs will remain unchanged but local markets are offering new possibilities for the DSO to develop its operations. The structure of the local market is the determining factor for DSO's role in the local marketplace. The DSO could take a role of local market operator, which is responsible for ensuring the functions of the local marketplace and guarantee the security of supply inside the microgrid or other form of local market. Local marketplace usually have connection to the distribution grid and in some cases local marketplace may use distribution grid for supply the electricity that marketplace's members are trading with each other.

Increase of technologies, such as EVs, electric heat pumps and PV solar panels, can cause need for increasing grid capacity. Intermittent renewable generation is causing the need for improving flexibility of the network. Luckily some of new DER technologies, such as energy storage, increase flexibility which is needed for network balancing. Also, in the future EVs will provide new flexible resources to be utilized. Most of the electric cars will be available for loading and unloading for several hours during the day, thus providing significant flexibility for network balancing. Grid capacity can be increased with grid reinforcement but by increasing networks' flexibility some of these reinforcements might be possible to be postponed or avoided. To facilitate efficient network operations, it is possible that in the future the DSOs could actively manage flexible resources, and reduce network loads by that way. One possible scenario is that the TSO shift some of its responsibility about load management and control to the DSOs (Timmerman, 2017). That topic was discussed also in the interview with Fingrid's specialists and new pilot project is under development but have not been launched yet. The DSOs could be facilitating and promoting the implementation of the services related to demand response and provide some of these services by themselves. (USEF, 2015)

In the cases where the DSO owns and maintains the grid structure of a local marketplace, the DSO is automatically involved in local market operation. In those cases the distribution grid would be used for deliver energy in customers' peer-to-peer trades, thus the DSO would be responsible for ensuring the delivery. The pricing mechanism and matching the buy and sell bids should not be the DSO's duty, since some other market actor is providing those services and it is not the DSO's business or expertise.

Local energy markets usually needs some central party to be the operator of the local marketplace. There are many options which market actor should take a role as local market operator, and one possible actor who could take this role is the DSO. That would require adjusting the DSO's regulations, and clearly defined responsibilities and rights of local market operator would be needed. Even if the DSO would not be the local market operator, it might take more active role to control customers' loads. Though the DSO cannot directly control customers' loads, one option would be to use aggregators as an intermediary for load controlling. If the DSO would be the local market operator, the DSO should be able to acquire flexibility from the local markets and ensure the security and quality of supply (Kilkki et al., 2018). According to Oliveira et al. (2013) the most important task for local marketplace operator is to determine the electricity prices inside the microgrid or other type of local market. The pricing mechanism affect the complexity of the marketplace operator's task and it might be possible for local market operator to outsource this tasks for some other market actor.

Even though increasing flexibility can be used in network operations, grids' designing will still be based on the peak power of the network, thus the network capacity requirements in designing processes cannot be calculated according to increased network flexibility. Interviewed stakeholders stated that it is not completely certain that this flexibility will be available in every situation, and due to that capacity requirements need to stay the same as before. (Stakeholder interviews, 2018)

New energy systems should try to improve the reliability of flexible resources availability, enabling system operators to reduce peak loads and maintain the network balance. The certainty of available flexibility is needed on both a short-term and a long-term. To prepare for an upcoming periods, operators prefer to ensure the availability to the flexible resources far in advance. Energy suppliers often want to keep the flexibility in their own control as long as it is possible, because then they can respond to possible unpredicted changes. These different standpoints of operators and suppliers may cause conflict in some situations. (USEF, 2015)

Typically the DSOs are responsible for the roll-out of the smart meters. Smart meters enable network operators to monitor the network operations in real-time and provide opportunity for various value-added services. Increasing and active information exchange is providing the possibility to develop new market services and market models, including local energy market options. For instance, demand response applications, load control and local network balancing are based on the data that smart meters are providing. In distribution network level, new control mechanisms which are embedded to the end-users' smart meters, are possible. Increasing amount of data and applications based on that data put communication systems to the essential position, thus reliability of these systems is extremely important. A breakdown in the communication systems might endanger the supply of electricity. In the case of energy communities, it is not completely clear if the DSOs should be responsible for the metering system. There is an option that some other market actor have a role as an operator of the energy community, and that party could be responsible of the community's metering system. (Timmerman, 2017)

Most of the local energy market solutions are designed from the standpoint where a local marketplace have a connection to the distribution network. Local energy communities and other local market models do not obviously remove the need for transmission and distribution grids, but new market opportunities can affect to the roles of the DSOs. In addition, connection to the distribution network enable local marketplace to participate in conventional electricity markets which provide much more market opportunities compared to being only operating in island mode. For instance, end-users of the local marketplace can participate through aggregators to the balancing markets, offered by the TSO.

When asked about the DSOs' future roles, Jouni Lehtinen from Helen Electricity Network Ltd stated that he believes the DSO's basic responsibilities and role is staying the same in the future. The most important responsibility will remain to secure the uninterrupted electricity supply and ensure that suppliers are able to deliver electricity to customers. The DSOs could offer electricity metering services for energy communities, since they have lot of expertise in that field and arranging metering in the community would not be a challenge for them. Increasing self-generation and storage systems will cause changes in the energy business but do not change the DSOs' main responsibilities and focus of the DSOs' business. (Stakeholder interviews, 2018)

4.2 End-users (prosumers, producers and consumers)

Prosumers, producers and consumers are the key participants in the local energy markets. They are transforming from passive end-users to market actors who actively participate in the electricity markets, and want to utilize local energy resources and to be able to share and trade their generation and flexibility with other end-users in the local marketplace and take a part to services related to demand response (Kilkki et al., 2018). End-users are more willing to actively participate in energy production, improve their energy efficiency and contribute to cleaner energy generation by investing in own or community owned renewable generation capacity. By investing in self-generation and participating in demand response services, end-users are seeking new possibilities to achieve savings in their energy costs (USEF, 2015). Some prosumers may even want to be completely energy self-sufficient, but in most of the cases, that can be difficult to achieve. Local energy markets, such as energy communities and microgrids, provide opportunity for end-users to improve their energy independence and be less dependent on conventional big energy companies.

One important question is that can self-supportive local marketplaces be economically feasible. To implement local marketplace and achieve end-users' involvement, local market should be able to bring economic benefits to its members. Completely self-supportive energy communities might be possible in rural areas, where typically are wider mix of DER available and production conditions, for example for wind energy, are in many cases better compared to densely populated areas (Timmerman, 2017). Economic aspect and opportunity to gain monetary benefits was mentioned in all stakeholder interviews as the most important factor to get end-users' involvement in local energy projects.

End-users appreciate user-friendly applications, thus smart applications and demand response services should not be decreasing the comfort level of their daily lives. In general, end-users are quite unaware of the electricity markets operations, thus they do not know the limitations of the existing market model, which is based on centralized energy generation. End-users want to use their energy assets at any given time and to be able to trade energy with any market participant in the system. To achieve this, changes are needed in the energy markets, thus new roles and responsibilities have to be defined. Changes should improve conditions for new business models, and facilitate service providers to develop new innovative services. (USEF, 2015)

Network operators are willing to utilize household level end-users' flexible capacity to the network balancing. Households' energy management applications will become a part of the network and enable customers to optimize their energy usage and participate in demand response services. Customers need to be encouraged to take part of these services by convincing them about the achievable benefits, which will result as savings in customers' electric bills. End-users want to know the reasons for why they should change their energy consumption behaviours and they want to be informed how that would be benefit for them and for the whole energy system (Timmerman, 2017).

Annala (2015) investigated household's willingness to engage in demand response in the Finnish retail electricity markets. Results of a web-based survey showed that 74 % of respondents would allow remote control of their electric appliances if that can bring savings in their electric bill. However, the required savings were relatively high, since 66 % of respondents whose consumption is 2000–4999 kWh per year would require savings being higher than 50 €, and 65 % of respondents whose consumption is between 15 000–25 000 kWh require savings of over 100 € per year. The survey also showed that possible emission reductions would motivate less than third of the respondents, and end-users are concerned about the reliability of the control system functions.

4.3 Suppliers and balance responsibility parties

The suppliers' main task have been, and will remain, to provide electricity to customers. The suppliers procure electricity from generators and traders, and establish a contract for electricity supply with their customers. Basically, the suppliers' profits are determined by the difference between the costs incurred for procuring the electricity from the markets and the price that they are able to sell electricity to their customers. Every supplier needs to have a BRP. The supplier itself could be a BRP or it can establish a contract with a separate BRP. (Sweco, 2015)

Most of the local energy markets are connected to the distribution grid and end-users will receive electricity also from the grid, addition to their self-generation. Consequently, end-users will have contracts with suppliers, similarly as in current market model. Consumers' transformation to prosumers lead to changes in the relationship between suppliers and end-users. End-users' self-generation will most likely not be constantly in balance with their consumption. They need to compensate their electricity surplus or deficit, and that is the area where suppliers could develop and offer new services. (USEF, 2015)

The local market concept might be able to provide these new market opportunities for suppliers, for instance one opportunity is to expand its business and start operating as an aggregator. Also, in energy communities might be cases where the whole community would establish a contract with one supplier. In those cases the community would be treated as one big customer and there would be only one imbalance settlement and invoice, since community would be responsible for the electricity distribution and metering inside the area of the community. Because energy communities have own electricity production in addition to consumption, it would be possible for suppliers to purchase electricity from the communities, in the situations when communities have surplus electricity. If the availability of the surplus electricity from the communities would be reliable enough, suppliers would be able to reduce their electricity purchase from the other markets. Suppliers could deliver electricity purchased from the communities to its other customers. (Kilkki et al., 2018)

If suppliers want to utilize prosumers' generation effectively in their portfolio, they should try to develop accurate prediction models for prosumers' electricity generation. With accurate forecasts and prediction algorithms suppliers are able to efficiently manage their portfolios and gain competitive position on the market. In addition, accurate prediction models provide opportunity for suppliers to use effectively the available flexible resources in their portfolios. Suppliers can offer services related to demand response, which can bring benefits for both sides, customers and suppliers. Demand response services provide a way to manage energy flows of intermittent renewable energy sources. These services help suppliers to optimize customers' flexibility and adapt customers' consumption profiles to the availability of the renewable energy sources. (USEF, 2015)

The BRPs are responsible for the imbalance settlement of its customers. They actively balance supply and demand of their portfolios' producers, prosumers and aggregators. All the parties connected to the grid are responsible for their individual balance positions, and due to that market parties have established contracts with the BRPs. In the future, the BRPs' might have more complex role on the electricity markets. Reason for that is the integration of DER and end-users' self-generation will increase the need for balancing and information exchange between market players. End-users' electricity generation might increase the BRPs' imbalance risks if they do not have accurate information of their prosumers' generation profiles. The prosumers have contracts with the suppliers, which are a BRPs themselves or have established a contract with the BRPs, and thereby the BRPs hold the imbalance risk on prosumers of their portfolio. (Sweco, 2015)

In Swecos' report (Sweco, 2015) it is pointed out the impact that DER integration has to the role and operations of the BRPs. Previously, the BRPs have tried to make accurate generation plans to avoid imbalances in their portfolios. They resolved for possible imbalances by using the generation side of their portfolios, while the consumption side have been almost constant. In the future, services related to demand side management enable the BRPs to use also the consumption side for imbalance management. Also, end-users' self-generation affect to the BRPs' portfolios, thus they need to take that account as well. Increase of DER will have a significant impact on electricity markets, thus the BRPs' balances will be dynamic from both sides, the generation and consumption sides.

The roles of the suppliers and the BRPs are dependent on the structure and market model of the local marketplace. It has to be ensured that for instance, aggregating services and peer-to-peer trading do not cause imbalance to the BRPs' positions or it has to be defined how imbalances will be compensated. In energy communities it could be possible for community members to establish shared supplier contract. In that case, community members could trade electricity with each other without causing imbalance to the BRP's position, since the trades would be executed within a single BRP's portfolio. The market settlement can be established at community grid connection point, where also supplier contract, grid service fees and balance services can be managed. In the DOMINOES local market concept these services are operated by Energy Community Service Provider (ECSP). Many different stakeholders could take a role of the ECSP, thus also suppliers may act as ECSPs. ECSP manages the local market processes inside the community and take care of the information exchange between the community and other market actors. The community services can include sharing of grid costs according to matching principles, enabling local trading, supplying electricity, invoicing, and also management and settlement of community's energy balance. The responsibilities of the ECSP are depended on the architecture of the local marketplace, thus the operations of the ECSP varies in different cases. (Kilkki et al., 2018)

4.4 Aggregators and energy service providers

Consumers' transformation to prosumers and increase of DER capacity provide new business opportunities, thus new market actors, such as aggregators, will enter into the markets. Aggregators are market players who accumulate flexible resources from prosumers and offer that flexibility to the markets. Aggregating services enable prosumers to maximize the value of their flexible resources when aggregators purchase the surplus electricity and flexibility of prosumers. Aggregating facilitates prosumers to participate into the electricity markets and prevents prosumers from exposing themselves to the risks that are involved in electricity market operations. The aggregators and prosumers establish an agreement where the commercial terms and conditions for the procurement of electricity and control of flexible resources are defined. Since the flexibility is collected from multiple resources, aggregation provide more reliable flexibility to the markets compared to the situation where flexibility is procured only from a single source. (USEF, 2015)

Local energy markets and increase of end-users' self-generation will increase customers' need for energy-related services. These services include, for instance, remote operation and maintenance of end-users' smart applications, and energy management services that are aiming to improve end-users' energy efficiency. Services related to demand response are welcome, since more flexibility is needed in power systems and some customers are interested to take part in demand response services and gain financial benefits from those. These services cover very broad range and new market actors are able to provide many of these services. There is need to define and standardize the market access conditions, thus it can be ensured that new actors can participate into the markets without unnecessary barriers. New actors can combine many services, since they can take a role of an aggregator and simultaneously provide many other energy-related services. (USEF, 2015)

Aggregator who comes outside of the conventional supply chain is called a third-party aggregator. This type of aggregators' services have impact on the BRPs' imbalance positions, thus it has to be defined how these imbalances are compensated to the BRPs. Aggregation requires sufficient information exchange between different market actors. In the Nordic TSOs' discussion paper "Unlocking the flexibility" (Nordic TSOs, 2017) it is presented different business models for aggregating services and what kind of interaction those models require between market actors. For example, reimbursement model with third-party aggregation and multi-BRP aggregation guarantees fair conditions to all market actors. Reimbursement model enables aggregators to participate in balancing power markets (mFRR) and that is piloted in Fingrid pilot project which started in the late 2017. The Fingrid pilot and aggregators' interaction with other market participants are discussed more deeply in Chapter 2.4.

Aggregators are important link between local energy markets and conventional electricity marketplaces, such as day-ahead, intraday and balancing markets. One scenario is that for example in local energy community, community's operator would act as an aggregator. Like mentioned earlier in this chapter, various market actors are able to take a role of a local energy community operator and aggregator is one opportunity. When community's operator is doing aggregating it would be easy to offer the community as one entity to the balancing markets. By aggregating whole community's flexible capacity and if the community has enough own generation capacity, it may be possible to be disconnected from the distribution grid for short periods, for instance in situations when there is need for up-regulation in the balancing markets.

Aggregating services may affect also to the DSOs' operations, when end-users' flexibility aggregating is getting more common and aggregated loads increase. In that case, the aggregators should inform the DSOs, in addition to the suppliers and the BRPs, about the customers whose flexible resources they have access to control. The aggregators' services could possibly be utilized in network congestion management. One opportunity would be that the DSOs could operate customers' loads through aggregators. It has to be evaluated how independent third-party aggregators' actions are affecting to the customers, suppliers, BRPs and DSOs, and find a solution that serves the best the electricity markets as a whole, and the customers get the best total benefit.

5 BENEFITS AND BARRIERS OF LOCAL ENERGY MARKETS

This chapter discusses about the benefits and barriers that are related to the local energy markets. The local energy markets are providing benefits in various levels, but also many barriers hindering the market development have been identified.

5.1 Opportunities and benefits

The local energy markets can open up many opportunities and benefits for all the market stakeholders. In this master's thesis, these benefits have been identified and further organized into four categories, which are 1) "Customer level", 2) "Network operator level", 3) "Service, technology and energy provider level", and 4) "Society level". On the customer level, the most important benefits are the reduced energy costs, increased security of supply and optimal usage of end-users' flexible resources. The benefits can be achieved due to customers' active participation in the electricity markets and the opportunity to trade self-generated electricity with other members of the marketplace. For network operators, local markets facilitate balance management of electric supply and demand due to services related to demand side management (DSM). Those services can also defer the need to make reinforcements in the distribution grid. The local market concept brings innovation in both the technology and service domains. The current market stakeholders' roles may change, which may result in the need for re-organization of their strategies and in the development of new services for customers. The local markets lead to optimized use of local energy resources, thus generating local economic growth. From a societal perspective, local energy markets lead to cleaner energy generation since they facilitate the implementation of DERs, which are consisting of a great extent in renewable resources. Local markets strengthen customers' role and improve transparency of the energy markets. The benefits that local markets may bring for different stakeholders are summarized in Table 3.

Table 3. Benefits of local energy markets.

Customer level	Network operator level	Service, technology and energy provider level	Society level
Strengthened and more active role of customers in the energy market	Deferment of new investments in distribution networks	Growth and diversification of energy market	Lower regional/global pollution as a result of cleaner and more efficient energy generation and use
Financial opportunities brought in by DER operations and by customer-driven DSM services	Lower loads in distribution networks due to customer-owned DER capacity	New business opportunities driven by technology innovation and market restructuring	Progress to fair, more transparent and customer-centric energy systems.
Increased local reliability and resilience, including avoidance of outage costs	Lower network losses	Room for new types of market actors	Help to reach the EU and other climate goals
More energy independence and greater sense of transparency and trust in the energy market	Better balance between electric supply and demand enhanced by customer-based DER generation and DSM services	Development of local/regional industry and businesses	
Lower local pollution as a result of optimized exploitation of local energy resources	Improved power quality and reliability in the distribution and transmission networks		
Community development and growth based on technology and services innovation	New opportunities driven by innovative business models		
More customer choice as a result of increased competition by local players			
Greater pressure on traditional power industry actors to better respond to customer needs			

5.1.1 Customer level

Local energy markets will strengthen customers’ role in the electricity markets. End-users’ will change from passive consumers to active prosumers who are able to consume their self-generated electricity while sharing/trading their surplus within the local market (peer-to-peer). Customers will participate into innovative DSM and other type of customer-driven services which aim to provide economic benefits to customers. These services may reduce customers' energy costs, because those help customers, for example, to shift electricity demand from an expensive hours to a cheaper hours. Customers are more aware that energy efficient solutions and optimized use of local energy resources can bring financial savings. Energy management systems are example of customer-driven services that improve customers' energy efficiency and optimize the households' energy use resulting in cheaper electric bill. (Koirala et al., 2016)

As mentioned above, possibility of energy trading among other customers is significant advantage of the local energy markets. In the literature, different trading system structures have been investigated for example in Ampatzis et al. (2014) and Ilic et al. (2012). The goal for all of the trading models are to maximize the efficiency of the marketplace, find the right price for electricity at every trading period and bring benefits for the market participants. Local markets generate local economic growth since prosumers can trade self-produced electricity and use full potential of DER. Prosumers gain more advantage when local marketplace is connected to the wholesale market, since that would be enabling them to sell their surplus electricity in there if they cannot find a buyer from their own community (Koirala et al., 2016).

End-users can provide their flexibility to the network operators through third party intermediaries called aggregators who combine various end-users' available capacity, forming a virtual power plants (Koirala et al., 2016). Aggregating the loads enable end-users to participate in different marketplaces like balancing and ancillary service markets because aggregator can offer higher capacity to the market compared to an individual prosumers. Individual household's balancing capacity does not meet the minimum requirements of the balancing markets without aggregation. For example, in Finland balancing energy bid has to be at least 5 MW if electronic activation is used and at least 10 MW with manual activation (Fingrid, 2018a). Finnish transmission operator Fingrid has started one year aggregation pilot project in early 2018. The goal of the project is to look into enabling aggregation from multiple balances and independent aggregator participation in the regulating power market (Fingrid, 2018b).

According to Koirala et al. (2016), the local energy markets are needed to optimize end-users usage of local DER. End-users ability to utilize distributed generation and storage systems in their homes is enabling them to take more control of their own energy usage. For some customers, having more control over their energy matters and be more independent is very important incentive to participate in the local energy market development (Timmerman, 2017; Ofgem, 2017). The local markets are connecting people of the community to achieve common goals like reduced cost of energy, have lower greenhouse gas emissions and be more energy self-sufficient (Koirala et al., 2016). These common goals build trust and improve customers' commitment to participate in the local market projects. Customer co-operation can make a wider scale of energy options economically and technically viable and facilitate local network balancing. Local energy markets improve transparency of the energy system, since customers have more control to choose how their electricity is produced, they are more independent and local resources are utilized effectively in energy generation (Mengelkamp et al., 2017a).

Microgrids can increase security of supply since those are not completely dependent on the distribution network and can be operated in islanded mode (Soshinskaya et al., 2014; Mengelkamp et al., 2017a). To be able to operate efficiently and to guarantee the supply of electricity during power outages in the main distribution grid, microgrids need to have enough of its own generation capacity and/or energy storage. The expenses or lost incomes incurred by power outages can be significant. Due to that, microgrids' reliable electricity supply, especially in rural areas where electricity distribution service is usually more unreliable, bring additional benefits for customers in the form of avoided outage costs.

Changes in energy markets' structures create a demand for new innovations for example in the fields of technology and service providers. That creates opportunities for a local businesses to develop their services and offer those to a local customers. Technology and service innovations at the local level promote local development and growth. Competition forces companies to develop their services, thus customers get more choices of products and services that they are interested. Traditional power industry parties will change their operations and strategies towards more customer-centric approach due to pressure caused by the market development.

5.1.2 Network operator level

Customer-owned DER generation impacts to the distribution and transmission networks' operations in many ways. For instance, increased flexibility, new DER capacity and more effective overall network operation may reduce the network operators' need to make new investments and reinforcements in the distribution grid (Ofgem, 2017; Koirala et al., 2016; Hall & Roelich, 2015). Also, the local energy markets can lower the network losses since there is less load in the transmission and distribution lines because customers' will have more their own generation capacity and/or storage systems.

The aggregation of the available capacity from multiple local customers can help network operators to balance the grid's supply and demand more efficiently (Koirala et al., 2016). Services related to DSM are aiming to help network operators to achieve network's balance efficiently and to increase flexibility of the grid. Demand side response facilitate congestion management at both TSO and DSO level (Nordic TSOs, 2017). To the TSO, it can increase elasticity in a day-ahead markets and it can be used for voltage regulation and balancing. Several reasons can cause a risk that the TSO cannot activate the flexibility that it intends to use because that flexibility will be locked by the network structure. Due to that and increasing complexity of electrical network operation, co-operation of the TSOs and the DSOs is essential to ensure that flexibility can be used where it is needed the most and has a greatest benefit to the society (Stakeholder interviews, 2018). DER at the grid edge opens up possibilities for provision of balancing market services. For instance, ancillary services, such as frequency response or voltage regulation are helping network operators in network management.

The operations of DER-based microgrids can improve network reliability by ensuring power supply and thus supporting the distribution grid in case of power outages. At the same time, microgrids can be operated in islanded mode if technical, economic or other reasons force decoupling from the main grid (Mengelkamp et al., 2017a; Wouters, 2015). When microgrids have internal power coordination and control system, microgrids do not threat safety of the distribution network when connecting and disconnecting from the superordinate grid. Microgrids, in which production capacity consists of various and flexible DER can increase power quality at the distribution level (Soshinskaya et al., 2014). Multiple interconnected microgrids can increase the reliability of the overall energy system and allow

DER utilization at larger scales, generating economic benefits in many levels. Overall, the flexibility and responsiveness of the distribution network enhances significantly due to optimized operation of interconnected DER in microgrids and customer load management (Koirala et al., 2016). Thus, microgrids can be a great asset to grid operators since those can facilitate the grid management.

New valuable market opportunities for network operators will arise from the local energy market development. These opportunities are driven by new business models and various forms of value-added and real time services which can be provided by the network operators. These can be, for example, real-time energy monitoring, real-time billing, DER asset management, customer generation/demand load aggregation, local balancing of supply and demand, distribution network lease for customer-owned DER by the DSOs, microgrid real-time management, etc. (Timmerman, 2017).

5.1.3 Service, technology and energy provider level

Local energy markets will rely heavily on modern technologies and on continual technology innovation. Because of new innovations and market changes, opportunities will emerge for current market stakeholders to reorganize their strategies, and to develop new products and/or services.

Active information exchange between stakeholders is the foundation of the local markets. Information and communication technologies are enabling the efficient operation of the network and flexibility management. Since most of the distributed generation is intermittent, it is important to have demand side flexibility. There are a significant business opportunities to develop and provide these flexibility and energy management services for customers. These services should be user-friendly and as unobtrusive as possible in customers' daily life. (Koirala et al., 2016)

Smart grid development creates demand for new technology and that is driving technology providers to develop their products' quality and affordability. For instance PV-systems, storage batteries, heat pumps and electric vehicles are going to be a major part of local energy systems at household level. Sales of those technologies will increase in the future because those provide options for flexibility management and increase households' overall energy efficiency. (Koirala et al., 2016)

Changes in the market structure will create an opportunity to new market actors to enter into the markets. Especially between customers and network and market operators will emerge possibilities to operate as third-party intermediaries. Good example of new market actor is aggregators. Aggregators are bringing advantage for both sides (customer and operator) and can simultaneously generate profit by providing these services. Aggregators do not have to be completely new companies on the energy markets, since old players could start offering aggregating services, creating new income. Microgrid/energy community operators are also new actors on the market, and there are different options who is operating the local marketplace. It can be operated by the DSO or there can be individual local market operator who is responsible of the operation and information exchange between the DSO and the local marketplace (Soshinskaya et al., 2014).

Local consumer targeted services are a significant business opportunity in developing markets. These services include energy awareness and advice schemes, energy efficiency schemes, collective switching and purchasing schemes, fuel poverty schemes and energy service companies (ESCOs). They promote customer empowerment and engagement, respond the customer needs and support emission reduction goals. For instance, ESCOs can achieve significant reductions in customer energy demand (Hall & Roelich, 2015). ESCOs offer various types and grades of innovative services that aim to increase customers' energy savings and to lower customers' electric bill. ESCOs are focusing on services that can be produced with energy (e.g. house heating, hot water, lighting…) and for customers buying those services can be more affordable than buying energy by a unit (Hall & Roelich, 2015). ESCOs' revenues are directly linked to the energy savings achieved. ESCOs are growing business in European market and the local energy markets are improving their business opportunities. The development of the local markets create an energy projects that generate local jobs thus strengthening local economic growth (Koirala et al., 2016).

5.1.4 Society level

Local energy market development is leading to a decentralized energy system which is more transparent and customer-centred compared to the traditional centralized system. Like it was already mentioned in the customer level benefits, customers have more control of their own energy management and local markets facilitate optimizing the use local energy resources. Customers are playing significant role in the future energy markets and that is increasing their trust to the system.

The local energy markets are driven by interconnected DER which facilitate the growth of renewable generation. That leads to cleaner energy generation lowering local emission levels. In the global scale local market concept reduce global pollution and helps to reach EU's climate objectives. (Koirala et al., 2016)

5.2 Challenges and barriers

Beside many benefits of the local markets, there are also barriers and obstacles which are hindering the local market development and implementation. In this master's thesis the main barriers have been identified and divided into four categories: 1) "Technical", 2) "Policy & legislation", 3) "Economic & market" and 4) "Societal barriers". The summary of these barriers is presented in Table 4. Technical barriers include, for instance, technical maturity of some DER, establishment of suitable market trading platforms and ensuring secure data handling. Policy and legislation barriers are heavily related to absent or unclear regulation. For example, there is need to clarify the regulation of DER ownership, interconnection rules and bi-directional power flows. Economic barriers include the high upfront costs of some technologies, split-incentives problem and the DSOs' ability to make investments in grid development if customers rely more on own generation. Present market actors can see local markets as a threat to their business. Due to that they might resist the local market development and that can be identified as one of the main market barrier. Resistance from non-willing customers is one of the main societal barrier. Customers' participation and involvement is extremely important when developing local markets.

Table 4. Barriers of local energy markets.

Technical	Policy & legislation	Economic & market	Societal
Technical maturity of some DER	Absent or inadequate regulation/legislation on the use of flexible resources by the DSO	Market maturity of some DER	Resistance to change from non-willing customers
Real-time management of local energy flows	Absence or inadequate regulation/legislation on several aspects of local ownership and production from DER	High upfront costs	Need for community-wide engagement and involvement of customers in decision-making
Smart meter roll-out is uncompleted in some countries	Interconnection issues of certain DER	Split-incentives problem	Meeting and aligning interest of different participating customers and/or stakeholders
Maintenance of local power quality and reliability	Non allowed islanding operation in some microgrid cases	Lack of clarification on value streams	
DER synchronization, fault detection, islanding if necessary	Non-allowance of grid bi-directionality prevents trading operations	DSOs' ability to invest in grid development if customers rely more on own generation	
Maintenance of active information exchange between stakeholders	Conflict between DSO-exclusive franchises/ crossing of distribution rights-of-way	Loss of revenue and/or need for reinvention of business practices by some of the traditional market participants	
Establishment of secure and transparent market trading platforms	Absent regulation on suitable entities that would operate and manage local energy systems	Inexistent business models capable of aligning the incentives of stakeholders and distribute value fairly	
Cyber-security challenges	Taxation issues concerning self-generated electricity fed into the grid		
Data privacy challenges	Absence of a clear definition of rights and requirements of BRPs in local energy markets		
	Ownership of local distribution infrastructure		
	Regulation of secure and transparent market trading platforms		
	Regulation of cyber-security and data privacy aspects		
	Lack of clarity as to the policy-making and regulation entities for local energy markets		

5.2.1 Technical barriers

Some DER technologies are not yet fully technically mature. One good example is energy storage system technologies, since many of those need more development to be adopted into a wider scale. Many reviews (e.g. Tan et al., 2013; Zhao et al., 2015; Yao et al., 2016) about energy storage technologies exist in the literature. Zhao et al. (2015), for instance, show that technologies of fuel cell, metal-air battery, solar fuel cryogenic energy storage, synthetic natural gas and thermal energy storage are still under development and not widely used at the moment.

Various technical challenges are associated to the operation of microgrids. For example switching from grid-connected to island mode and reconnecting to the distribution grid. After decoupling, synchronizing islanded microgrid with the main grid may require more voltage and frequency controls than usually, because dual-mode operation is probably causing imbalance between generation and loads (Soshinskaya et al., 2014). Managing instantaneous active and reactive power balances between two grids can be difficult under network voltage profiles (Agrawal & Mittal, 2011). The DSOs need to maintain admitted frequency and voltage quality in the network. Thus, there are specific power and frequency control requirements to grid-connected microgrids and those requirements might be difficult to achieve, since a significant extent of the generation in microgrids comes from intermittent sources (Soshinskaya et al., 2014).

Smart metering is crucial for local energy market operations and flexibility management (Wouters, 2015). Smart meter roll-out is at different stages in EU-countries. Thus, there is need for development and standardization in metering schemes. For example, in Finland, smart meter implementation is already done but, for example, in Czech Republic implementation is still at an early stage (The USmartConsumer Project, 2017).

The distribution network “perceives” the microgrid as an individual electrical entity rather than as many DER loads. There are some challenges in the point of common coupling to control bi-directional power flows. Exporting power to the distribution grid can require changes on the medium voltage network protection settings, and that is not desirable from the networks operators’ point of view. (Soshinskaya et al., 2014)

Some problems are related to communication and control aspect. There are large variety of communication and control software options and that can sometimes cause challenges since each software have different solving algorithms and different functionalities (Soshinskaya et al., 2014). Control systems should be compatible with other components of the microgrid, enabling sufficient operation and therefore standardization would facilitate microgrid implementation.

Because the concept of local energy markets is new and still undergoing development, there are issues and unsolved questions as to how to establish secure and transparent local market trading platforms. For instance, Mengelkamp et al. (2017a) has reviewed how blockchain technology can be used in the local energy markets. It is mentioned that one of the greatest advantages of blockchain is the transparent, distributed and secure transaction log that allows for a complete and continuous tracing of even the smallest energy transactions. Despite many benefits of blockchain there are also some problems, such as scalability issues, complexity of technical protocol and implementation with current components.

Significant amounts of data is collected and exchanged in the local energy markets. Thus, secure data handling is essential to be guaranteed in every situation and that can cause some challenges. Energy systems have to be protected from cyber security threats which have different types and are developing constantly. Mustafa et al. (2016) have analysed security problems and users' potential privacy threats. Based on that study, basic security and privacy requirements have been identified and those should be considered when designing local energy markets. It is important to use secure user authentication mechanism to verify that the data is from the right source and by that way prevent the possibility that someone tries to manipulate the data. Data includes sensitive information like user identify, contracted suppliers and meter readings thus it has to be well-defined who has access to this data. Information exchange between stakeholders is crucial, hence the clear definition of responsibility over the maintenance of the information exchange system is needed.

5.2.2 Policy & legislation barriers

Legislation and regulatory framework in some countries are hindering the development of local energy markets and the full-blown utilization of renewable sources. Fernández et al. (2010) gathered some problems of microgrids in Spain, where, for example, it is not allowed the combination of PV-systems in low voltage networks with other generation technologies, storage systems or electric loads connected between the solar panels and the metering system. Electric loads and PV-panels have to be in independent circuits, combination of wind and PV-generation is prohibited and customers are not allowed to sell energy from the storage. Legal frameworks on these aspects vary significantly globally and across the EU, hence any implementation should be addressed at a case-by-case basis.

Winkler & Ragawitz (2016) have investigated solar energy policy in EU. In different countries regulations varies for the remuneration procedures that are defining how prosumers are compensated for the electricity that they feed into the grid. One option is to use net-metering schemes, where prosumers get a retail price for self-generated electricity. Exported electricity is measured and that amount is reduced from the prosumer’s electric bill. In the worst cases, prosumers are not remunerated for their surplus electricity at all. This restrains the households’ micro-generation investments size, because they cannot get revenues for the electricity that they are not able to consume themselves. One of the most important feature of the local energy markets is prosumers ability to sell surplus electricity and receive revenues from that. Due to these problems, it is important to develop appropriate regulation geared towards having prosumers selling their surplus electricity to the grid or trade it with other end-users.

There are some taxation issues, which are hindering the local market development. For example in Finland, owners of the electric storages have to pay taxes for electricity charged to the storage. That leads to double taxation because taxes are payed again when electricity is delivered for consumption from the storage. According to Finnish Ministry of Employment and Economy’s smart grid workgroup, one possible taxation model could be price dependent model. Electricity price-dependent taxation would improve markets’ flexibility and would send better market signals for customers. (TEM, 2017)

Some projects may have to go through long administrative procedures, and it may take a long time to get approvals and permissions. Sudden changes and policy instability is an additional risk for investors, who want to be sure their investments are profitable. Clear regulations are missing in many countries for rural areas’ small-scale renewable generation units’ grid connection. Also, it is unclear who pays the costs of connecting DER to the distribution grid and possible expansions of the network. (Ali et al., 2017)

The traditional transmission and distribution networks were designed to be passive and for unidirectional power flow. Policies and regulations have to be changed to be more supportive for integrating distributed generation to the grid (Ali et al., 2017). Regulators have to consider how new regulations or adjustments in the old ones facilitate and serve best for grid’s bi-directionality. In the microgrid cases, the problem of controlling bi-directional power flows at the point of common coupling hinders the local market development and the prosumers’ ability to sell electricity via distribution grid (Soshinskaya et al., 2014). Current regulatory environment in some countries does not allow microgrids to export electricity to the distribution grid, thus preventing prosumers’ ability to sell electricity to the wholesale market. Also, islanding is often prohibited, due to the voltage stability problems, and because the small size of the networks and the bi-directional power flow set challenges for microgrids’ safe operation (Wouters, 2015). Furthermore, although utilizing demand response would facilitate more efficient use of the distribution networks, economic regulation of the DSOs often incentivizes infrastructure investments over the use of demand response (Vallés et al., 2016).

The ownership of the distributed generation capacity is in some cases difficult to define and there is a need to clarify the regulation. One problem standing out is the regulation of who owns and is responsible of the maintenance of the generation units that serve a whole community but are not installed in every household (Wouters, 2015). Energy co-operatives is one example of the ownership structure where members share the revenues and benefits of microgrids or other local energy systems (Koirala et al., 2016). In the microgrid case, a central utility-owned microgrid might facilitate the regulatory process and standardization (Wouters, 2015). Additional infrastructure is often needed to integrate residential buildings with microgrid configuration. That new infrastructure might cross privately or publicly owned land, hence it is important to have clear regulation for electrical supply installations (Wouters, 2015).

The absence of clear regulation of various aspects of local energy markets remains as one main barrier. For instance, there is a lack of regulation that would define suitable entities to operate and manage local energy systems. There can be conflicts who owns and manages the distribution infrastructure in microgrid networks. Especially, when part of microgrid network intersects with local distribution network, clear rules for network operations are essential. (Mendes et al., 2018)

The control of customers' loads is another issue which might cause conflict of interest. Customers' flexibility could be utilized for several purposes, for example traded in the balancing power markets or ancillary services markets or used to maximize utilization of local generation capacity. Due to that it is important to have clearly defined responsibilities and rights of the balance responsibility parties. Also, the clear rules and courses of actions of the BRPs need to be defined if some third-party intermediary outside of the conventional supply chain is controlling customers' load. (Mendes et al., 2018)

5.2.3 Economic barriers

Renewable energy projects have high upfront costs and that is affecting these projects' payback time and investors' decisions (Ali et al., 2017; Koirala et al., 2016). Expensive technology hinders the commercialization of microgrids and consequently its wider scale deployment and local energy market development. In recent years, PV technology and storage systems have become more affordable and that has brought consumers closer to be able to invest in their own generation units. End-users' small-scale energy production is increasing constantly, hence promoting local market development. Nevertheless some technologies are still too expensive for commercial viability. For example, large scale storage systems and EVs are important for local energy management, but the prices at the moment are too high for commercial utilization.

Split-incentive problems can emerge in energy communities and energy efficiency projects because the benefits of the investments are distributed but expenses are directed only for investors (Koirala et al., 2016). This problem is related to the definition of DER ownership. Correspondingly, the benefits and costs of each project should be fairly distributed amongst its stakeholders, to reach the full potential of local markets. These split-incentive problems might affect to customers willingness to participate in the local markets and invest in new technologies.

As prosumers increase their share of self-generation, they start paying less for grid fees, taxes and other distribution network use-related fees to the DSOs. That can lead to increasing electricity prices and grid fees for other customers who do not have their own electricity generation (Winkler & Ragawitz, 2016). Increasing self-consumption could also affect the DSOs ability to invest in grid development and maintenance if their revenues from grid fees decrease.

It is possible that present energy market actors show resistance to the local market development, because they might be afraid of losing their market share and positioning. For example, the DSOs might fear decreased revenues from network services if end-users' self-production increases significantly. On the other hand, new opportunities would emerge for the DSOs to provide new services to customers, as the distribution network will remain a necessary asset within the local markets. Local markets may use part of the distribution network for energy trading among customers and for connecting local markets to the transmission network and to the wholesale market. Innovative DER-based business schemes like local energy markets and aggregating services will continue putting pressure over traditional market players such as centralized generation and operator companies. The pressure forces market actors to do changes on their operations and business strategies, until a new market balance will be reached.

5.2.4 Societal barriers

According to Soshinskaya et al. (2014), customers' engagement and involvement is crucial when developing well-functioning local energy marketplaces. Local market and microgrid developers can face resistance from customers because customers may not have enough information or understanding of highly innovative and technically-complex concepts such as DER technologies and microgrids. This type of resistance to change may vary in different locations and be more critical and sensitive to handle in the projects which take place in socially-fragile areas. Developers should respect customers' opinions because overlooking the preferences of local residents will likely increase the resistance of the project. Actions that will facilitate customers' position and involvement in the decision-making processes should be done. Local market concept is customer-centric system, thus it is important to involve customers in the designing process.

Another challenge is that some of the benefits, such as lower emissions and sustainable electricity supply are more or less intangible and not just direct benefits for individual customers (Timmerman, 2017). More substantial and direct benefits, like ability to trade electricity with neighbours, seems to be more attractive for most of the customers.

To gain customers' acceptance and trust in a project, they have to be convinced of benefits that local markets can bring to individual customer and also for the whole community. The concept of local energy markets should be clarified and information channels between developers and customers have to be active during the whole project. Overall, customers need to be provided with clear and up to date information and pursue towards greater awareness as to the local market concept.

6 CONCLUSIONS

Consumers' transformation into active prosumers and integration of DER are the main drivers of local energy market concept. End-users are seeking opportunities to utilize full potential of their generation units and flexible resources, providing business opportunities to service providers and other market actors to develop services and market models which facilitate customer empowerment. Increased competition provides more choices to customers and put pressure on conventional power industry players to better respond to customer needs. End-users want to be more energy independent and support renewable energy by utilizing local DER. Local energy markets can give customers greater sense of markets' transparency and improve trust in the energy markets. Another important aspect for customers is supporting and improving local economy, since most of the energy consumption can be covered with local marketplace's own generation resources. Local energy markets promote increase of renewable energy, thus cleaner energy generation help at global level to reach climate goals of EU and other organisations.

For network operators' viewpoint, local energy markets may offer flexible capacity which can be used in network balancing. Customer-owned DER capacity can lower loads in distribution networks and services related to DSM can cut networks' high consumption peaks. In some situations effective DER integration and local energy market operations may postpone or defer the expensive network reinforcements and expansions. That is not always the case, and Jouni Lehtinen from Helen Electricity Network Ltd stated in his interview that customers' self-generation does not have much impact on network investments, since designing standards are based on other, more determinative factors. For instance in Finland, cold winter conditions are one determinative factor which are taken into account in network designing. In the wintertime customers' self-generation is at its lowest, thus energy communities and other local market models probably need distribution networks for ensuring the security of supply, since there may not be enough self-generation. Stakeholder interviews also pointed out that local energy markets' connection to the distribution network provide wider opportunities for local markets to gain monetary benefits, because then flexible resources can be offered to the reserve and balancing markets. Nevertheless, local markets' possibility to operate in island mode is great asset, since it improve the power quality and security of supply within a local marketplace. Power cuts in the distribution networks can cause significant financial losses, thus island mode operation enables local marketplaces to avoid these expensive outage costs.

Beside various benefits of local energy markets, many barriers were identified during the research process. These barriers were categorized into 1) “Technical”, 2) “Policy & legislation”, 3) “Economic & market” and 4) “Societal barriers”. Both, the literature review and stakeholder interviews pointed that technical and economic maturity of DER technologies are not yet at a sufficient level that the local energy markets could reach all the potential benefits. For instance, energy storage technology is still too expensive for average end-users and that hinders local marketplaces’ capability to achieve complete energy independence. Nevertheless, technology is constantly developing and the prices of technologies are decreasing, thus these barriers will inherently be resolved in the future.

Information technology and metering solutions have essential roles in the local energy markets in which end-users trade energy with each other. The stage of smart meter roll-out varies in different countries, thus the implementation of local marketplaces can be easier in those places where smart meters are already installed. Optimized use of local flexible resources may require real-time or almost real-time energy management. Real-time measurement and control can set challenges and be expensive, thus it has to be considered when and where it is needed. According to stakeholder interviews the upcoming Fingrid datahub project may facilitate also local market development even though the datahub is not designed because of local markets. In the future, some of the calculations and net-metering services can be executed in the datahub, and it provides opportunities for market actors to develop new customer-friendly services. Fingrid’s specialists stated in their interview that first version of the datahub is not designed from local markets’ point of view, but when local energy communities and other market models are legally defined, datahub can be developed in a direction that it can offer services also to local marketplaces.

Secure and transparent market trading platforms need to be established when peer-to-peer trading is involved. It is unclear who will be the regulating entities and operators for such platforms and what minimum requirements those platforms should meet. Cyber security challenges are involved in complicated trading platforms and information exchange systems, thus the data privacy must be secured in all situations. Blockchain is suggested to be suitable technology for establishing transparent trading platforms, and it is already tested in the Brooklyn microgrid and new projects are coming. Despite promising results, also some challenges are identified. These challenges include scalability issues, complexity of technical protocol and implementation with current components, thus more research need to be done with blockchain.

Many identified barriers are related to regulatory and legal aspects. The regulating entities are unclear and local energy markets' policy-making needs to be clarified in general. There is a need to establish legal definition of local energy markets and determine what are the rights and responsibilities of such marketplaces and operating market actors. In some countries, end-users energy trading is impossible because of local legislation. Conflicts may occur especially if part of the distribution network is used in local marketplaces' energy trading. Customer remuneration schemes for surplus electricity fed into the grid varies significantly and in some cases are inexistent. Energy taxation issues related to end-users' self-generation and energy trading are hampering the local market development. Such legislative frameworks vary significantly across the EU and globally, and will affect local energy market development.

Split-incentive problems can emerge in local energy markets, in cases where benefits are split between various stakeholders but costs belong exclusively to the investors. Business models that are capable of aligning the incentives of the stakeholders and distribute local marketplace's value fairly need to be established. Resistance to change of non-willing customers can set challenges in some local energy market projects. Customers' resistance may appear especially when projects take place in impoverished communities and socially-fragile areas. Customers have an essential role the local energy markets, thus involvement of customers in decision-making can improve community-wide engagement and build trust between customers and other stakeholders.

It is likely that traditional energy market players show resistance to the development of local energy markets, since they may have fear of loss of market shares and positioning. On the other hand, new opportunities will emerge for these important and experienced players to provide new types of services to their customers. Conventional business models and roles of the market stakeholders will change, due to customer empowerment. Structure of the local marketplace affect to these possible roles, thus stakeholders' roles may vary between different cases. In addition, new market players, such as aggregators, will enter into the markets. Aggregators can be completely new market actors or traditional market players, such as suppliers, may start offering these aggregating services. Stakeholder interviews pointed that aggregating can bring benefits for all the levels of the energy markets. Fingrid specialists stated that aggregators provide more flexible capacity to the reserve and balancing markets, and by that way, aggregators help the TSOs in network balancing. Markus Logren from Helen Ltd, stated that aggregating brings opportunities for suppliers to develop new services which serve better customer needs, since it improves customers' possibilities to optimize the use of their flexible resources.

The balance responsibility is electricity markets' basic prerequisite, thus the BRP have to be clearly defined in local energy market operations. Interviewed stakeholders stated that there remains unsolved questions regarding to local markets' balance responsibility. For instance, a third-party aggregators are allowed to aggregate flexibility from several BRPs' portfolios, thus it has to be ensured that aggregating rules are transparent and load control do not have negative impact on the BRPs' imbalances. Structure of a local marketplace have an impact on complexity of the BRP arrangements. For example, a local energy community can have one mutual supplier, and therefore the whole community would be under one BRP's portfolio. If community members have different suppliers, there are many BRPs involved and, for instance, peer-to-peer trading of community members would have an impact on the BRPs' imbalances. Since many different entities may control customers' flexibility for different applications, balance responsibility comes more complex. Hence, clear rights and obligations applicable to the BRPs have to be ensured.

The objective of this master's thesis was to review the opportunities, benefits and barriers of local energy markets. The used research methods were literature review and stakeholder interviews. The objective of the study was achieved, since literature review provides comprehensive overview of the local energy markets and the results of the stakeholder interviews confirmed many of the identified benefits and barriers. In addition, the stakeholder interviews provided the latest information from the markets and offered another perspective to some issues compared to perspective of the literature review. It has to be mentioned that sample of interviewed stakeholders is quite narrow, thus interviewing more representatives from each stakeholder groups would have provided wider view of the stakeholders' standpoints.

The concept of local energy markets is still under development, thus many aspects require more research. There have been launched new pilot projects, which results will provide valuable information for local market developers. For instance, transparent peer-to-peer trading platforms and third-party aggregating provide lot of opportunities for further research. In addition, to overcome all the identified regulatory barriers, policy-makers and researchers have an important role. The development of local energy markets require clear regulatory framework that determines the rights and responsibilities of the market actors. Stakeholders' co-operation is necessary in order to develop novel market models and to achieve well-functioning local energy marketplaces.

REFERENCES

Agrawal, M., Mittal, A. 2011. Micro Grid Technological Activities Across the Globe: A Review. International Journal of Recent Research and Applied Studies, Vol. 11, No. 2, pp. 147-52

Ali, A., Li, W., Hussain. R., He, X., Williams, B.W., Memon, H.M. 2017. Overview of Current Microgrid Policies, Incentives and Barriers in the European Union, United States and China. Sustainability, Vol. 9, No. 7.

Ampatzis, M., Nguyen, P.H., Kling, W. 2014. Local Electricity Market Design for the Coordination of Distributed Energy Resources at District Level. 2014 5th IEEE PES Innovative Smart Grid Technologies Europe (ISGT Europe), October 12-15, Istanbul.

Annala, S. 2015. Household's willingness to engage in demand response in the Finnish retail electricity markets: An empirical study. Doctoral Dissertation. Lappeenranta University of Technology. Available at: http://www.doria.fi/bitstream/handle/10024/113819/Salla%20Annala%20A4.pdf?sequence=2&isAllowed=y

EDSO. 2017. EDSO position paper on local energy communities. [Online]. [Accessed 26 April 2017]. Available at: https://www.edsoforsmartgrids.eu/wp-content/uploads/170914-EDSO-position-paper-on-local-energy-communities_final.pdf

Eid, C., Bollinger, L.A., Koirala, B., Scholten, D., Facchinetti, E., Lilliestam, J., Hakvoort, R. 2016. Market integration of local energy systems: Is local energy management compatible with European regulation for retail competition?. Energy. Vol. 114. pp. 913-922.

Electricity Market Act 588/2013. [Online]. [Accessed 5 March 2017]. Available at: http://www.finlex.fi/fi/laki/alkup/2013/20130588

Energiateollisuus 2017. Finnish Energy's position on the features of next-generation electricity meters. [Online]. [Accessed 5 March 2017]. Available at:

https://energia.fi/files/1697/Finnish_Energy_position_paper_features_of_next_generation_electricity_meters_final_20170810.pdf

European Commission. 2016a. Proposal for a Directive of the European Parliament and of the Council on common rules for the internal market in electricity (recast). COM(2016) 864 final/2. [Online]. [Accessed 11 January 2018]. Available at: http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2016:0864:FIN

European Commission. 2016b. Commission regulation establishing a guideline on electricity balancing. [Online]. [Accessed 20 December 2017]. Available at: https://ec.europa.eu/energy/sites/ener/files/documents/informal_service_level_ebgl_10-10-2016nov.pdf

European Commission. 2016c. Horizon 2020 Work Programme 2016 – 2017, 10. 'Secure, Clean and Efficient Energy'. [Online]. [Accessed 3 January 2018]. Available at: http://ec.europa.eu/research/participants/data/ref/h2020/wp/2016_2017/main/h2020-wp1617-energy_en.pdf#page=66

European Commission 2017. 2030 Energy Strategy. [Online]. [Accessed 3 January 2018]. Available at: https://ec.europa.eu/energy/en/topics/energy-strategy-and-energy-union/2030-energy-strategy

Fernández, G., Trujillo, M., Sanz, J.F., Sallán, J. 2010. Spanish Microgrids: Current Problems and Future Solutions. International Conference on Renewable Energies and Power Quality. Las Palmas de Gran Canaria (Spain). 13th to 15th April, 2010, pp. 1-6.

Fingrid. 2018c. Datahub. [Online]. [Accessed 5 March 2018]. Available at: https://www.fingrid.fi/en/services/information-exchange-services/datahub/

Fingrid. 2018a. Balancing Energy and Balancing Capacity Markets. [Online]. [Accessed 14 February 2018]. Available at: https://www.fingrid.fi/en/electricity-market/reserves_and_balancing/balancing-energy-and-balancing-capacity-markets/#balancing-energy-bids

Fingrid. 2018b. Aggregation Pilot Project in the Balancing Energy Markets. [Online]. [Accessed 14 February 2018]. Available at: https://www.fingrid.fi/en/electricity-market/reserves_and_balancing/aggregation-pilot-project-in-the-balancing-energy-markets/

Finnish Energy Authority. 2017. Energiayhteisöjen oikeudelliset edellytykset EU:n ja kansallisen verkkosääntelyn kannalta. [Online]. [Accessed 18 April 2018]. Available at: http://www.energiavirasto.fi/documents/10191/0/Energiaviraston+selvitys+5.9.2017+TEMlle+energiayhteist%C3%B6jen+oikeudellisista+edellytyksist%C3%A4.pdf/

Finnish Energy Authority. 2018. Sähkönpientuotanto kovassa kasvussa - Aurinkosähkön tuotantokapasiteetti 2,5 -kertaistui vuodessa Sähköverkkoon kytketty aurinkosähkökapasiteetti yli kolminkertaistui vuodessa. [Online]. [Accessed 10 June 2018]. Available at: https://www.energiavirasto.fi/-/sahkonpientuotanto-kovassa-kasvussa-aurinkosahkon-tuotantokapasiteetti-2-5-kertaistui-vuodessa

FinSolar. 2017. Aurinkosähköä taloyhtiöihin – mahdollistaako lait hyvityslaskentamallin?. [Online]. [Accessed 24 April 2018]. Available at: http://www.finsolar.net/aurinkosahkoa-taloyhtioihin-mahdollistaako-lait-hyvityslaskentamallin/

Fruhmann, C. & Knittel, N. 2016. "Community Energy Projects: Europe's Pioneering Task". Climate Policy Info Hub. [Online]. [Accessed 22 March 2018]. Available at: http://climatepolicyinfohub.eu/community-energy-projects-europes-pioneering-task

Fruhmann, C. & Tuerk, A. 2016. "Renewable Energy Support Policies in Europe". Climate Policy Info Hub. [Online]. [Accessed 23 March 2018]. Available at: http://climatepolicyinfohub.eu/renewable-energy-support-policies-europe

Hall, S. & Roelich, K. 2015. Local Electricity Supply: Opportunities, Archetypes and Barriers. University of Leeds. [Online]. [Accessed 21 February 2018]. Available at: https://research.ncl.ac.uk/ibuild/outputs/reports/local_electricity_supply_report_WEB.pdf

Holtschulte, D., Erlangga, A.S., Ortjohann, E., Kortenbruck, J., Leksawat, S., Schmelter, A., Premgamone, T., Morton, D. 2017. Local energy markets in Clustering Power System Approach for smart prosumers. Clean Electrical Power (ICCEP), 2017 6th International Conference.

Ilic, D., Goncalves Da Silva, P., Karnouskos, S., Griesemer, M. 2012. An energy market for trading electricity in smart grid neighbourhoods. Digital Ecosystems Technologies (DEST), 2012 6th IEEE International Conference.

Kilkki, O., Lezama, F., Nylund, J., Mendes, G., Honkapuro, S., Annala, S., Trocato, C., Faria, G. 2018. Local market reference architecture and business requirements. Dominoes project Deliverable 1.1. [Online]. [Accessed 20 April 2018]. Available at: http://dominoesproject.eu/wp-content/uploads/2018/06/D1.1_DOMINOES_LocalMarketReferenceArchitecture_v1.2_final.pdf

Koirala, B.P., Koliou, E., Friege, J., Hakvoort, R.A., Herder, P.M. 2016. Energetic communities for community energy: A review of key issues and trends shaping integrated community energy systems. Renewable and Sustainable Energy Reviews 2016, 56, pp. 722-744.

Lo Prete, C. & Hobbs, B.F. 2016. A Cooperative Game Theoretic Analysis of Incentives for Microgrids in Regulated Electricity Markets. Applied Energy 169, pp. 524-541.

Mendes, G., Nylund, J., Annala, S., Honkapuro, S., Kilkki, O., Segerstam, J. 2018. Local energy markets: Opportunities, benefits, and barriers. CIRED Workshop - Ljubljana, 7-8 June 2018, pp. 1-5.

Mengelkamp, E., Gärttner, J., Rock, K., Kessler, S., Orsini, L., Weinhardt, C. 2017a. Designing Microgrid Energy Markets A Case Study: The Brooklyn Microgrid. Applied Energy 210, pp. 870-880.

Mengelkamp, E., Staudt, P., Gärttner, J., Weinhardt, C. 2017b. Trading on Local Energy Markets: A Comparison of Market Designs and Bidding Strategies. European Energy Market (EEM), 2017 14th International Conference on the 2017 14th International Conference on the European Energy Market, June 2017, pp.1-6.

Morstyn, T., Farrell, N., Darby, S.J., McCulloch, M.D. 2018. Using peer-to-peer energy-trading platforms to incentivize prosumers to form federated power plants. Nature Energy. Vol 3. pp. 94-101.

Mustafa, A., Cleemput, S., Abidin, A. 2016. A Local Electricity Trading Market: Security Analysis. IEEE PES Innovative Smart Grid Technologies Conference Europe, Oct. 2016, pp. 1-6.

Nordic TSOs, Stattnett, Fingrid, Energinet, Svenska kraftnät. 2018. The Way forward – Solutions for a changing Nordic power system. [Online]. [Accessed 20 April 2018]. Available at: https://www.fingrid.fi/globalassets/dokumentit/fi/tiedotteet/sahkomarkkinat/2018/the-way-forward---solutions-for-a-changing-nordic-power-system.pdf

Nordic TSOs, Stattnett, Fingrid, Energinet, Svenska kraftnät. 2017. Unlocking flexibility – Nordic TSO discussion paper on third-party aggregators. [Online]. [Accessed 24 April 2018]. Available at: https://www.svk.se/siteassets/om-oss/nyheter/nordic-tso-discussion-paper-on-third-party-aggregation.pdf

Ofgem. 2017. Ofgem's Future Insights Series: Local Energy Transforming in Energy System. [Online]. [Accessed 2 February 2018]. Available at: https://www.ofgem.gov.uk/system/files/docs/2017/01/ofgem_future_insights_series_3_local_energy_final_300117.pdf

Oliveira, P., Pinto, T., Praça, I., Vale, Z., Morais, H. 2013. Intelligent Micro Grid Management using a Multi-Agent approach. IEEE Grenoble Conference. [Online]. [Accessed 23 May 2018]. Available at: https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6652263&tag=1

Paliwal, P., Patidar, N.P., Nema, R.K. 2014. Planning of grid integrated distributed generators: A review of technology, objectives and techniques. Renewable and Sustainable Energy Reviews 2014, 40, pp. 557–570.

Pöyry. 2017. Seuraavan sukupolven älykkäiden sähkömittareiden vähimmäistoiminnallisuudet. [Online]. [Accessed 5 April 2018]. Available at: http://tem.fi/documents/1410877/3481825/AMR+2.0+loppuraportti+15.12.2017/6a2df7e6-a963-40c0-b4d8-d2533fbca488/AMR+2.0+loppuraportti+15.12.2017.pdf

REN21. 2018. Renewable Energy Policy Network for the 21st Century. Renewables 2018 Global Status Report. [Online]. [Accessed 10 June 2018]. Available at: http://www.ren21.net/wp-content/uploads/2018/06/17-8652_GSR2018_FullReport_web_-1.pdf

Soshinskaya, M., Crijns-Graus, W.H.J., Guerrero, J.M., Vasquez, J.C. 2014. Microgrids: Barriers and Success Factors. Renewable and Sustainable Energy Reviews 2014, 40, pp. 659-672.

Stadler, M., Cardoso, G., Mashayekh, S., Forget, T., DeForest, N., Agarwal, A. Schönbein, A. 2016. Value Streams in Microgrids: A Literature Review. Applied Energy, 162, pp. 980-989

Stakeholders' interviews. 2018. Fingrid Oyj: Risto Lindroos, Laura Ihamäki, Heidi Uimonen. Helen Ltd: Markus Logren. Helen Electricity Network Ltd: Jouni Lehtinen. Interviews were done in May 2018.

Sweco. 2015. Study on the effective integration of Distributed Energy Resources for providing flexibility to the electricity system. Final report to The European Commission. [Online]. [Accessed 29 May 2018]. Available at: https://ec.europa.eu/energy/sites/ener/files/documents/5469759000%20Effective%20integration%20of%20DER%20Final%20ver%202_6%20April%202015.pdf

Tan, X., Li, Q., Hui, W. 2013. Advances and trends of energy storage technology in Microgrid. Electrical Power and Energy Systems, Vol. 44, pp. 179–191.

TEM (Finnish Ministry of Employment and Economy). 2017. Matkalla kohti joustavaa ja asiakaskeskeistä sähköjärjestelmää. Smart Grid Workgroup's progress report. [Online]. [Accessed 20 February 2018]. Available at: http://julkaisut.valtioneuvosto.fi/bitstream/handle/10024/80792/TEMrap_38_2017_verkkojulkaisu.pdf

The sonnenBatterie. 2018. The sonnenCommunity. [Online]. [Accessed 27 July 2018]. Available at: https://sonnenbatterie.de/en/sonnenCommunity

The U.S. DOE. 2012. Ton, D., & Smith, M. The U.S. Department of Energy's Microgrid Initiative. The Electricity Journal, Vol. 25, pp. 84–95.

The USmartConsumer Project. 2017. Smart Metering Benefits for European Consumers and Utilities. [Online]. [Accessed 13 February 2018]. Available at: http://www.escansa.es/usmartconsumer/documentos/USmartConsumer_Final_Report_Publishable.pdf

Timmerman, W.H. 2017. Facilitating the Growth of Local Energy Communities. Doctoral Dissertation. University of Groningen. Available at https://www.rug.nl/research/portal/files/41690059/Complete_thesis.pdf

Universal Smart Energy Framework (USEF). 2015. The Framework Explained. [Online]. [Accessed 12 April 2018]. Available at: https://www.usef.energy/download-the-framework/#

Vallés, M., Reneses, J., Cossent, R., Frías, P. 2016. Regulatory and market barriers to the realization of demand response in electricity distribution networks: A European perspective. Electric Power Systems Research, Vol. 140, pp. 689–698.

VNa 66/2009. Valtioneuvoston asetus sähköntoimitusten selvityksestä ja mittauksesta. [Online]. [Accessed 5 March 2018]. Available at: http://www.finlex.fi/fi/laki/alkup/2009/20090066

Voltalis. 2018. Voltalis' homepage. [Online]. [Accessed 8 May 2018]. Available at: https://www.voltalis.com/corporate#about

Winkler, J., & Ragawitz, M. 2016. Solar Energy Policy in the EU and the Member States, from the Perspective of the Petitions Received. European Parliament: Policy Department C: Citizens' Rights and Constitutional Affairs. [Online]. [Accessed 6 February 2018]. Available at: http://www.europarl.europa.eu/RegData/etudes/STUD/2016/556968/IPOL_STU(2016)556968_EN.pdf

Wouters, C. 2015. Towards a regulatory framework for microgrids – The Singapore experience. Sustainable Cities and Society, Vol. 15, pp. 22-32.

Yao, L., Yang, B., Cui, H., Zhuang, J., Ye, J., Xue, J. 2016. Challenges and progresses of energy storage technology and its application in power systems. Journal of Modern Power Systems and Clean Energy, Vol. 4, No.4, pp. 519–528.

YLE. 2018. Uudet älymittarit muuttavat kodin arkea – Sähkönkulutuksesta saa pian reaaliaikaista tietoa kännykällä. [Online]. [Accessed 6 February 2018]. Available at: https://yle.fi/uutiset/3-9577330

Zhao, H., Wu, Q., Hu, S., Xu, H., Nygaard Rasmussen, C. 2015. Review of energy storage system for wind power integration support. Applied Energy, Vol. 137, pp. 545–553.