MSc Program
Environmental Technology & International Affairs

Microgrids for macro impact
Smart trading for the energy transition

A Master's Thesis submitted for the degree of
"Master of Science"

supervised by
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Vienna, 1 June 2016

Affidavit

I, **VIT LICHTENSTEIN**, hereby declare

1. that I am the sole author of the present Master's Thesis, "MICROGRIDS FOR MACRO IMPACT SMART TRADING FOR THE ENERGY TRANSITION", 71 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
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Abstract:

For several years, increasing energy consumption and a lack of alternative energy sources have posed a challenge to the world economy. One of the possible solutions to avoid future energy shortages could be the steadily greater use of renewable sources of energy on a local level and a change of generation and distribution of energy itself. This thesis describes the option to produce and trade electric energy locally. This change in energy production and distribution can bring high-efficiency gains if handled skillfully. Dubbed energy transition, these changes will play a central role in future electricity supply and trading. The research methods for this thesis are comparative and qualitative analyses of trading, technological aspects and the social impact on society. The findings indicate that the best solution for future energy production is a combination of electricity production on a centralized level for factories and a decentralized level for households. This transition in electricity production would allow selling locally generated energy surpluses via virtual power plant. End consumers would lower their electricity expenses due to flexible tariffs. Household electricity producers would enjoy a higher income due to automated software controlling the trading process. Further research should focus on the financial aspects and economic viability of energy decentralization.

Table of Contents

List of Abbreviations

AC	Alternative Current
AMR	Automated Meter Reading
AMR	Automated metering system
APX	Amsterdam Power Exchange
CAISCO	California Independent System Operator
CEE	Central and Eastern European
CEO	Chief Executive Officer
COP21	Conference of parties
e2m	Energy to market
ERU	Energy Regulator Office
ESCO	Energy Service Company
EU	European Union
IPO	Initial Public Offering
kWh	Kilowatt-hour
MWh	Megawatt-hour
NASDAQ	National Association of Securities Dealers Automated Quotations
NIMBY	Not In My Back Yard
OECD	Organisation for Economic Co-operation and Development
OMEL	Operador del Mercado Ibérico de Energía
OTC	Over the Counter Market
PSE	Prague Exchange Inc.
PV	Photovoltaic
PXE	Power Exchange Central Europe
RES	Renewables Energies Sources

TESLA	TESLA Motors
U.S.	The United States of America
UK	United Kingdom of Great Britain and Northern Ireland
UN	Orgainsation of United Nations
UNEP	United Nations Environmental Program
VPN	Virtual Private Network
Wh	Watt-hour

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First and foremost, I would like to thank my parents Věra and Michael and my sister Markéta for the support they have provided me over the years and especially during my studies. Without their assistance, I would not have been able to finance neither my undergraduate studies nor the postgraduate master's program „*Environmental Technology and International Affairs*".

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1 Introduction

Electrical energy has always been one of the most important commodities. Energy has become the driving force for progress, increasing life expectancy and living standards, but also becoming a source of conflict. With the increasing importance of electrical power for humans, the field of energy trading and the future of energy production is an area of high interest for the general public, professionals and companies. However, the functionality of microgrids as a complex structure is important in coexistence with current energy markets (Hatziargyriou 2014). Therefore, it is clear that the development of the current energy system will play a major role in the sustainable development of the whole society.

With this in mind, this thesis will deal with the question how microgrids can be best implemented into the existing energy structure. To answer this central question, Central Europe will be used as a case study in the chapter Trading. The energy system is experiencing turmoil. In the new global economy, energy has become a central issue for trade, progress, research, and development (Motlik 2007). In recent years, interest in new sources of energy has considerably increased. For instance, Renewable Sources of Energy are thriving. Along with the growth in renewable energy sources (RES), however, there is increasing concern over their impact on the whole energy structure (Roebuck 2012). Investments into hydrogen and fuel cells, photovoltaic panels, wind, hydro, geothermal, bioenergy, and ocean energy are rising every year. The past decade has seen the rapid development of renewable energy sources in many fields. These changes are reflected in professional literature. Recent studies suggest that this broad availability of energy sources could lead to Democratization of Energy (Rifkin 2013). This energy transition entails a significant challenge for governments all around the world, but especially in the United States of America (U.S.), the European Union (EU) and the Middle East. Most energy giants, who base their business plans on extracting, selling and using fossil fuels, are facing significant changes akin to a transformation of the whole sector. These giants are not ready for energy evolution. This applies especially for this moment in time, when generating one`s own energy is becoming a viable option for most of middle-class households. Furthermore, these energy companies are often state-owned and a lack of dividends each year could cause significant problems for budgets. However, what will happen if the learning curve of new technologies will be faster than the business model of these multi-billion dollar companies which must adapt to them?

The production of energy must be continuously adjusted to the current energy consumption. As regards the electricity generation industry, feasible methods to store electrical energy economically in large quantities do not exist. Therefore, it is necessary to balance electricity consumption and production. Contrary to that, electricity production and distribution via microgrids to households could help diversify the way the energy market works. Apart from (Hatziargyriou 2014) and (Galvin, Yeager a Stuller 2008) there is a general lack of research in the field of energy balancing. The possibility of a new mode of energy balancing will also be described in the following chapters.

Technological changes bring growing demands pertaining to the accuracy of information on energy consumption. Measuring electricity consumption thus becomes one of the most important activities. Deep knowledge of electricity demand patterns is an important input for predicting future consumption and thus managing power production efficiently. Furthermore, with this data it is also possible to trade with the surpluses of household electricity production (Chemišinec 2010). New types of measuring devices called smart meters allow for more accurate and frequent measurements.

Growing manufacturing resources broaden the fields of connecting various appliances. For example, the network called the Internet of Things will permit to connect daily used house equipment into one system. Another example in this field is the development of e-mobility. Electric cars represent a new kind of electric appliance, which will use a considerable amount of electricity.

To sum up, with the requirement to control electricity production, transmission, distribution and consumption raises new issues which must be addressed. One of the solutions could be a diversification of electricity generation and, especially for households, the concept of a modern decentralized electricity grid called microgrids.

1.1 Core objectives

The core objective of the energy transition is to provide sustainable and affordable energy for the 21st century (Grubb 2012). Some states are already aware of this future challenge. One of the first and at the same time biggest countries that decided to change its energy structure was Germany. Germany decided to phase out nuclear power plants by 2020 and coal power plants by 2050. This energy shift termed "*Energiewende*" could turn out to be a very smart move. German companies will force other markets to speed up their energy shift, and the know-how of German companies could be spread all around the world. However, according to German political elites, this energy transition should be based on a smart grids solution. If Germany decides to implement this energy change, it must consider two main issues. These issues include the costs of new grid systems and the problems with energy storage (Hatziargyriou 2014). European and also German electricity grids systems are outdated and in dire need of massive financial investments to upgrade them. Another problem is that many German citizens don't want to have new grids on or near to their property, even though they are overall supportive of the new direction of their energy system. This phenomenon, known as NIMBY or 'not in my backyard', is a recurring problem for ambitious plans to construct new renewable energy systems and their necessary grids, particularly in democracies. Furthermore, even if Germany will succeed in building a new grid system, they will also need massive storage capacities for balancing the grid. For example, Germany will produce wind energy in the northern part of country, where one can find the best environmental conditions to do so. However, the highest energy demand occurs in the southern part of Germany. How will they transfer this electricity? Will this be economically feasible?

A considerable amount of literature has been published on Smart Grids. For example, (Grubb 2012) and (Lenhardt 2012). These studies encourage the production of electricity from RES. However, very few books were considering a solution that could make electricity production available to people and could cause an energy revolution. This solution is called Microgrids systems. This thesis contends that current households could use Microgrids to cover their energy demand, and that this energy shift would be economically feasible from the mid- and long-term perspective (20-30 years). This paper attempts to show that even without state subsidies, it will be efficient to invest in

Microgrids. Households are the engine of each economy and therefore, this thesis will focus only on households' demands.

The aim of this thesis was to clarify several aspects that must be considered when building Microgrids. This thesis is based on comparative and qualitative analysis of investment opportunities of decentralized electricity production from RES. A question is for instance, who will finance the necessary investment in these Microgrids? Who will maintain the grid system? This thesis intends to determine the extent to which investment costs could be covered by equity and to what extent it would be necessary to use a senior loan or other forms of financing.

The basic research questions, which will be examined in this work, are: What is the future way of energy production? How could electricity production in a system based on microgrids be profitable for households? What would be the most economically feasible market and business model for microgrids? How will the energy demand be covered from microgrids?

1.2 Structure of thesis

The study will be structured into five chapters, including an introductory chapter and a conclusion. Each chapter consists of several subchapters which are covering different issues. In the introductory chapter basic research questions are described and the methodology of the thesis, core objectives, the methodology, and the bibliography are presented.

Chapter two begins by laying out the theoretical overview of the current energy system. This theoretical dimension is covering the often overlapping social and technical aspects of energy changes. Thus, the second chapter helps to understand a possible energy transition towards energy production for households based on microgrids. Furthermore, in the second section the theoretical and practical differences between future energy networks, future energy architecture and difference between a smart grid and microgrids are discussed. For example, in the second chapter, the question of what the differences between smart grids and microgrids is raised alongside the question of what kind of implication the energy transition to microgrids could have. As mentioned, the second chapter also describes different forecasts that are necessary for electricity production. For instance, population growth, energy demand, efficiency improvements and other issues, which could come up alongside these changes. The second chapter should help readers to orient themselves in the subject of energy generation from Renewable Sources.

The third chapter tackles the topic of trading produced energy. Throughout the third chapter the current status of trading with electric energy is described, from the standpoint of the case study from the Prague exchange to the description of the most important exchanges in Europe. Another part of the third chapter deals with theoretical and practical business and market models. For instance, in the third chapter it is described how microgrids energy trading could work. This explanation is supported by a Canvas business model case study, where it will be shown what kind of essential elements necessarily have to be fulfilled.

The fourth chapter deals with the examples of current companies dealing with energy trading. The described companies have an innovative approach towards electricity production and that is also reflected in their electricity trading philosophy. It also describes the available financing for Microgrids projects in the future.

Finally, the conclusion gives a brief summary and critique of the findings. What kind of further research could be done on this topic and what is a possible scenario of the microgrids trading transition.

1.3 Citation of main literature and methodology

This thesis is a comparative and qualitative study. The prime focus is on different approaches to the energy evolution. The central question is how to transform the current energy production and distribution network. For the comparative study various sources of information are used. From the printed bibliography, books from Professor Nikos Hatziargyriou about Microgrids and its architectures and control are essential. Other important printed sources used for this thesis are, for example, books by Robert Galvin, Jay Stuller, Kurt Yeager*: "Perfect Power: How the Microgrid Revolution Will Unleash Cleaner"*. All of the mentioned books are approaching the topic of microgrids more from an academic perspective. However, for more financial insight, the most current research papers and articles, which are focused on trading and business side were used, like for instance, Gregoratti, David, and Javier Matamoros: *"Distributed Energy Trading: The Multiple-Microgrid Case"* or Key, Peter: *"Innovation: Energy trading, thanks to microgrid software"*.

This thesis also considers the social aspect of the whole microgrids transition. The whole of energy production and distribution change has a diverse impact on society. Thus, it is not enough to look purely at the technological aspect, but also consider the social aspects of the energy transition. The most used books that are considering social aspects and are used in this thesis are: *"The Third Industrial Revolution"* written by Jeremy Rifkin and book by Roebuck, Kevin: *"Microgrids: High-Impact Strategies - What You Need to Know: Definitions, Adoptions, Impact, Benefits, Maturity, Vendors"*.

The financial part of this thesis is conducted from the qualitative point of view. In this sense, e-sources were important. For instance, documents from the Prague exchange, from the Czech Energy Regulator Office (ERU) or a study conducted by Bill Martin, who proposed non-linear thinking about decentralized applications.

The approach of this thesis is multidisciplinary with the focus on energy trading and the microgrids transition. The lack of printed bibliography was substituted by the most recent electronic academic publication from 2014-2016.

2 Overview

Our present electricity grid system is at least hundred years old. Since the time of Thomas Alva Edison and Nicolas Tesla, the production and distribution of electricity did not dramatically change (Lenhardt 2012). Contrary to the tendency of decentralization and people-to-people sharing of information and goods, electricity production remains centralized. This centralized electricity production and transition networks are run and supervised by companies with a strong state presence. However, today we find ourselves in a situation where all aspects of human activities are interconnected, and pressure for efficiency is high (Newland 2013). We can also see changes in electricity production and distribution. Electricity demand and the yearning for a sustainable approach to power generation were never so high in the history of mankind. To be able to face these challenges and allow a future society to grow, we must ask ourselves a fundamental question: What should be our approach to electricity production and distribution?

To achieve sustainable development, some authors argue that a change in how human activities are functioning and societies are organized is necessary. This could be implemented for example by social, economic and technological decentralization (Elliott 2003). These considerations also apply to the vital issues of production and supply of energy. Without electric power, no modern human society can survive. However, the decentralization of power generation is such a new approach that so far no consensus on its precise definition has been established in the literature. The standard terms for describing decentralization are a shift towards technologies producing on a small scale and shortening distances between production and consumption of energy.

Anglo-American authors describe decentralization as dispersed or embedded energy generation. European authors speak about decentralized power generation (Ackermann 2011). All these terms are often a combination of a particular category of technologies: for instance, *"technologies transforming* renewable *sources (RES) into electric or thermal energy"* (Ackermann 2011). In the most recent publications*, "the terms decentralization of energy production and microgrids"* are used together. That is why in this thesis, these terms will be employed. The principle of decentralization could also be used for power generation from fossil fuels. However, nowadays the decentralization concept is tightly connected with the development of renewable energy sources.

Some studies raised the issue of the current degree of centralization of energy production and defend its shift towards decentralization (Wolfram 2003), (Ackermann 2011). Electricity generation is concentrated in large power plants from which power is distributed to consumers over long distances. This centralization brings security, logistics, and economies of scale. Centralized electricity production, however, is mostly based on limited fossil reserves and has a negative environmental impact, while the decentralized model is better suited to renewable energy production and has less negative impact on the environment (Wolfram 2003). Furthermore, a decentralized system is based on local resources and thus is less sensitive to fluctuations in the energy market (Motlik 2007) and political changes in the countries where fossil fuels are concentrated. The last and for this thesis most compelling question for decentralization-microgrids is the question of ownership of microgrids. It is of vital importance to prevent the outflow of money from the region where the energy is produced. It is necessary that local stakeholders, like local household communities, will be financially involved in microgrids projects. This involvement will provide local civil society connection and even employment for the whole area.

2.1 Info-energy Net and Energy Democratization

Imagine the following situation: You are in the 1980s. The World Wide Web is still a luxury place for technological geeks and university students, but you can feel that this will change. This change will influence every aspect of human society. With the political changes in Eastern Europe also the system of how we perceive information also changes. Live News Broadcasting is a driving force for better technological infrastructure. Throughout the 90s, the Internet becomes a medium of democratization. We can call it Info-democratization. Now let's come back to the present. We are in 2015, in Paris, at the Climatic Conference of the Parties (COP 21) where politicians are proclaiming a need for a more sustainable energy approach. In 2016, energy production from renewable sources is still a luxury for geeks, university students or companies. Only small portions of these technologies are meant to be installed in households. Prices are simply too high. Does this situation sound familiar? We could argue that the situation of the Internet in the 90s of the 20th century is similar to the energy changes we are facing now. The current grid system is outdated and needs fundamental upgrading which could power the energy democratization.

As stated at the beginning of this chapter, a certain kind of energy decentralization appears as the ultimate goal. Centrally integrated systems could be inflexible, vulnerable and have a profound undesirable environmental impact. Moreover, they have a tendency to be under bureaucratic and monopolistic control (Elliott 2003).

Future power grids would be transformed into an Info-energy net, allowing millions of people who produce their energy to share surpluses peer-to-peer. *"The conventional top-down organization of society that characterized much of the economic, social and political life of the fossil fuel-based industrial revolutions is giving way to distributed and collaborative relationships in the emerging green industrial era"* (Rifkin 2013). Electricity household demand is a future challenge. According to recent data from the Organiation for Economic Cooperation and Development (OECD), total household consumption on average is approx. 3,450 kWh/year. This total consumption varies on each continent, from approximately 12,000 kWh/year in the North America to 400 kWh/year in China (WEC 2016). However, the trend of growing electricity consumption is evident. The International Energy Agency expects energy demand to increase by 37 % between 2012 and 2040 (Agency 2014). In response to this, the European Union plans to produce 20 % of electricity from renewable sources by 2020. The growing trend towards automation and the usage of new electrical devices underlines the crucial task of adapting and managing household electricity demand. How will we make increasing electricity demand affordable? Could this energy shift be connected to the changes in the whole society?

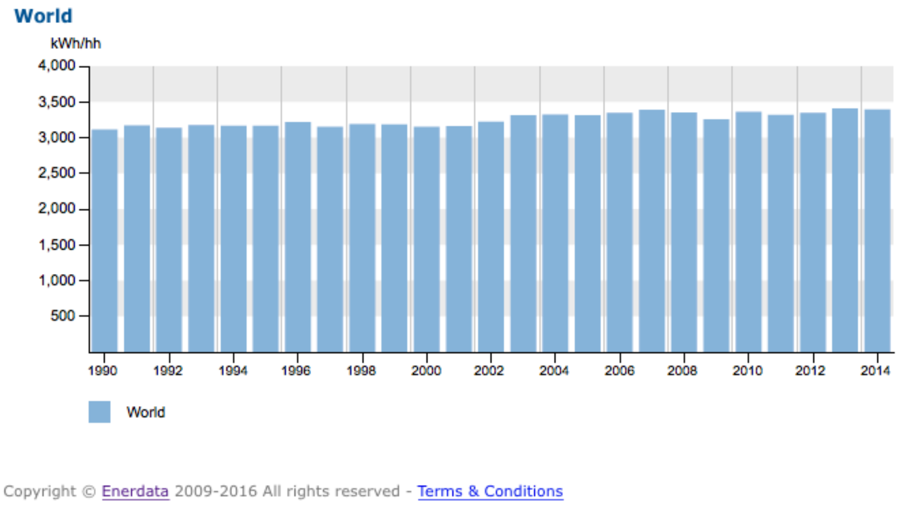

Figure 1: Worldwide average energy household consumption from 1990; Source: WEC (WEC 2016)

A large number of authors agree that the use of renewable energies can promote significant new jobs creation and shifts connected to the whole society (Scheer 2002), (Grubb 2012), (Colin 2000). Job creation is one of the principal motives for the political support for the development of renewable energy sources. Technologies necessary for the processing of RES lead to the creation of more jobs. Moreover, these sites can be concentrated in rural and mountainous areas regions where they are needed most to lower high unemployment rates. The aspect of energy biomass processing is also critical, since it can raise the employment of farmers, forestry workers and entrepreneurs in this area (Scheer 2002).

2.2 Smart grids and microgrids

Currently, the most promising approach to handling future energy challenges is a combination of centralized and decentralized energy production. These future challenges are to be found in the concepts of using more renewable sources of energy. In the context of this more sustainable approach, enter the issue of smart grids and microgrids. This thesis will describe possibilities of microgrids usage and trading of energy produced from microgrids which are connected to the main grid system. However, this paper will not describe other possibilities of connection, for example off-grid microgrids, utility-integrated campus microgrids and nano grids. These possibilities of connection and energy production could be an aim for further research.

2.2.1 Smart grids Definition

Smart grids are the class of technology that uses centralized computer-based remote control and automation (Key 2015). *"According to the European Technology Platform of Smart Grids, a Smart Grid is an electricity network that can intelligently integrate the actions of all users connected to it. A grid employs innovative products and services together with intelligent monitoring, control, communication and self-healing technologies"* (Hatziargyriou 2014). However, until now, there is no standard global definition. The biggest advantage of smart grids is their ability to reduce power consumption at the consumer side during peak hours and to maintain and improve reliability, quality, and security of supply. However, the biggest disadvantages are a lack of storage systems for a centralized network and the unwillingness of the public to construct new distribution networks. The phenomenon of public resistance against the construction of new grids is called *"Not In My Back Yard (NIMBY)"* and is widespread, especially in developed countries.

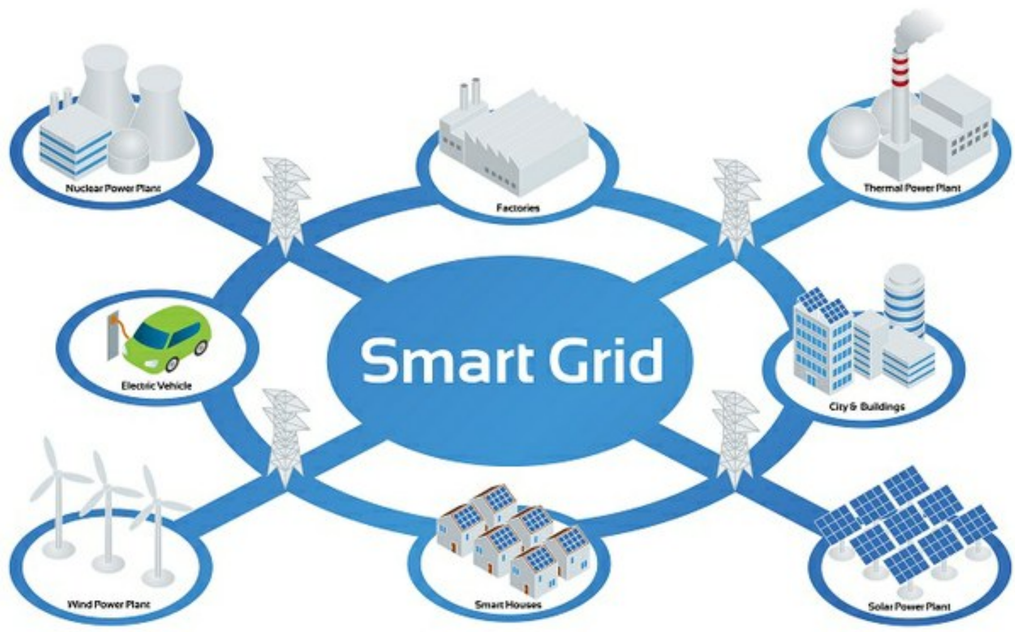

Figure 2: Elements in smart grid; Source: ENISA (Security 2016)

2.2.2 Microgrids Definitions

The term *"microgrids"* will refer throughout this thesis to locally produced small power systems for households. This electricity system should be able to cover basic household demands during a day. *"Microgrids provide both thermal and electricity needs, and in addition enhance local reliability, reduce emissions, improve power quality by supporting voltage and reducing voltage dips and potentially lower costs of energy supply"* (Hatziargyriou 2014). Microgrids systems are also able to fulfill the same tasks as smart grids, but the investment costs are much lower because of their decentralized character. Currently existing technology could power energy production for household demand, but the investment cost of storage systems and transportation are not economically viable yet. In this thesis, the functioning of community microgrids, which connect each households within defined area to the utility network, will be described.

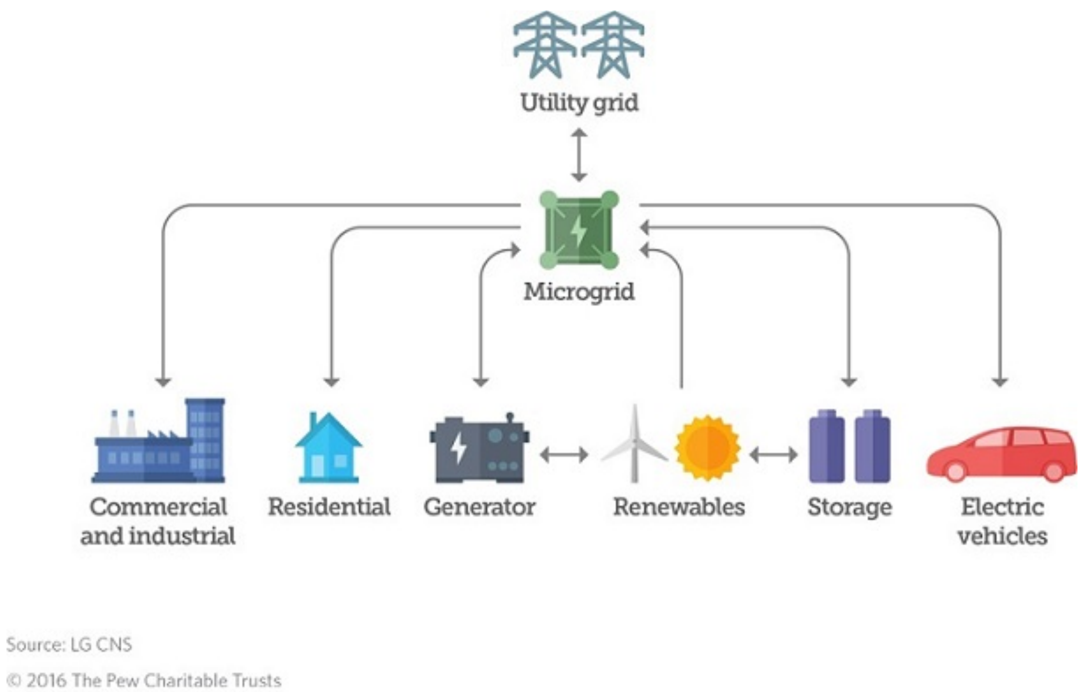

Figure 3: Elements in microgrid; Source: Microgridmedia (Burger 2016)

2.3 Social and Technological Challenges

The aging population and the increasing demand for technological infrastructure needed for stable electricity supplies will grow in the upcoming years. Already now we can observe an increased amount of automation where the consumer owns and operates a whole system (Grubb 2012). For example, for powering the current *phenomenon "Internet of things"*, where many electronic appliances are interconnected, a reliable electricity backup is an essential need.

Increasing electricity demand will also drive a change of structure in community participation. Therefore, some forms of communal control, whether owned or co-owned, will be championed in order to develop projects with a focus on RES. Additionally, this form of ownership will improve the acceptance of these projects acceptance. In the current situation, it could be difficult to convince a community to invest into long-term installations. However, local ownership and a local share of financial benefits of the project could act as a compensation for possible negative impacts of the project.

Figure 4: Internet of Things an schematic overview; Source: MOVEMENT (Boddington 2015)

Another challenge we witness in electricity generation is the tendency to go more in the direction of sustainable production of electricity. This results in a decreasing number of employees necessary for electricity production but more employees needed for maintenance. In this sense, we can see two main directions for further developments. The first model uses computer principles to manage smart grids which still need relatively many skilled workers. A smart grids principle is more centralized and has a broad scope. The technological challenge arising out of this centralized system is represented by the so-called *"Duck Curve"*.

2.3.1 Technological Challenges

The *"Duck Curve"* describes the temporal difference between the production and consumption of electricity from solar and wind generators. The California Independent System Operator (CAISO) the first time described the *"Duck Curve"*. According to this theory, the net load difference over a day will dramatically increase. For example, most of the electricity is consumed in the morning at 9:00 and in the evening at 21:00. Unfortunately, the energy production of solar panels and wind generators are highest in different parts of a day. A rapid increase in power generation could thus lead to technological issues regarding the balancing of the grid system.

The following picture will show a *"net load"* which is the total demand for electricity minus whatever renewable energy is on the grid, over a typical spring day in California (Roberts 2016).

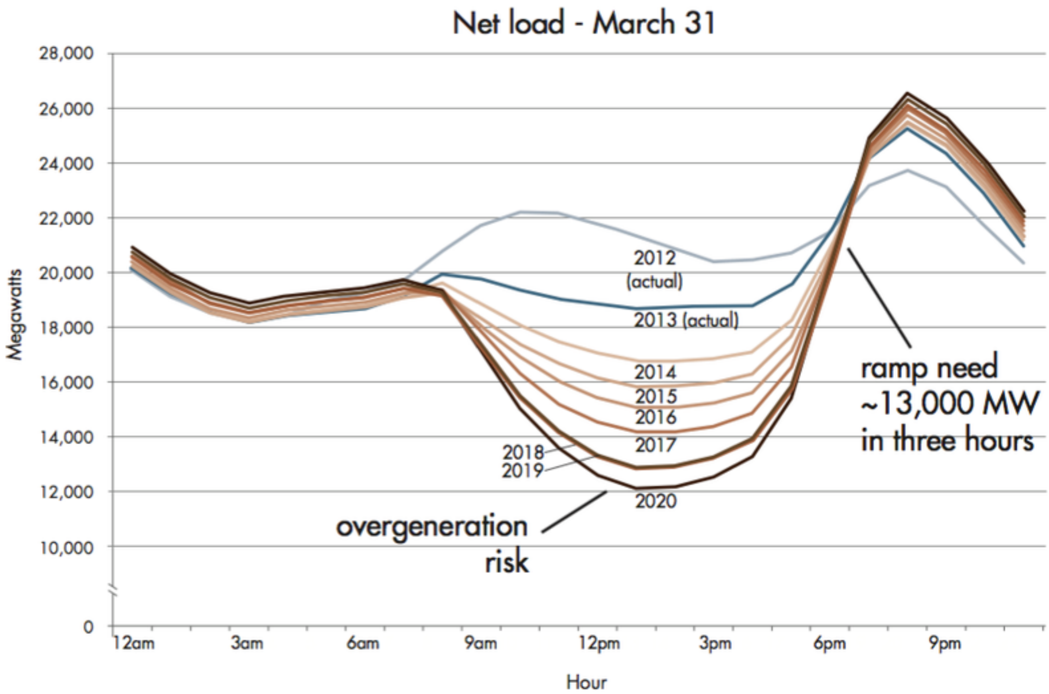

Figure 5: Net Load demand for electricity in California during average spring day; Source: CAISCO (Corporation 2016)

How to flatten the Duck Curve? We can see three basic approaches. The first one is to build a lot of new grids, which will help balance, the electricity load. The second method is to invest in storage systems and restore the electricity production by storage of electricity (Roberts 2016). Unfortunately, both approaches are very costly and politically difficult to handle. For example, not so many people will let one build new grids on their property. Many people insist that these utilities should be built everywhere but *"Not In My Back Yard (NIMBY)"* and are adamant in their opposition. The third solution could be a combination of both approaches. That is, to build new grids and storage systems but on the regional and decentralized level. In this way, communities will understand why a new grid system is created on their property. Furthermore, community households will use the new grids and energy they produce. These communities could invest in storage systems, which on a localized level will not be so expensive because they will be dimensioned for a smaller storage capacity. Microgrids use the modern atomization principle and at the same time try to reduce cost and increase sustainability for local communities. This could be the most economical and social way to flatten the Duck Curve. Another possible solution could be to limit generation capacities.

2.3.2 Social Challenges

Technological challenges are closely connected with social ones. Primary drivers of demographic change are the aging population and immigration processes throughout the whole world. These changes could have an impact on the structure of household owners and energy consumption. For example, the OECD graph below shows population changes between 1960 and 2016 with projections until the year 2100.

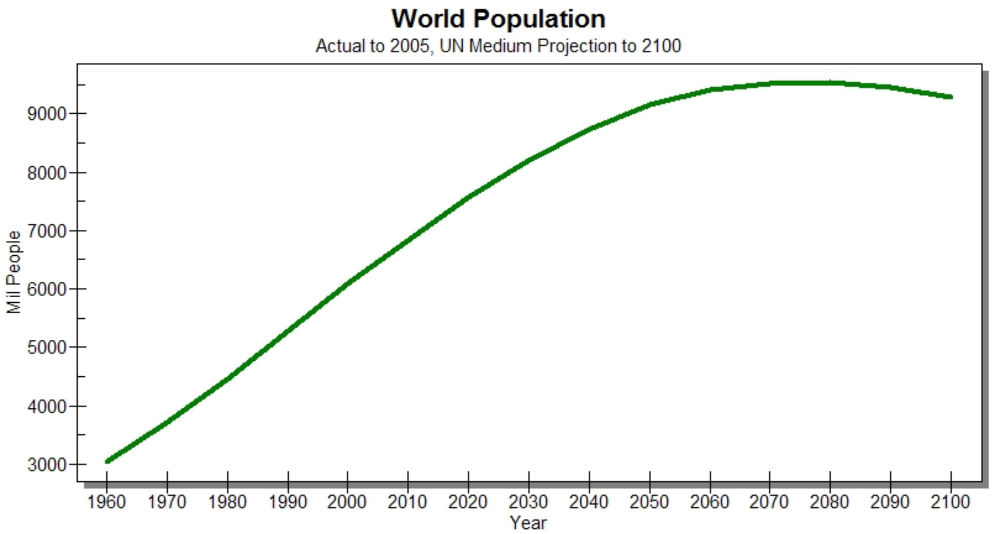

Figure 6: Graph shows the population growth prediction; Source: UN (UN 2016)

A United Nations Environmental Program (UNEP) study suggests a steep increase of 30 % in the mean life expectancy until 2050. In the meantime, all the fundamental needs are influenced by technological changes and developments. Even in less technologically developed parts of the world, technologies that we would have considered high-tech only a few years ago are being used, notably smartphones. Finally, there is also the aspect of demographic changes in household structure. The phenomenon of single people is leading to higher material usage. All of these studies from renowned institutions expect the same: The aging of population and structural household changes will result in higher demand for new technologies.

Lastly, we can also consider environmental challenges, for example, the goal of replacing fossil fuels. This could significantly increase air quality and thus quality of life. Additionally, the rapid decrease in the amount of harmful substances in the air could attract tourists to the region. However, it is crucial to determine carefully during the planning phase what kind of renewable sources of energy shall be used. Diversification is necessary. Only building biomass systems, for instance, could considerably change the character of forests in the area. All these technological and social changes could be a direction for a sustainable future.

2.4 Electricity network connections

Electricity network systems have two main installation possibilities. The first one is a network connected to the primary grid and thus is called on-grid solution. The second option is isolated from the main network and thus is called off-grid (island) solution.

On-grid systems are installed in most densely populated areas. The produced electricity is distributed through the inverter to the grid. The microprocessor automatically controls an alternative current (AC) of the entire system, which is connected to the distribution network (Murtinger a Truxa 2010). The peak amount of electricity consumption connected to the distribution system is usually in the range of kWh or maximal MWh per year. This system works on the roofs of houses or even for large-scale photovoltaic power plants built in open areas.

The off-grid solution is the opposite of the on-grid system. The system of off-grid solutions is independent of the distribution network. For instance, off-grid systems are applied in a place where there is no electrical connection due to difficult geographical environment, for example in mountainous areas. Another example of an island solution could be a rural area which is isolated from the main electricity distribution network, or street lamps. Performances of off-grid systems typically vary in the range from 1 Wh/ year to 10 kWh/year of electricity peak consumption.

Islanded systems also emphasize minimizing energy losses and trying to install to most efficient technology available. Island systems can be further broken down into systems with direct power and hybrid systems. Hybrid systems work on the principle of electrical energy accumulation (Maehlum 2013). Systems with direct power are applied where there is no need for constant connection. For example, when sufficient amounts of sun radiation occurs in the area, the sun radiation could heat up heater for hot water or charge batteries of small devices. To put it simply, the direct power electricity production is very similar to an island solution. Finally there are hybrid solutions, which combine the island and on-grid solution (Hatziargyriou 2014).

For microgrids, a hybrid solution is the most suitable installation. Installations usually are constructed for a higher performance in winter, when the solar radiation produces significantly less power than in summer. Therefore, the preferable alternative may be an extension of a backup source of electricity. This backup would help to cover electricity consumption during periods of insufficient sunlight. Another alternative is electric power generated by other renewable energy sources like a wind power generator or a small hydropower generator. Systems with electrical energy accumulation are used where there is a demand for electricity, in periods without sunshine, for instance during nights. These systems have additional batteries to be able to provide a backup in the times without sunshine. An electronic controller and a smart meter control the optimal charging and discharging of batteries. Traffic lights, streetlights or light commercial banners work under the same principle.

Finally, the most used solution for microgrids is a combination of on and off-grid solution and thus a hybrid system, for example, installing photovoltaic panels on the roof or household façade. This application has a positive impact on the future energy costs of the building and this will strengthen the whole energy system. According to (Motlik 2007) the use of solar panels on buildings is a modern approach to house building and could even replace traditional building materials. Microgrids could benefit not only from low-cost energy generation. On a bigger scale, it is even possible to sell energy surpluses via microgrids. These trading options will be described in a subsequent chapter microgrids trading.

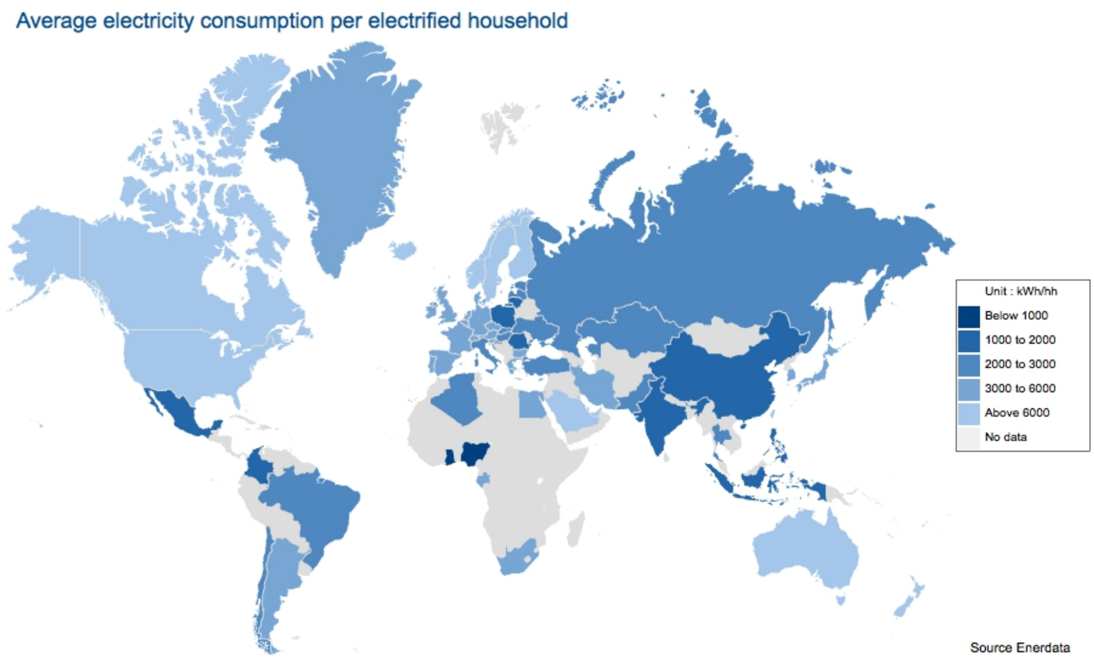

Figure 7: Average electricity consumption per electrified household; Source: WEC (WEC 2016)

2.5 Smart Meters

Metering systems are electronic measuring devices meant to control electricity consumption. The classical metering technology is applied for the industry and private households and works on a passive information-gathering (one-way) basis. That means that these meters are measuring the usage of electricity in households and industries, but workers must collect this information (Roebuck 2012). The classical metering devices could receive a command, but the device is not capable of communicating back with the distribution center. This old approach is used since more than fifteen years. A Joint Project of the EEI and AEIC Meter 2011 states that *"Previous systems, which utilized one-way communications to collect meter data were referred to as Automated Meter Reading (AMR) Systems. AMR has developed over time, from its roots as a metering reading substitute to today's two-way communication and data system"* (EEI and AEIC 2011).

Contrary to the classical version of metering, smart meters work differently. Smart Meters work by mutual data communication between the delivery point and the command center. This two-way communication enables better data collection, automatic scoring, connection or disconnection to the supply, household electricity balancing, and a real-time electricity price calculation.

This approach has several advantages. From the perspective of the customers, smart meters bring the advantage of automatization. This automatization could help to provide greater reliability of supplies, better control of consumption via special applications and the possibility to choose between different tariff fares (Galvin, Yeager a Stuller 2008). All these options could also be set up automatically, and smart meters would balance all these variables on their own. From the perspective of a distributor, smart meters bring the advantage of better control. This control could help to detect attempts to manipulate the device. Providers could react in real-time. Another example would be an emergency situation. During such an emergency situation, the command center could balance the distribution network without inflicting harm on the whole distribution infrastructure.

The disadvantages of smart meters are the financial costs and the possibility of connection within households. As every technology has its learning curve, smart meters are also still developing. With the increasing number of investment into household appliances and the Internet of Things, a higher number of smart meter installations can be expected.

Smart meters already help to improve efficiency and communication between utilities and households. This new way of measuring energy consumption is the baseline to bring new technologies closer to energy consumers and to provide them the toolkit to track their expenses.

Another reason for the importance of installing a smart metering system is the potential connection to the Internet of Things in the household. This combination of expenditure control and installing new technologies should improve the efficiency of energy usage. Katarina Grolinger (2015) provided an in-depth analysis *"Recent advances in sensor technology and the proliferation of smart metering devices that measure, collect, and communicate energy consumption information have created possibilities for development of sophisticated energy services"* (Gregoratti a Matamoros 2015). One main engine behind the transition to smart metering systems is the European Union (EU), which requires in its Directive 2009/72/EC all EU member states to implement intelligent metering systems for an active participation of consumers in the electricity market by 2020. By 2020, at least 80 % of consumers should be equipped with this metering system. One can already observe the implementation of smart meters in the United Kingdom of Great Britain and Northern Ireland (UK), where the program to replace outdated metering systems with smart ones was already begun and should be finished by 2020.

When planning the usage of microgrids, the smart central device is fundamental, because it will help to offer flexible prices within a community in real-time. The smart metering system works basically in two ways. On the one hand, the smart metering technology collects data while on the other hand, it communicates via radio frequency with a utility.

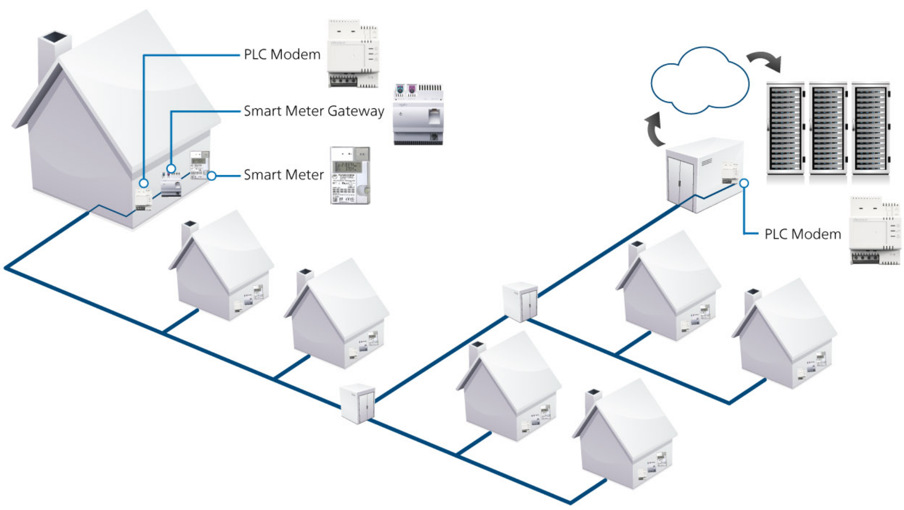

Figure 8: Smart meter scheme; Source: (Devolo 2016)

2.6 Security dimensions of Microgrids

This subchapter will outline the fundamental questions that should be considered regarding readiness for cyber security threats and emergency situations of energy blackouts. These questions are not only essential for the technical functioning of grids, but also necessary for the complex operation of a state, since the energy grid can be considered as strategic state infrastructure.

There is not one single uniform definition concerning the security dimension of microgrids. Energy security can be divided into two parts. The main difference is differing perceptions of energy security from a strategic and market point of view.

A strategic approach is based on political considerations. According to this, it is the most valuable player who should take care of energy security, hence the state. The market approach, one the other hand, is based on economic considerations and requires energy security to be consistent with a market environment.

Therefore, on one side there is the state that aims to have the means to ensure the supply of electricity and on the other side, there are private entities whose goal it is also to provide an uninterrupted supply of electricity albeit with different motives and methods. The desired outcome, this thesis is arguing, would be a combination of both approaches. In case of emergency, including blackouts, the state should be ready to protect strategic infrastructure. However, in the case of microgrids, private entities should consider investing in microgrids security solutions. This division of responsibilities would decrease the possibility of fatal electricity emergency situations, which can be caused by human activity or natural events. These accidents threaten life, health, property or the environment and require rescue and relief work. In the case of energy networks, we mainly talk about emergency situations in a context of terrorist attacks or a total blackout of the grid systems.

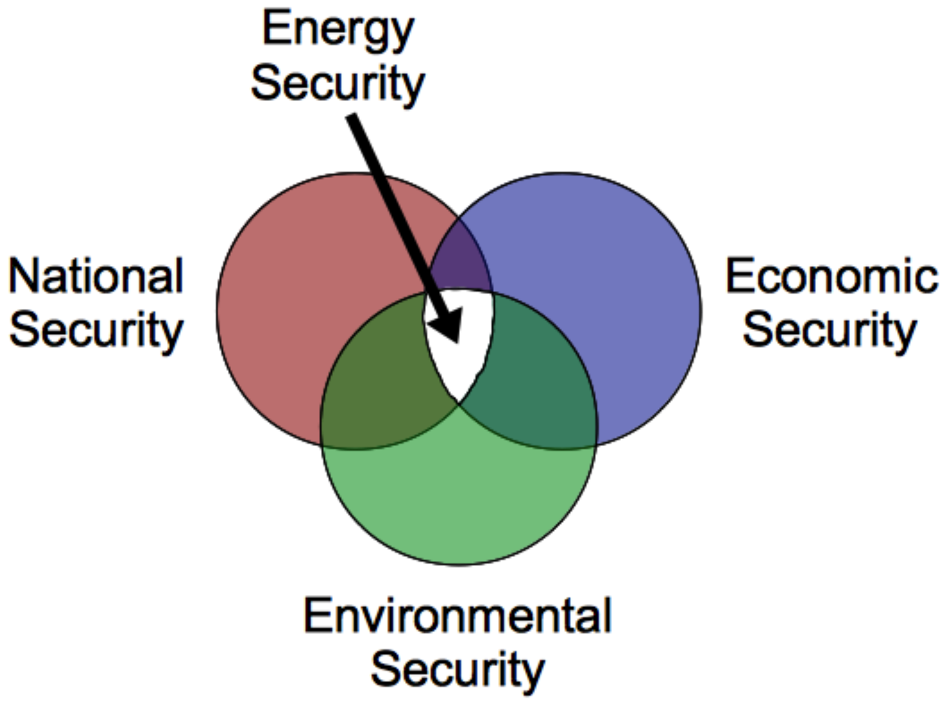

Figure 9: What consists of energy security; Source: SIMEC (Limited 2016)

2.6.1 Cyber security and networks architecture

In cyber security and energy emergency planning, there are three recognized types of networks - centralized, decentralized and distributed network. These systems could be applied to social, economic or technical networks. These three networks differ from each other by their composition. The first approach is a centralized grid. *"The working arrangement of a centralized system is shown in Figure 10. In this system, individual units are represented by nodes in the figure. Example of centralized system is local governments, which are directly controlled by the central power"* (CFFN 2009). In the case of the centralized network, all grids forming the network are connected to one center. If something will happen with the central point of a network, the entire network is immobilized.

The second approach is a decentralized network as shown in Figure 10. In a decentralized system, several centers are connected. As a consequence, a problem at one point doesn't necessary have fatal consequences for the whole network. However, fatal failure may cause a cascading effect and a potential collapse of the entire network.

The third approach regarding safety and the safest model is a decentralized distributed network. A distributed network is interdependent of individual issues and problems because it is almost always possible to find a connection to replace the damaged one. A distributed system can be seen in the third sketch of Figure 10. In practice, it is tough to achieve this state due to the economic costs of building such a network. However, on the localized level, the costs of building microgrids could be divvied up and will be paid by each household individually. Cost optimization could reduce expenses of installation, implementation and maintenance.

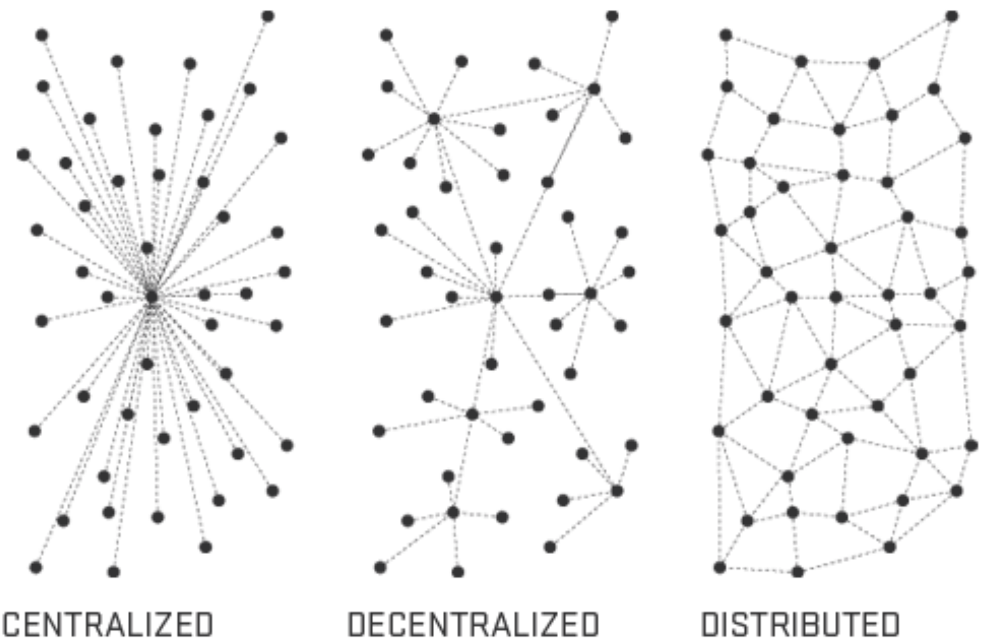

Figure 10 : Networks architecture overview ; Source: How to ? (Ahmad 2013)

2.6.2 Blackout

"Blackout" is a universally and internationally used term for a situation of extensive sudden lack of electricity supply (Martinovský 2013). The possibility of a blackout in an energy grid is closely connected with the set-up of a network. We can describe blackouts from a technical and a general perspective. According to (Silvast a Kaplinsky 2007) a technological and general blackout is a moment when there is an imbalance between the production and consumption of electricity which breaches the security supply and, as a consequence, power is not delivered. In today's world, blackouts are the main security threat.

One of the most severe risks is an emergency situation where households would be suddenly without electricity. This case is called power blackout. As already indicated, in an event of power outage, electricity transmission is interrupted. A blackout is the result of failures and weaknesses, particularly in transmission and distribution networks. The entire power system is a dynamic system that requires constant balancing of production and consumption. The entire classical transit network is based on the principle that in every moment the amount of electricity produced must be about the same as the amount of power consumed. The installation of renewable sources of energy and thus the increased needs of balancing the grid could cause blackouts. Future balancing issues can be depicted by the illustration of an evolving *"Duck Curve"* where the amount of PV electricity fed into the grid system increases each year.

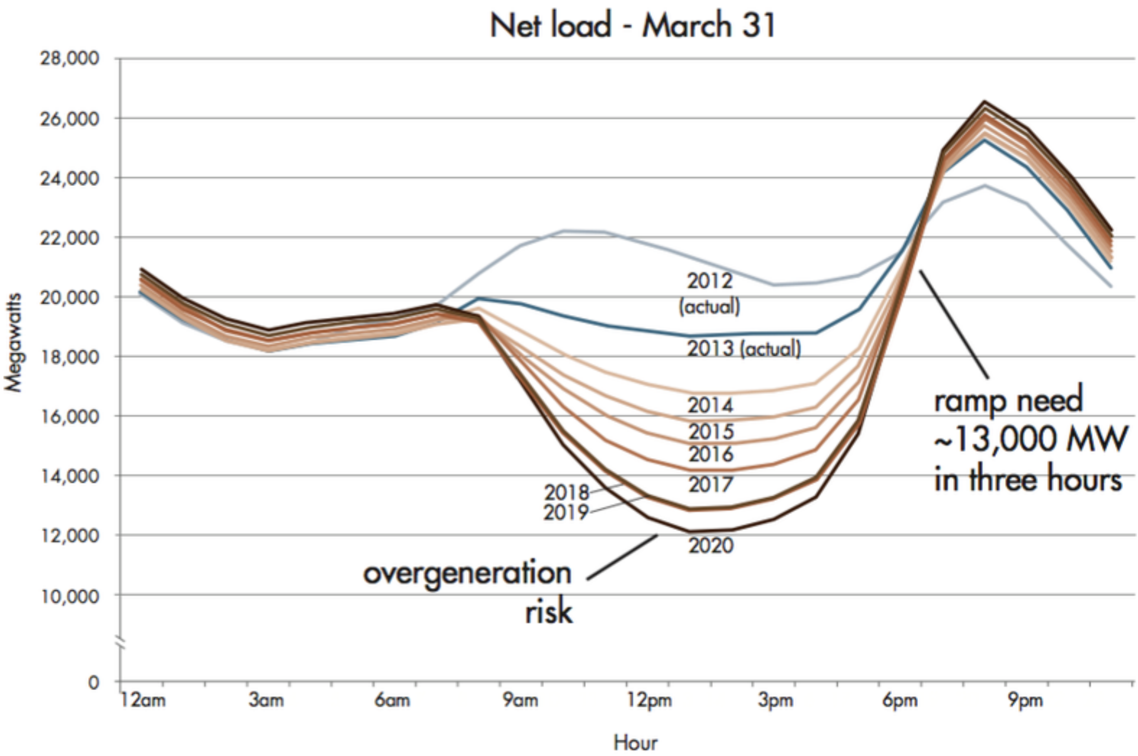

Figure 11: Net Load total demand for electricity in California during spring; Source: CAISCO (Corporation 2016)

In this sense, microgrids bring dramatic change. Due to the decentralization of the whole network and the spatial distribution of electricity generation, a theoretical blackout could be easily averted by substituting failing power sources with others. This principle of a distributed approach is described in the paragraph above. Another advantage of microgrids is the possibility to limit electricity production. For instance, microgrids household system could be limited by a maximal amount of kWh of electricity trading. That means the balancing problem will disappear and one of the main reason of blackout as well.

Finally, regarding cyber security, microgrids and decentralized processes of energy distribution could help to lower cyber and blackout threats. Cyber security threats must be understood not only for their technical dimension which can lead to the collapse of the power grid, but the topic should also be considered from the aspect of international relations. Cyber security threats could cause a breakdown of state infrastructure of one state caused by another state or particular interest group. The Internet, as one of the most powerful communication medium, represents an essential factor for energy infrastructure. With the continuous development of new technologies, centralized smart grid integration becomes increasingly problematic. A smart grid could cause new security risks, because communication needs for smart grids are very demanding. This process of centralized communication thus results in more security threats. Contrary to that, decentralized distributed networks would allow the implementation of more customized security measures for households. Decentralization and distribution, two features of microgrids, allow better preparation against cyber-attacks. Investment costs for security devices would be smaller too, and each homeowner will be more aware of how the energy system works. Microgrids are a safer version of electricity distribution since microgrids and smart meters don't share any vital information with a central point, and the whole system can be easily balanced.

2.7 Battery storage systems for households

Storage systems of electricity are one of the most challenging issues of our days. Electricity storage systems are particularly important for the storage of electricity production during a day and availability of energy for consumption at night. As Plumer (2016) remarks *"Utilities can deploy batteries or other forms of storage so that the electricity generated by solar panels in midday can be saved for use later, when it's more valued. You'd have to install a lot of storage as solar grows — especially to deal with seasonal swings in sunlight."* Costs of these storage solutions would then be very high on a centralized level. However, on the local level, this installation of small power storage units is possible. In the future will be possible to store electricity on a short-term scale. However in the relations of months it would not be economically feasible

There are different approaches to storage systems. Different storage modes differ in their material composition. Batteries also differ in frequency and how much storage capacity they can provide. For a grid solution, the best option for grid systems according to a report of the World Energy Council are batteries, super capacitors, and flywheels. From all current possibilities, the most promising were introduced by TESLA Motors (TESLA) in 2015. This battery system for households is called power wall and is based on ion-lithium principle. For instance, TESLA introduced two types of cells for houses and one 100 kWh battery storage system for factories. The first battery system for households is available with a capacity of 10 kWh and is designed to function as a backup in case of power outages. The second option has 7 kWh capacity which should be sufficient to cover normal daily operations. Both versions can be connected to a photovoltaic power station and also to the grid. Both can also act as a backup during a power failure. In homes with greater energy demands several batteries can be installed and used simultaneously (Motors 2015). The retail price for the Powerwall system is 3500 USD per 10 kWh and 3000 USD per 7 kWh unit. The price excluded inverter and installation costs. Other Companies like AES Corp. (AES) a General Electric Co. (GE), LG Chem Ltd. or SunEdison Inc. (SUNE) also invest in research and development of battery storage, but TESLA Motor is at the moment offering the most promising product for households. The other mentioned companies are focusing on factory electricity storage systems.

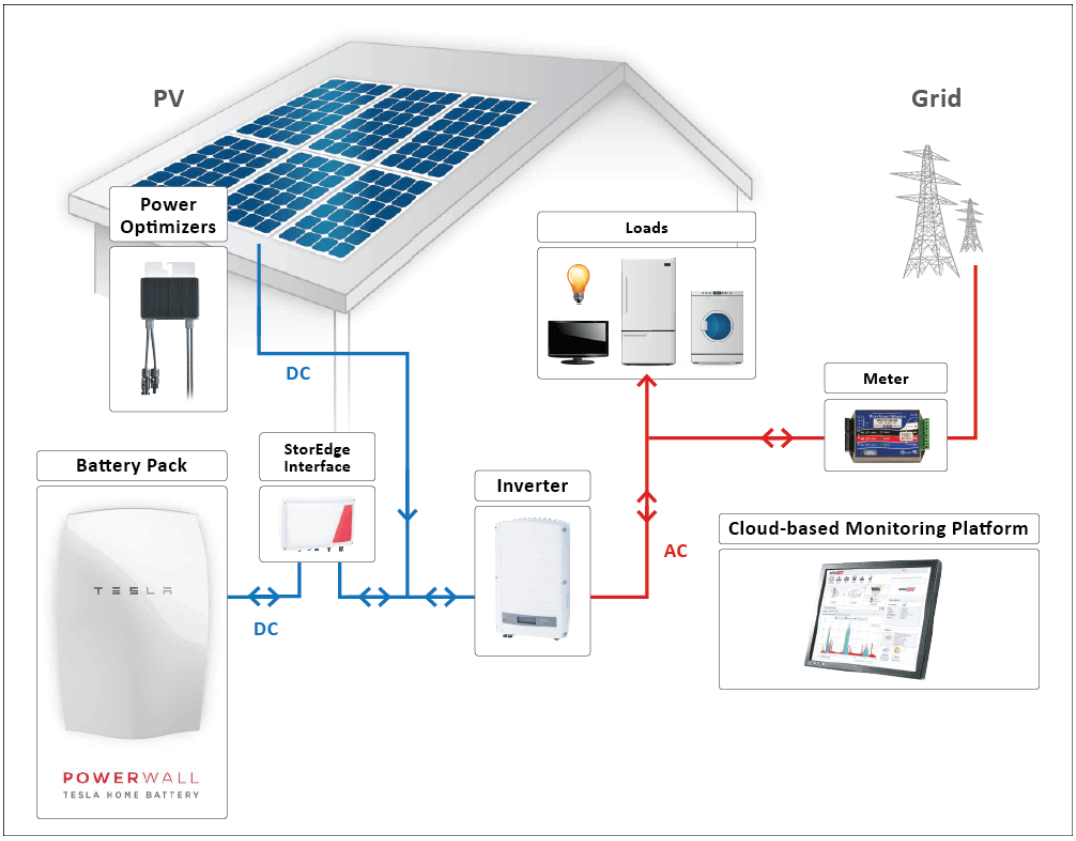

Figure 12: Future home overview; Source: Wind and Sun (Sun 2016)

2.8 How will this change work in practice?

In future households, the brain of the whole house will be the smart meter which will be able to evaluate off and on peak hours. This smart meter will be able to balance energy consumption throughout the day and will also be able to sell the surplus of household electricity production to another unit within the microgrids circuit. This trading of electricity will be a fundamental turning point for energy democratization. Not anymore will it be only a few countries in the world, which are securing and providing power for the development of humankind. Not anymore will it be necessary to start wars for natural resources – if this transition is managed and implemented well. This change in producing and distributing electricity could bring a real democratization for humanity.

Similarly, Rifkin in his book The Third Industrial Revolution notes that *"...to generate and distribute energy could be a power shift from the exclusive province of governments and lease-holding corporations toward individual actors and communities* *armed increasingly with solar panels and wind turbines and Smart Grids. The bedrock relationships between producer and consumer, the government and the governed, will forever be changed"* (Rifkin 2013).

Decentralized energy generation, even with increasing energy demand, could be an engine for energy democratization. This production of electricity will also lead to the most sustainable way for power generation. Rifkin argues: *"If the industrial era emphasized the values of rigid discipline and hard work, the top-down flow of authority, the importance of financial capital, the workings of the marketplace and private property relations, the collaborative era is more about creative play, peer-to-peer interactivity, social capital, participation in open commons and access to global networks"* (Zeller Jr. 2011).

3 Trading

In the recent past, electricity trading underwent a process of profound change. In the last couple of years, a market dominated by vertically integrated energy giants, sometimes even monopolizing the energy market in their respective countries, has morphed into a freer market with much more competitive pressure but also more insecurity. The monopoly model was characterized by the absence of competition, active state control, little diversity of products and centralized control operations. Monopoly companies owned all parts of the electricity network, namely power plants, distribution systems and also natural resources. These companies were closely connected to the state. Economic goals and considerations were thus not always in the first place and the regulation framework was often more adapted to the needs of the conglomerates rather than the other way around. The primary goal of these enterprises was to provide electricity for the domestic market and working opportunities for local citizens. However, market liberalization led to the foundation of several companies which tried to break up this rigid status quo with more flexibility, new products and lower prices.

A liberalized market provides to customers the option to choose between different electricity suppliers, thus diversifying the whole system. Therefore, today`s energy market consists of energy producers, final consumers, and traders. Consequentially, this liberalization also brought about new specialized trading companies which are selling and reselling energy between different traders.

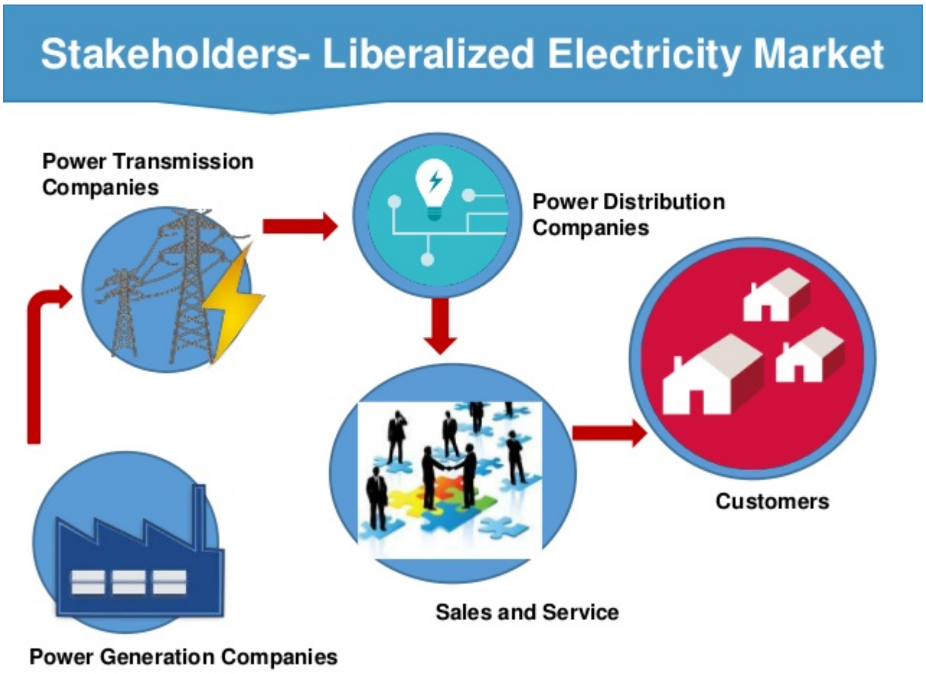

Figure 13: Electricity liberalized market structure; Source: Ahmad Fahmy (Fahmy 2016)

At present, the end price of electricity is composed of two main parts. The first part is the regulated and the second the unregulated price. The unregulated part is the price of physical electricity. The regulated part consists of a rate of transmission, distribution, system services and other costs, which differs from country to country. Other expenses factored into this regulated component are for example a fixed contribution to expand renewable energy plants or costs for the functioning of the market operator. Additionally, the actual price of distribution splits up into a fixed and a flexible tariff. The flexible tariff depends on consumption and the fixed tariff gives a price for reserved electricity.

Currently, electricity trading is separated from the distributional part. The share of the regulated and unregulated component depends on the specific consumption rates in each country and the respective voltage levels. The share of high voltage distribution is approximately 40 %. High voltage electricity is used to power factories. The low voltage distribution, used for households, makes up about 60 % of the total. The regulated part is a (political) given. Traders are forced to have an agreement with distributors and often are compelled to pay them in advance and this payment has to be covered by principals up to ten times of the annual consumption. This fact significantly limits the amount of capital investments (Quantum 2014). Thus, different ways to produce and consume electricity will be discussed in this chapter and presented in model market dimension. The energy markets in the Central European Area will be analyzed as an example. The regulatory framework for energy will not be considered in this chapter due to different national policies which to examine in detail would be far beyond the scope of this thesis.

Figure 14: Complexity of Energy trading; Source: EDP (Portugal 2009)

3.1 European Energy markets

The market of energy commodities can be characterized as consisting of two parts – organized and not organized exchange. Not organized exchange is also known as Over the Counter Market (OTC). This market is based on bilateral trade without a central physical location (Ivestopedia 2016). Individual traders conduct business with each other without a central clearing post. Hence, the specifications of the settlement contracts vary and depend entirely on negotiations. In general, the price for electricity is as a consequence often higher but in return clear and definitive.

Organized markets are regulated, and participants must comply with stock exchange rules and regulations. The price on the organized market is formed by supply and demand as reflected by the trading frameworks provided by clearing houses, stock exchanges or other institutionalized forms of exchange. Generally, organized markets offer trade with commodity futures, forwards, options and Contracts of Difference. Contracts of Difference mean hedging against price differences in different areas. In the region of Central Europe, several stock exchanges are dealing with energy trading.

The first example is Power Exchange Central Europe (PXE) (EUROPE 2008). This stock exchange was established in 2007. It was founded by Prague Energy Exchange Inc. under the supervision of the Prague Exchange Inc. (PSE). The largest stakeholder in PSE is Wiener Börse AG. This Stock Exchange is part of the Central and Eastern European (CEE) Exchange Group. Electricity traded there gets distributed to the Czech Republic, Slovakia, Hungary, Poland and Romania. Trading is only possible electronically through a Virtual Private Network (VPN) or a direct connection via web service or data interface.

The second example is European Energy Exchange (EEX), which was established in 2002 by combining the Frankfurt and Leipzig Energy Exchanges. The major stakeholder of this exchange is the French PowerNext. At this exchange place, also coal and emission allowances are traded. Geographically, the exchange covers Germany, France, Austria and Switzerland. Contracts at EEX are traded also at markets in Germany, which are called Phelix Futures and France, which are called French futures.

The third region for organized energy trading is Northern Europe, where this activity takes place at Nord Pool SPOT and National Association of Securities Dealers Automated Quotations (NASDAQ) OMX Commodities Europe (OTE 2016). Before this transformation, only the Nordic exchange Nord Pool existed, which was established in 1996 in Oslo. Nord Pool was the second oldest energy exchange in Europe and gradually grew to the current dimension. The Nord Pool exchange was split up in 2002 into two independent exchanges. One exchange trades spot products, the other one derivatives of the energy market. Furthermore, Nord Pool was also present at the birth of EEX and French PowerNext. The owners of the newly established Nord Pool SPOT are the owners of the transmission system operators of European Nordic countries. The second part of Nord Pool is under the supervision of the NASDAQ group. At this exchange, derivatives and emission allowances are traded. Other Exchanges, which are present in

Europe, but will not follow to be examined in depth in this paper, are for example Dutch *"Amsterdam Power Exchange"* (APX) or Spanish *"Operador del Mercado Ibérico de Energía – Polo Español, S.A."* (OMEL).

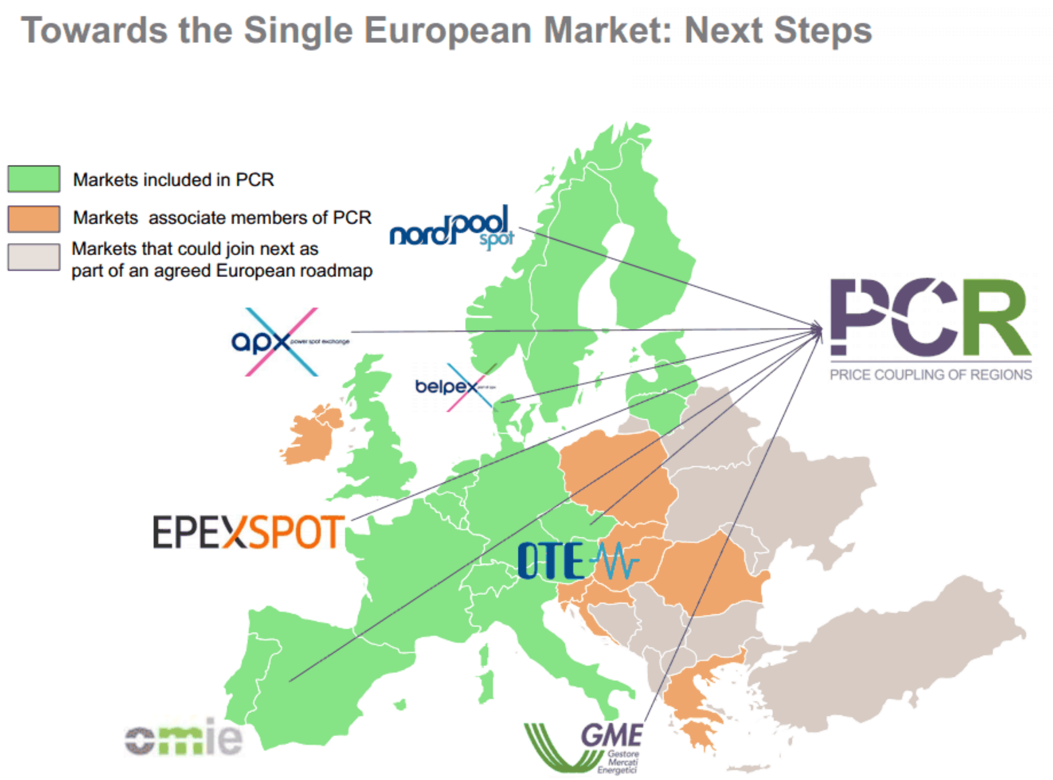

Figure 15: Electricity market integration; Source: Revolution (Clapaud 2015)

3.1.1 PXE Case study

To be able to understand the current energy trading system, this thesis will describe the PXE trading system. This subchapter will show how the energy price emerges, how the processes of trading work and how much it costs to be allowed to trade at PXE. This thesis will describe the PXE exchange because it is not so complex compared to the EEX, for instance. Still, it does provide an excellent overview of the trading methods that are used at other exchange markets. For an Initial Public Offering (IPO) at PEX four basic conditions must be fulfilled. It is necessary to own a license for trading electricity in the Czech Republic, Slovakia or Hungary, to have a contract with a clearing bank, to have a contract with a distributor network operator and to have a contract with PXE.

The process of trading has several steps. According to (OTE 2016) at PXE, trades are taking place anonymously in euros and are concluded with a central counterpart. All participants in trading have a contractual relationship with a clearing bank. Products are physically delivered or based on financial settlement. All trades in the stock exchange are guaranteed and regulated. Once the deal is closed, it cannot be retracted. Volumes can be either in MW/h or EUR (price per 1 MW/h). For trading at PXE, two systems exist. The first one is an order-driven system. In this system, the price is determined according to the current situation in the order book. The second system is called *quota driven* system. In the *quota driven* system, the price is determined according to actual quota that the market offers. The PXE trading system is a combination of both systems.

The necessary payments to conclude trading at the PXE are divided into four parts.

"• ***Fee For Participation***

Trading Participants have to pay a one-time fee amounting to 15,000 EUR to be allowed to trade at the PXE.

- ***Fee for Futures Trading of electricity***

Participants need to pay a general monthly fee of 1,225 EUR for the allowance to trade futures of electricity.

- ***Fees for Futures Trading of natural gas***

A monthly fee for the allowance to trade futures and on the spot market of natural gas.

- ***Other fees***

A registration fee to OTE is 0,005 EUR/ MWh for the transaction for both gas and electricity. " (OTE 2016)

The market operator is called OTE and it is owned by the Czech state. OTE is independent of trading participants. The exchange operator is responsible for evaluating, clearing, the settlement of imbalances, financial security, balancing the market by regulating energy doses and keeping track of emission trading.

3.2 Microgrids Trading

Basic principles for future Trading Models for microgrids are energy decentralization and peer-to-peer energy trading. Exchange platforms for this kind of trading are not established yet unlike the trading system with centralized electricity, which was described above. To be able to trade electricity with microgrids, a new product must be developed on current exchanges or alternatively, a new microgrids exchange would have to be established. In this chapter, possible methods and approaches to microgrids energy trading will be examined. Furthermore, it shall be considered what kind of business model could be applied with such a new trading architecture in place.

A fundamental benefit of centralized energy production is the stable power generation. However, given the political will to invest in RES and given the demographic changes society is facing, the implications of an over-reliance on these old-fashioned ways to generate energy should be carefully assessed. Nowadays, we can use the newest technologies and build new grid systems. However, without paying attention to the future economic impacts, the economic viability of many of these new models might be in question. Considering the decreasing feed-in tariffs in many countries, it is risky to invest only in one aspect of energy production, for example photovoltaic cells. The return on investment (ROI) poses the border lifetime of utility. Currently, the investment often will only amortize if an investor wants to use the electricity for personal consumption. This thesis will not consider a learning curve of technologies, which could significantly speed up investments into new renewable technologies for microgrids use.

3.2.1 Market models

In most business scenarios, three basic market models for microgrids trading can be described – Monopoly, Liberalized and Prosumer Model. In the monopoly model, the infrastructure and trading platform is owned by one stakeholder, who provides the electricity to the consumer. As a consequence of the monopoly structure, the drive for competitiveness will not be so high. The next model is the liberalized business model, which consists of several stakeholders. These are mainly consumers, transfer grid operator and supplier. The stakeholders are ideally independent from each other. Consequentially, it is necessary to examine which drawbacks microgrids trading could possibly have. One of the major drawbacks of energy trading in microgrids is size. *"Due to their relatively small size, microgrids cannot participate directly in the wholesale or retail market. Thus, they can enter as a part of a portfolio of a retail supplier or an energy service company (ESCO)"* (Hatziargyriou 2014).

. However, such remarks tend to overlook the fact that households themselves are behaving like companies who will be able to sell their surplus of produced electricity. Therefore, even though microgrids are small-sized, in a prosumer market model, households could be actively trading. Thus, the prosumer business model seems to be the best solution for microgrids.

3.2.2 Fixed versus Time of Use Tariffs

This part will evaluate the possibility of selling electricity on an automatic basis. For instance, during peak hours in the morning and evening, the pricing could be different from during the day or the night. Another function could be setting up maximal and minimal limit of amount and price of electricity.

"Electricity pricing can be fixed, that is, a microgrid is subject to a fixed selling price and a fixed buying price (under a uniform pricing scheme both prices coincide) for participation in the energy market or varying with time – time of use (ToU) prices – that is, a microgrids obtains hourly (or time-of-day block) prices for both selling and buying electricity." (Hatziargyriou 2014).

In a case of ToU, the final price is lower compared to the fixed tariff. This difference is due to the possibility to adjust flexibly according to the price of a day. Moreover, microgrids which can sell surpluses of electricity and are not island-based or only connected to the main grid system, could offer this power for sale and thus will reduce electricity prices for the whole community.

Table 1: Microgrid pricing schemes; Source: (Hatziargyriou 2014).

Case	Local Consumption	Locational Value	Tariffs wrt. Time
Reference	No	No	Fixed
Island	Yes	No	Fixed
Hybrid	Yes	No	ToU
Exchange	Yes	Yes	ToU

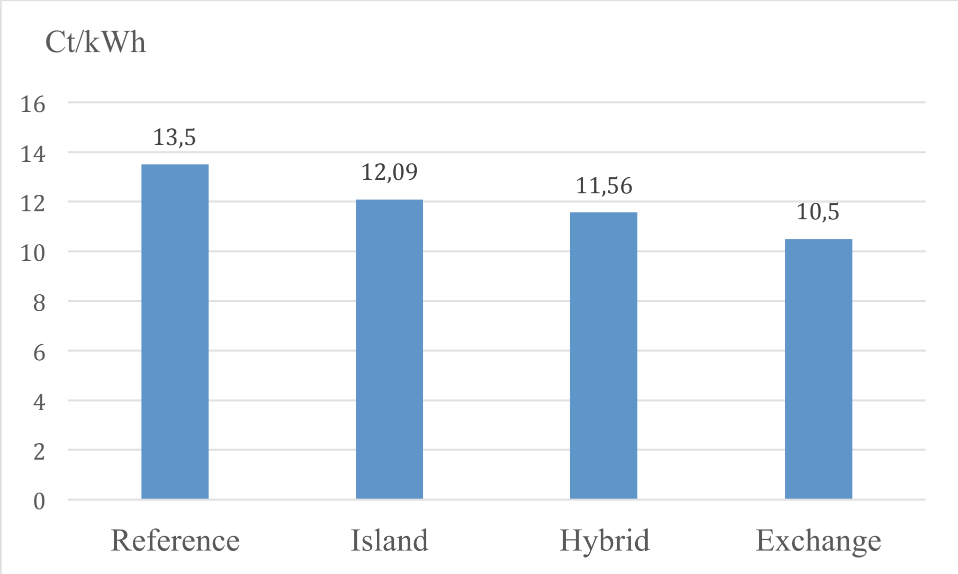

Figure 16: Per kWh electricity costs under different pricing strategies; Source: (Hatziargyriou 2014).

3.2.3 Microgrids prosumer trading model

The primary rationale and purpose of the prosumer model is to minimize the use of an existing grid system and replace it instead with a decentralized system. The prosumer market model comes from a need to decrease prices of electricity and increase efficiency of energy generation. The major source of profit is trading between microgrids stakeholders on the local level. This paper will, therefore, give a general overview of how microgrids could operate with the prosumer consortium model. Future research should thus focus on the examination of other market models which could fit other environments.

Prosumer means that producer and consumers of electricity are one entity. In a prosumer model, microgrids are owned by a consortium of individuals who run the whole process of energy generation and trading. This could seem to be a very used way to tackle market difficulties, but at a larger scale, prosumer models could bring difficulties. Yael Parag and Benjamin K. Sovacool describe these problems in their paper. *"As the number of prosumers increases, the electric utility sector of today is likely to undergo significant changes over the coming decades, offering possibilities for a greening of the system, but also bringing many unknowns and risks that need to be identified and managed"* (Yael 2016). However, the prosumer market model is the best alternative to other market models for setting up microgrids. Other models to consider are for instance monopoly models or liberalized trading models. The difference between these models is the trading and ownership structure. In the monopoly and liberalized market models, the stakeholder structure is more complex, which could cause some difficulties.

Another variable which should be considered is the grid connection. To be able to provide reliable energy for households, we must take into account whether the microgrids will be connected to the grid system or not. The off-grid solution operates as an isolated unit. *"Successful stand-alone systems generally take advantage of a combination of techniques and technologies to generate reliable power, reduce costs, and minimize inconvenience. Some of these strategies include using fossil fuel or renewable hybrid systems and lessen the amount of electricity required to meet your needs"* (Energy.gov 2016). Contrary to that, an on-grid solution has a grid backup system. *"Households are connected to the utility grid, so they can send out to the grid any surplus electricity generated by the RE system, and use utility electricity when needed"* (Woofenden 2009). When considering these two options, most the consumers will decide according to the price. For some, especially in remote locations, the off-grid solution would be the best choice. To be able to extend connection to the remote areas would be too expensive. On the other side, if a connection to a grid system is already available for a household, this grid system connection could be a safe solution to ensure energy supply. The best possible solution, therefore, would be a combination of these options. Hence, this paper suggests, to connect several units of microgrids with each other in order to create a system capable of providing backup by trading energy and in addition have a main electricity breaker as the last option. This would be the best solution balancing energy in a microgrids system.

3.2.4 Energy Trading Participants in Microgrids

The key stakeholders of Microgrids energy trading are producers and consumers. All other stakeholders play a significant role in electricity distribution, legal Microgrids operation and maintenance, but producers and consumers are the key participants. This simplification in the energy generation structure is one major reason for the possibility of rapid installation and maintenance of these systems. On the other hand, it is important to be aware of the complexity of Microgrids models. In this system, the head of energy distribution doesn't have to be a Chief Executive Officer (CEO) of a multi-billion euro company, but merely is the household owner. In the following scheme are the key players for setting up microgrids.

- Consumer – Because the focus of this thesis is on the household energy production, a customer will be considered as a home or household. However, the house could also stand for any small to mid-sized company. The consumer is the key player. Household consumers own the Microgrids.

- A producer is responsible for running the Microgrids and, as the example above elaborated, the household could be a small to mid-sized company.

- The legal regulator´s role is to provide legal supervising. The main tasks are to oversee the fulfillment of legal and environmental implementation rules.

- Technology companies provide technical equipment, installation, and conduct maintenance.

The roles of the principal actors are drawn in the following mind map scheme.

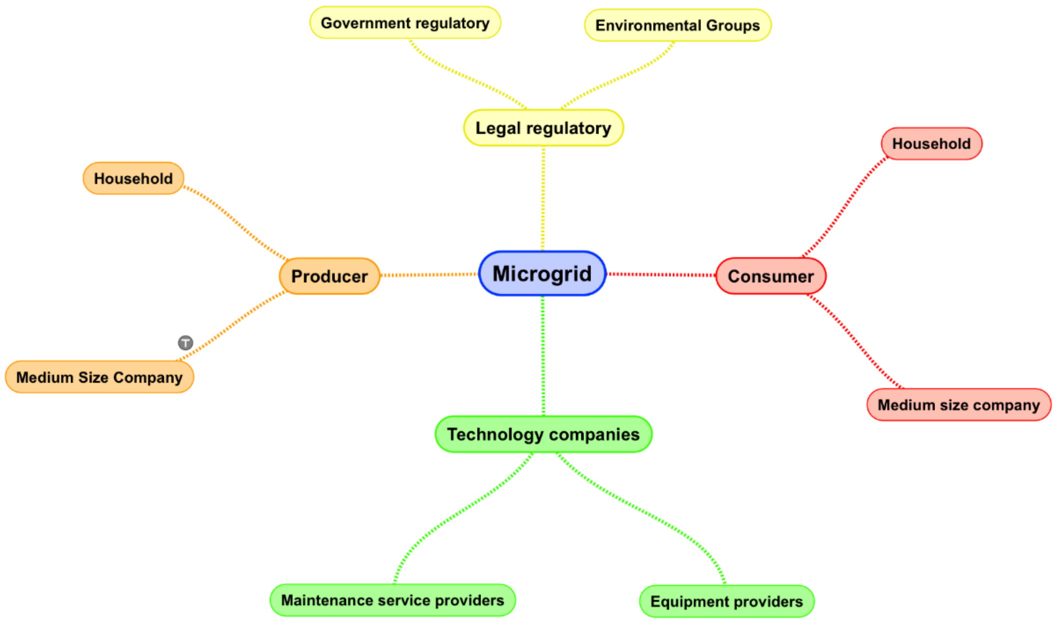

Figure 17: Microgrids trading participants

According to Nikos Hatziargyriou: *"Due to relatively small sizes, Microgrids cannot participate directly in the wholesale or retail market. Thus, they can possibly enter as part of a portfolio of a retail supplier or an energy service company (ESCO)"* (Hatziargyriou 2014).

Most recent attention has focused on the possibility of energy market trading systems. Energy Trading is the critical aspect for the future when considering the expanding number of Microgrids. Many companies think that the number of Microgrids will dramatically rise in the upcoming decades. For example, Siemens is focusing on this business model. However, to be able to operate Microgrids, they must make economic sense. Setting up rules and regulations for functioning Microgrids is thus necessary (Key 2015).

3.3 Business Model

This thesis focuses not only on microgrids energy trading companies, but also on the application of this trading and thus the most suitable business model. This model would provide a scheme of how to bring added value to clients, especially by providing a platform for trading and managing the complex function of a trading system. Thus, not only the business model will be examined in this paper but also how two essential functions of a successful Microgrids systems can be best organized – the trading system and a service platform.

Service platforms describe the role of individual agents as follows the energy supplier is also the end consumer and owner of microgrids. The energy trading company provides a platform for energy trading and is responsible for its maintenance. The client is a consumer of electric energy which is bought from an energy supplier through an energy trading company. The main aim is to provide clients with different tariffs and accordingly better electricity prices.

Microgrids trading systems would supply households with reliable and environmentally friendly energy. The service provider would offer new tariffs, which would more accurately reflect the daily load provided by the power source and the demand for the production of power. The provider would offer three different rates. The first tariff would cover peak time marked by high electricity demand, thus prices for kWh would be higher. In periods of lowest daily consumption, electricity prices would be cheapest. The third option would be a moderate price during the day. These prices would change in a real time depending on the electricity demand. However from a long-term perspective, the highest demand would be in the evening (see chapter Duck curve in this thesis). This would ensure smoother consumption of electricity during the day and would decrease prices for the time when electricity is most expensive. For example, clients would choose for the tariff they want to use mainly for electric car charging. The energy trading company could plan better network operations and improve in electricity balancing. However, selecting a specific plan ahead of time does not mean a client is obliged to use only the chosen tariff, as is described in the following cases.

1) A client returns home in the afternoon. The client wants to charge an electric car for the next day. According to the pre-selected tariff plan and according to the time of the day, charging the battery could be postponed for a later time or the client could choose to charge the e-car immediately. At the same time, the smart meter transmits information on the current price per kWh to an application pro-

vided by the energy trader. According to gathered data from the customer's behavior, the electricity tariff could change every month automatically or the client can switch tariff himself at will with his application.

2) A client needs to charge an electricity vehicle on the road away from home at a public charging station. For this case, each client is equipped with an individual chip which is the bearer of a unique identifier for each client. This chip is used for login and the client can thus use charging station immediately. The customer will be charged according to defined and announced electricity price shown on a display of the charging station. This process can be compared to a petrol station.

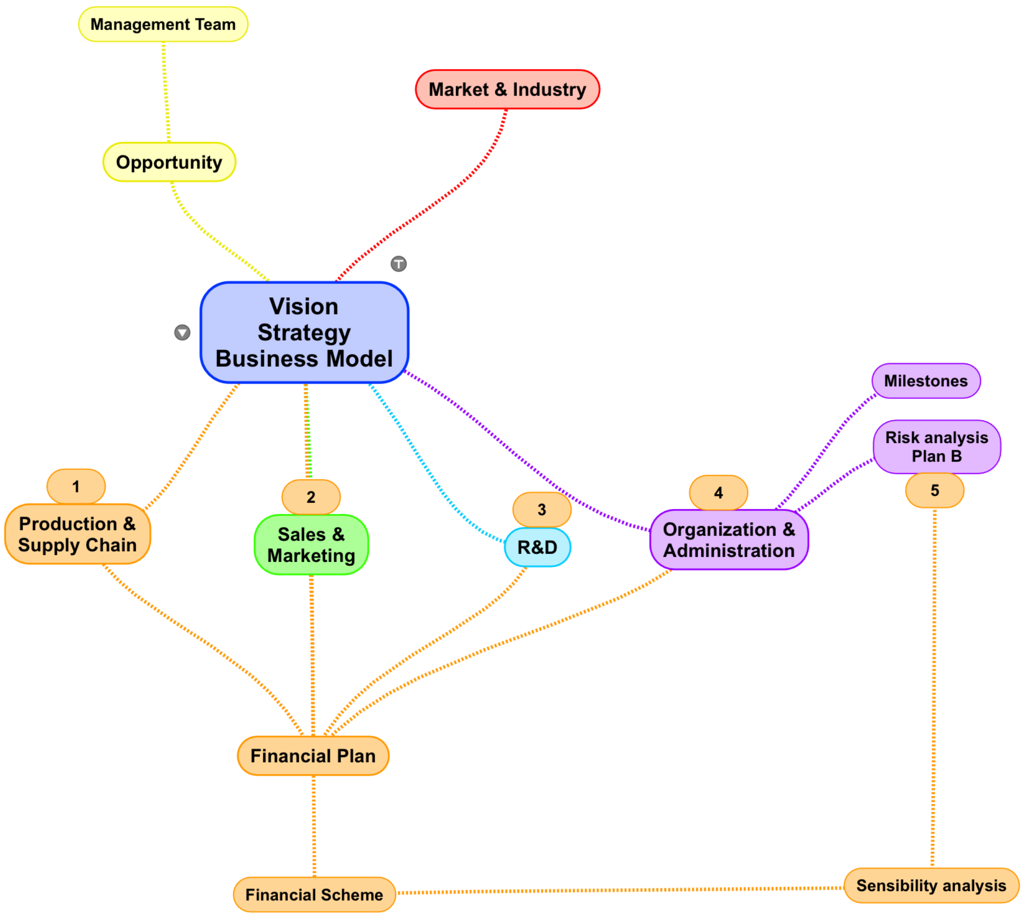

Figure 18: Typical Business Model Structure

3.3.1 Business Model Canvas

This thesis will use the business model Canvas. The Canvas business model is accepted as a base model for designing business plans. The author of this model is Alexander Osterwalder (Martin 2008). The Canvas Business Model has the form of a visual diagram (Canvas), which is divided into nine parts. These parts describe the key elements of the business model.

The key elements of a Canvas business model are closely connected. These elements are Key Partners, Key activities, Value propositions, Key Resources, Customer Relationships, Customer Segments, Channels, Revenue Streams and Cost Structure. These factors indicate the added value which is created for the clients and the firm as well as potential costs and revenue.

1) The first element provides an overview on who are the Key partners and suppliers to operate the service. It is crucial to mention there the benefits for partners and service providers. Furthermore, the activities expected to be taken by these actors are listed and described.

2) The Key activities part describes the necessary operations for successfully carrying out the service.

3) Value propositions tell us how to create value-added service to clients and solve their problems.

4) Customer relationships describe the progress of the relationship between the service providers and their clients. It is an assessment of how the provider deals with clients while providing the service.

5) Customer segments features the type of service which are intended to be delivered.

6) Key resources names relevant provided resources needed for successful operation of a service.

6) Cost structure informs about the most important key activities and how costly they are.

7) Revenue streams describe what clients are willing to pay for the offered value-added services. It describes which profits will flow to the provider for offering services.

9) Channels show the communication ways to reach clients. The crucial question is which one is best suited.

This chart shows a detailed description of a Canvas business model

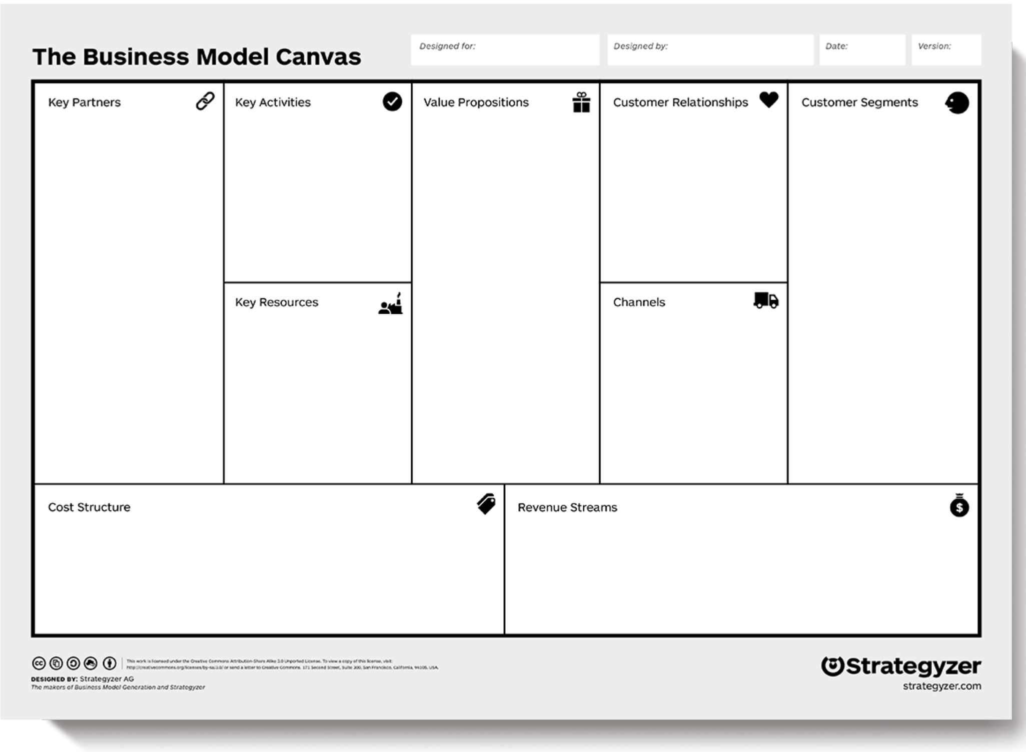

Figure 19: The Business Model Canvas; Source: Strategyzer (Strategyzer 2016)

3.3.2 Business Model Canvas for microgrids trading

This thesis understands trading in microgrids as households trading with the surplus of electricity. The principle of this trading is described in the trading section of this thesis. The following subchapter will explain how the trading system could work within the Canvas business model. This subchapter will also describe nine main elements for a successful microgrids trading process from a mid- and long-term perspective.

The first element is that key partners take part in the cooperation between energy suppliers, energy consumers, and trading clearing houses. An important source of information for all three partners is the electricity tariffs. All of them also provide data for the future use. Because of adequate and accurate information from the suppliers and consumers, services can be improved and the final product can be the more affordable but yet more environmentally friendly by optimizing production, consumption patterns and trading. Energy clearing houses offer materials and databases with possible fares to future investors. These databases are publicly available. For the facilitator, it is a way to acquire new clients. For instance, the suppliers collect data from smart meters and provide this information to clearing houses and consumers. This ensures transparency during the process of energy trading and builds trust between all key business partners.

The second element is key activities. As a provider of trading services, a trading company also offers applications to compare different tariffs and thus integrates consumers into the trading database which in turn is used to maintain the energy trading system. This ensures that the end client will not be bothered about anything during the trading process but will be able to check at any time the tariffs and how the trading with his or her surplus of energy is going.

The third point is a value proposition. What is the added value for clients? What problem does this trading system solve? It allows customers to find a cost-effective solution for their electricity demand. Microgrids trading systems also allow client to profit from energy trading, participate in environmentally friendly power generation and negotiate a better electricity tariff from a grid system. Clients have an accurate overview of the generation and use of electricity because they are the electricity producers. In connection with the Internet of Things, a design application allows to control and balance the electricity consumption in real time. On the other hand, a client could offer a better tariff to another household which could be interested in cheaper electricity than the one provided from the main grid system. Based on the collected information from smart meters, accurate tariffs can be assembled and offered to clients, possibly also with a focus on specific groups of people and times during a day. Energy and know-how suppliers offer registration charges for the legal trading framework and the brokerage contract with clients. Energy suppliers can integrate their fares to their website and showcase the comparison of the other tariffs and how many households could earn and save by joining microgrids trading scheme.

The fourth part is dedicated to customer relations. The most important of all is the partnership between the customers. Clients of this trading process (households, small businesses) are not tightly bound to use this service. It is up to them to use it or not. It might be that supplier will provide the better price on the market, than they can switch, but are not obliged to sign any long-term contract. This will lead to a win-win situation for all partners involved in the energy trading.

The fifth element of a Canvas business model is the Customer segment in the microgrids trading. This segment is intended for households and small businesses. The service is offered to large companies and industrial enterprises who could invest into microgrids capacity building and maintenance. However, for large companies and grid systems, the price of electricity is provided in another way. This thesis is solely focusing on trading between households.

The next part deals with key resources. An important source for delivering high-quality results is a professional tariffs database and real-time application. This will help with service implementation and further work with energy clients' profiles.

One of the most important principles is cost. In the trading business model, the highest costs from the point of view of the trading company are the management of applications (including legal fees), the maintenance of tariff databases, the web portal and the whole architecture of the energy trading system. Thus, for the energy trader, the costs are mainly on the investment side. Secondly, it is necessary to consider the operational costs. The ultimate aim is to establish a company system guided by the automation principle. A company should afterwards work with minimal maintenance costs.

The eighth element is revenue. Registering for the services will be free for the end customers. The trading company will receive a fee for the amount of electricity traded between microgrids. The trading company will also be able to trade a potential surplus of energy with the main grid system on the energy stock exchanges. This method of trading has to be as transparent as possible to be able to build trust between a trading company and its end customers.

The ninth point is communication channels. Clients learn about energy trading in microgrids and investing into microgrids system from the Internet, television, social media and print products. Advertising is targeted to different groups in different media. When combined with viral marketing, this could also attract a younger audience, who is most prone to invest in new housing and thus the perfect target group for informing about such microgrids systems. New providers and companies offering microgrid solutions can for instance use communication channels to demonstrate people how they could cut their electricity bill massively in the medium to long term. Such an assessment would be based on the energy profile of clients from their classic electricity supplier and thus could be a potent and convincing argument.

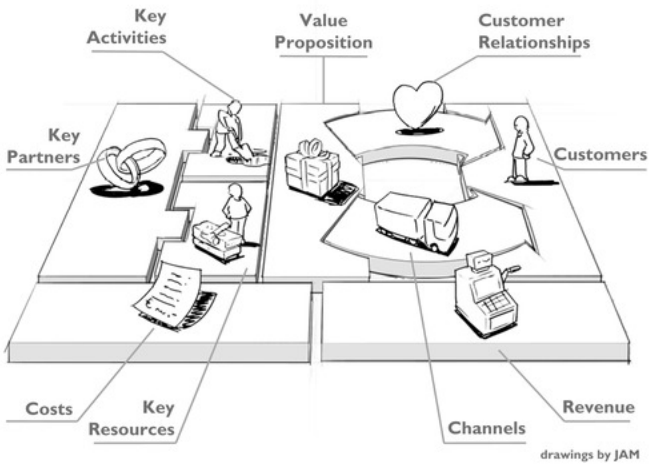

Figure 20: The Business Model Canvas explanation; Source: Tumblr Inc. (TUMBlr 2016)

3.4 Trading Closure

Energy investments were always considered as very secure, long-term and lucrative. The need for energy has always been perceived as one of the clear and basic needs. However, with the increasing number of stakeholders, the margin decreases. The new energy-efficient renewable installations gradually increase, and that brings new investment opportunities.

Each variant of investment has its pros and cons. Considering carefully certain and uncertain circumstance is therefore necessary. The options described in this chapter cannot be generalized, but the whole portfolio for investment should be diversified if possible. This part of the thesis is claiming that current energy trading works in principle and that it is necessary to keep it working in the future. However, this chapter also argues, that an alternative trading system based on decentralized energy trading should be established alongside the existing one. Diversification of energy production and distribution into a centralized and a decentralized system could help to balance the whole power structure without burdening the state too much with politically contentious and expensive investments in infrastructure. While drafting a business model or conceptualizing a new trading structure for microgrids, it is crucial to consider the initial conditions for potential investors.

The high importance of a trading platform for microgrids remains intact. This platform could be of high interest for many different stakeholders. However, the whole structure of microgrids trading should stay very simple and transparent without any additional fees, since the aim is to motivate households to invest into their future energy solutions. Thus, the Canvas business plan and a prosumer market model are the best and most convenient solutions for microgrids. This business plan and market model is described in this trading chapter and could be used as a role model for the energy transition on a decentralized level.

One of the key challenges of any microgrids operation system is to develop a functioning market model. Different business models exist in the energy market. The main difference between market models is their different ownership and stakeholder structures. Throughout this chapter, the term 'market model' is used to refer to the prosumer model. This part of the paper is focusing on the trading system as an essential element for a successful operation of microgrids. Therefore, in this paper, the legal, regulatory framework is not discussed. The complexity of the regulatory framework is left for further research. To be able to understand the whole approach of energy trading, this chapter described the key stakeholders, the hardware, and the necessary trading processes. By undertaking a qualified analysis of existing trading models, the most efficient approach for microgrids should be drafted.

The decision whether to invest or not depends not only on one factor but relies on many variables. Investment is becoming an individual and more decentralized decision. The basic question is which funds are available and how long the investment horizon is. Additionally, knowledge about new technologies and contacts to industry companies and traders also play the most significant role.

3.5 Case Study Czech Republic and photovoltaic production for households

In the Czech Republic all sources of renewable electricity production are supported. The Energy Regulatory Office (ERU) regulates the method of support. Currently it is possible to ask for subsidies and special green bonuses for photovoltaic (PV) panels. In the Czech Republic, the sun shines on average around 1460 h/year with the range between 1300 and 1800 hours/a. This sunshine time depends on the location where the PV panels are installed. The sunniest days are in the area of the southeast of the Czech Republic around the city Znojmo.

For the purpose of this thesis, we will estimate the annual sums of global radiation for the whole Czech Republic at around 1081 kWh/m2/a. This sun radiation means that one square meter of PV panel of monocrystalline cells delivers an average of 110-122 W. Furthermore, in case of PV efficiency 15 to 20% results in average 160 to 216 kWh/m^2/a. Consequentially, one can generate up to 122 kWh of electricity during an entire year when installing such a panel on the roof (Perlin 2005).

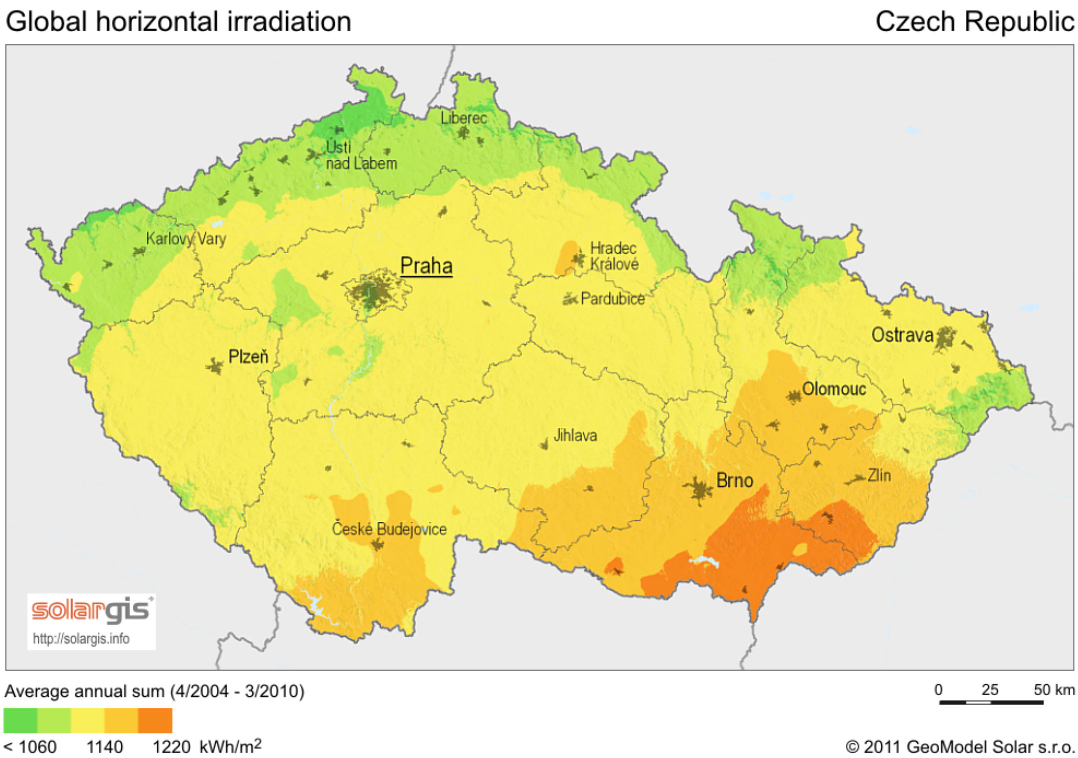

Figure 21: Average annual sun radiation in the Czech Republic; Source: Wiki (Wikipedia 2015)

3.5.1 Network

A network connection for a household can be divided into three parts:

- An existing centralized supply point with an existing connection which meets the parameters of the connected PV power
- A new decentralized connection according to the performance of the PV panels. More power always needs higher voltage. For example, bigger solar energy plants need transformer stations of 22/ 04 kV.
- A new decentralized distributed network. The households with such a network will not need to invest into high voltage transformer.

Given the significant difference in energy production during a year, it is commendable to combine all three principles.

3.5.2 Market model

For the supply of RES, purchase prices, fixed prices and green bonuses can be used as extra incentives added to the market price of electricity. In the case of selling the surplus production of microgrids, the producer chooses if the trader or the final consumer will get the bonus. The green bonus is based on the signed submitted statement (lidi 2005).

In the prosumer market model for household microgrids, the situation could look as follows. The household which invests in microgrids is using its own produced electricity and selling the surplus to neighbors. At the same time, this household is connected to the main grid. This combination allows using green bonuses for the trading of the customer. For example, traders will buy 1,000 kWh of produced electricity for 29.6 EUR/kWh. The positive side is that in the current situation without any preset feed-in tariff from ERU, this possibility is actually the more beneficial one for how to deal with electricity surpluses. The downside is that to be able to use these green bonuses, producer must sign a contract with a trader or consumer six months in advance. This could cause the risk of traders or customers defaulting on what they owe. However, in the case of selling electricity to another household, this risk of financial default is limited due to personal familiarity with a client. This version of selling electricity up to 0.5 MWh/year is the most economical for households. The main advantage of the green bonus is the possibility of achieving a higher yield than the grid purchase price would.

To comply fully with the Czech legislation, it is necessary that microgrids household have the official license from ERU to sell and buy electricity. Without this license, it is not legal to carry out a prosumer market model. Another option would be to trade electricity via the trader who has a permit and will integrate microgrids into a virtual power plant. This solution is more complex but less difficult to set up. Some companies like German company E2M are already using this kind of business model. More about this possibility will be written in the fourth chapter.

3.5.3 Risks

Risks of the microgrids solution are:

- Correct site selection. This depends on the days of the sunshine, which we examined above.
- Ownership of the property. The most suitable model is that the owner of the microgrids is also owner of the property.

- Investment costs. It is necessary to consider interest rates and other conditions of the loan contract for constructing the microgrids. The costs of purchasing different devices should also be taken into account. On average, it is calculated that 1kWh ranges between 2 960 to 4 811 EUR. The most important aspects are the type of PV panel used.

- Operation Costs. Operational cost includes inspection fees, security, insurance fees etc. It is also necessary to factor in maintenance costs. However, the biggest expense nowadays is the cost of insurance. Approximately 7 401 EUR/ annually.

To sum up, in the example of the household in the Czech Republic we can see that installing microgrids is possible and can also be made economically viable. However, it is necessary to take into account several variables. Because microgrids installation are not yet widely used by household owners, more time will be needed for planning and preparation. Currently, it is also advisable and helpful to use green bonuses from the state. Without these bonuses, microgrids would not be financially viable. The best solution for selling electricity surpluses is the possibility to simulate a virtual power plant operator. This type of generation and distributing electricity is sustainable and thus suited for long-term solutions to solve future energy chaos well as provide a platform to integrate further renewable sources of energy one day.

4 Comparisons of Trading Companies

An Electricity Trader is an entity that buys electricity with the purpose of reselling it. Power producers are required to possess a license which is issued by the Energy Regulatory Office of every respective country for a limited lifetime of the utility. After getting this license, electricity producers have the right to connect to the electricity grid or connect directly to the distribution systems. Also, the suppliers of electricity are authorized to offer and provide support services (Chemišinec 2010). For example, electricity producers are allowed to maintain an electricity utility or to terminate electricity supply to its customers due to illegal consumption.

This traditional concept of energy trading companies is applied all around the world. These days, the installation of microgrids and decentralization of electricity supplies offers a new possibility of alternative trading solutions but still within the regulatory framework of each state. One of the most significant obligations according to regulatory laws in EU member states is the obligation to follow the rules of the transmission system or distribution system.

There are several possibilities regarding electricity energy trading in microgrids. One option is to directly produce and supply power to the grid or to become the only distributor. This prosumer model is described in the chapter on possible market models. Another option is based on the possibilities which arise directly from the physical laws of electrical networks. This method is based on trading with the aim of balancing the market. Electrical energy that is delivered to the system must be immediately consumed if it is not stored. Otherwise, there is a danger of network overloads and blackouts. However, how to ensure a steady state when electricity consumption is constantly changing (ČEPS 2015) during a year? It is necessary to distinguish between pure traders who operate exclusively on the wholesale market and electricity suppliers who are entering a retail market. Electricity providers are only buying and selling electric energy and thus do not own source of electricity production or a distribution network.

The installation of microgrids brought many different balancing and trading opportunities. In this chapter, two different approaches from Austria, Germany will be introduced, where renewables installation is blooming and one global company from the USA. *"A typical microgrid is composed of generators, loads and storage units which can be divided into three categories. The first category is buyers, i.e. (non-critical) elastic loads. The second category is sellers, i.e. (non-renewable) genre- actors. The last group is storages, which can act as either buyers or sellers, depending on the operation condition of the microgrid"* (Suli Zou 2014).

4.1 EnerNOC

In recent years, we have witnessed different approaches worldwide towards the new energy challenges. The company EnerNOC focuses on balancing short-term electricity demand in the market. EnerNOC was established in 2003 and believes that a fundamental economic potential lies in the sector of energy intelligence and distribution, where the opportunity to locally utilize engine generators combined with software implementations can bring high-efficiency gains.

The core of the company business lies in the use of classical energy production with a combination with the most modern demand response system. The demand response system at EnerNOC informs a business about possibility to reduce an energy use and thus decrease the price of electricity. This process helps to balance the whole grid system and prevent emergency situations. The entire business model is based on offering energy intelligence products for business and utilities.

According to (EnerNOC 2016), the businesses offer consists of:

"▪ *Budgets & Procurement*

▪ *Demand Management*

▪ *Demand Response*

▪ *Distributed Energy Resources*

▪ *Facility Analysis & Optimization*

▪ *Project Tracking*

- *Sustainability & Reporting*
- *Utility Bill Management"* (EnerNOC 2016)

"Our demand management tools highlight opportunities to save money for reducing energy use over peak periods, and quantify the savings at stake. Take full advantage of distributed energy resource options — whether it's solar, wind, storage, or green power purchasing — with strategic advice on which options best suit your business, and analytics that reveal how much you're actually saving" (EnerNOC 2016).

The second business aim, according to (EnerNOC 2016), lies in offers to utilities:

"
- *Customer Engagement*
- *Demand Response*
- *Energy Efficiency*
- *Operational Effectiveness*
- *Wholesale Procurement "* (EnerNOC 2016)

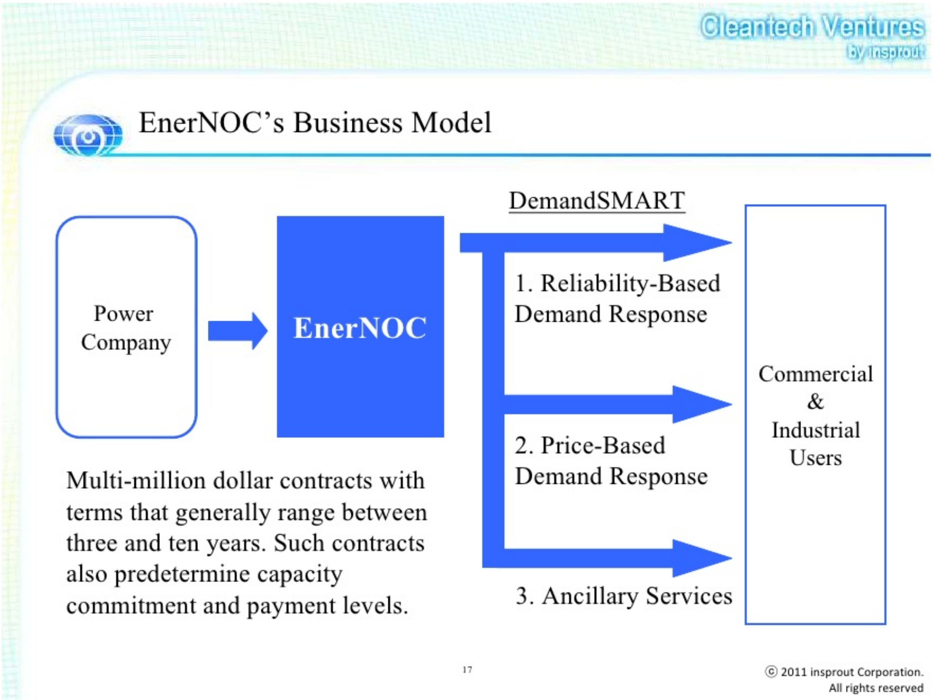

Figure 22: EnerNOC`s Business Model; Source: Cleantech Ventures (Ventures 2009)

Offers for utilities comprise tracking of expenses and optimization of energy usage. The whole process of energy intelligence could also be used partly in microgrids for households. However, the main aim of the business of EnerNOC is larger utilities and enterprises. EnerNOC is considered as a future leader of providing energy intelligence software and services.

4.2 E2M

The e2m (energy to market) company is a trading company that focuses on direct energy selling with decentralized energy production. E2M was founded in 2009 in Leipzig, Germany. Since then, e2m introduced a virtual power plant as a pool for distributed energy, balancing market tool and direct marketing technology (EEG). Currently, the company operates in Germany, Poland, Finland and Italy (E2M 2016).

The principle business model of e2m is binding together several electrical energy producers and establishing a virtual power plant (VPP). With the establishment of a virtual power plant, e2m could behave like a regular electricity producer. This official establishment will allow to follow the legal, regulatory framework and be certified as energy trader, even though it sells energy produced from decentralized sources and does not own energy producers directly. The primary focus of the energy trading conducted by e2m is trading electricity from biogas power plants.

"A virtual power plant (VPP) is a cluster of direct energy producers which are collectively operated by a central control entity. A VPP can replace a conventional power plant, while providing higher efficiency and more flexibility" (Hatziargyriou 2014).

The prime aims according to (E2M 2016) are:

"• Direct marketing
- *Energy Control*
- *Electricity trading*
- *Tailored production*
- *Supply and demand management*
- *Flexible trading*
- *Balancing management*
- *Schedule and portfolio management "* (E2M 2016)

The Energy Academy supports the innovative approach of e2m. This Institution is directly under the control of e2m GmbH and was established in 2016. The Energy Academy aims to provide a platform to share ideas about the future of the energy sector and also provide a place for workshops. The whole system of direct selling could be used in microgrids. With this know-how and infrastructure, the next business clients could be households who want to sell their energy surpluses.

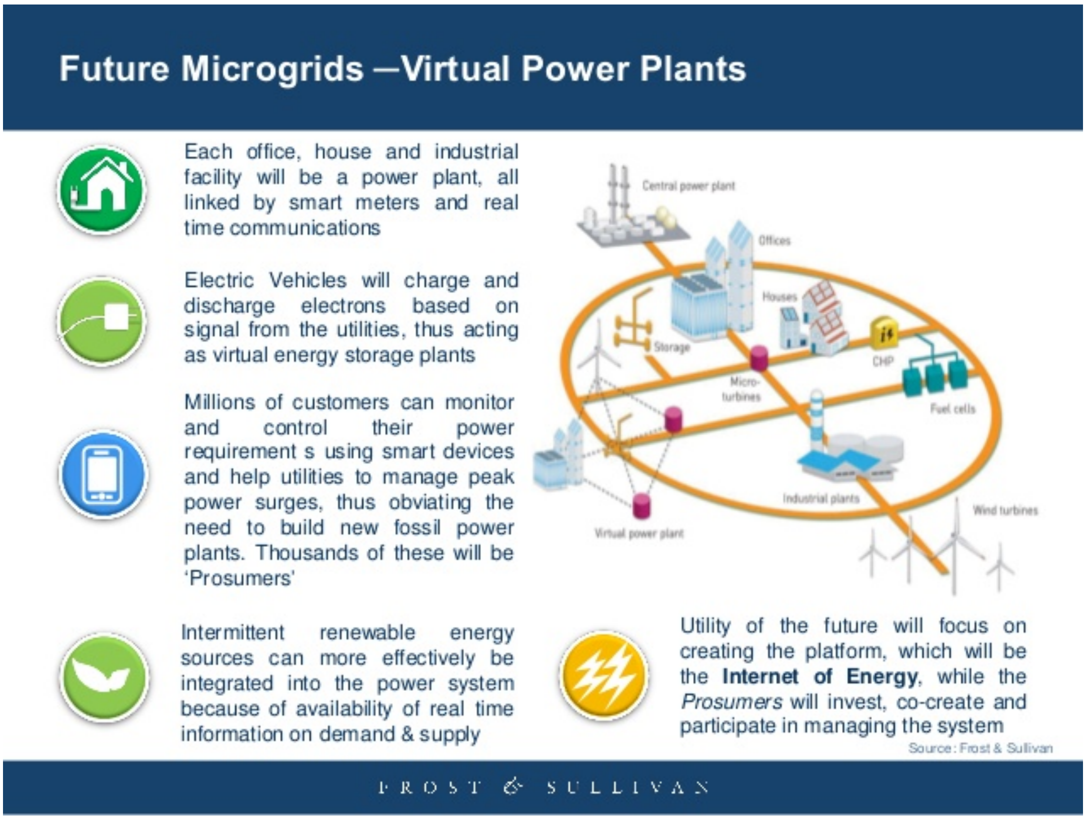

Figure 23: VPP scheme; Source: Frost and Sullivan (Sullivan 2014)

4.3 aWATTar

The third example of a new approach to energy trading is the Austrian company aWATTar. This company offers to directly sell renewable energy from exchanges. To extend the possibility of cost savings, aWATTar offers software to control energy expenditure, which is adjusted monthly and hourly. Electricity tariff adjustment work according to a similar principle to the one described in the chapter of smart metering. Together with a smart meter, this method helps to consume cheaper energy at the right times.

The business model of aWATTar is based on monthly or yearly fee payment, which will provide the customer the possibility of buying energy produced by RES for the same price like from an energy exchange. The market prices are calculated daily for specific hours. The company offers hourly offers of electricity depending on the part of the day. The smart meters are provided by the network provider and the data is transmitted hourly to aWATTar. However, aWATTar is not working mainly with microgrids systems but is instead focusing on optimizing prices produced from RES.

To sum up, new startup companies provide a range of applications for consumers and aspiring producers of electric energy. However, only an increase in the number of energy traders is not enough. A prerequisite for the decentralization of power generation is economic decentralization. Without this decentralization process, the small trading providers would end up being owned by a small number of companies and thus the competition pressure would be rather low. Economic, social and security consequences would then not be so different from the centralized structures which are existing now.

In this part of the thesis, three companies were presented which are representing three vital parts of successful functioning of microgrids and trading within microgrids. These three sections are energy balancing, direct electricity selling, and real-time trading transparency. These parameters and more intense competition are fundamental to make energy trading accessible and possible for households.

5 Conclusion and reflection

In this thesis, the economic, social and security implications of microgrids trading were examined. The topic was put into a context of decentralization theories. In the introduction it was shown that local ownership and the involvement of local communities is expected to benefit from the decentralization process of energy production which may be additionally powered by further development of renewable sources of energy generation.

It was pointed out that the democratization of power system is closely connected with the decentralization of energy networks. This transition could lead to info-energy democratization where people will not depend on the center of electricity and information distribution so much anymore. The municipality can control their own energy production. However, the state should provide power for the strategic industry infrastructure. This division of responsibilities could provide a more secure energy distribution and could prevent NIMBY movements from gaining strength.

These energy changes could bring positive and negative externalities which were described in the chapter of social and technological challenges. The aging population and increasing demand for electricity supply are closely connected to this topic. It was noted that one positive externality could be that decentralization will generate new jobs in areas with higher unemployment, for example in rural areas. The negative externality represents The Duck Curve. If a transition to decentralized distributed energy will not be satisfactory, it is possible to expect technological difficulties, which were described in the second chapter.

Among the most important security aspect of energy production from renewable sources are the possibility of blackouts and network distribution problems. In this sense, a diversification of energy production would be of profound benefit for the stability of the whole system.

In the part on practical trading, it was shown what the current situation at the energy exchange market looks like. The focus was on the Central European area with a case study from the Czech Republic. It was also described how microgrids trading systems could work from a business point of view and what kind of market tools are necessary. All of these descriptions were supported by schematic visualizations. After the practical trading part, modern companies and their approaches towards new energy trading possibilities were mentioned. In the fourth chapter, three of these companies following different model were described, all part of the transition towards a more balanced energy future.

At the beginning, several research questions where posed, mainly focusing on whether the decentralization of energy production from renewable sources will be the future of energy production. For answering these questions, comparative studies and qualitative information supported by practical examples were employed.

The first question was what will be the means of producing energy in the future. As described by examples in this thesis, the combination of decentralization and centralization of energy distribution would be the most secure way how to supply energy to households and strategic companies.

The second research question was dealing with the energy transition towards microgrids energy generation. How could microgrids electricity networks be profitable? In the current situation, it is possible and viable to invest in microgrids but without state incentives it would still be difficult to build these microgrids. This statement differs in its applicability from region to region, but this thesis focused on the Central European area and as the example of Czech Republic showed, state support is still very much needed. However, we can expect that the learning curve of technologies will make PV panels, smart meters, batteries and other devices much more efficient and affordable.

Thirdly, based on the current examples and business model structures, the most promising market model used for microgrids is the prosumer market model supported by a flexible tariff structure. This claim is supported by the widely acclaimed Canvas Business model.

Lastly, the question how energy demand will be covered from microgrids has several layers. It is necessary to understand that the whole energy trading and production transition is evolving. These changes could not be done dramatically. Therefore, the answer for this question is that in the current situation, it is necessary to keep microgrids connected to the main grid, which could provide backup in a case of lack of home-produced electricity. However, as it was shown in the examples, now it is already possible to cover a big portion of electricity demand with one's own microgrids energy production. This portion of decentralized energy production will most probably increase. Decentralization could lead to more trading opportunities with energy surpluses.

Future studies regarding microgrids trading could have a broad scope of interest. Future research could be dedicated to the modeling of an energy company which would be providing complex solutions for microgrids. Another field of research within microgrids trading would be a feasibility study of microgrids installation in rural and in urban areas.

To sum up, smart trading is the future of energy production. This encompasses trading with surpluses of electricity via virtual power plant and the usage of flexible tariffs to decrease the price of electricity. The installation of automated software, which will help to balance the whole energy network structure, is another milestone. These are only a few examples of the direction the energy sector will head towards in the future. As always in human history, learning is the key to progress. Nowadays, the electricity energy sector is going through this evolution. Different approaches might lead society via different pathways, but the common goal is the same. The aim is to a system of sustainable energy production, providing electricity to local communities and enabling their social, economic and technological development.

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List of Tables

List of Figures