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Digital transformation of the regulatory framework in the electricity market

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"Stay hungry. Stay foolish."

~ Steve Jobs quoted from the Whole Earth Catalog 1972

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List of abbreviations

ACER	Agency for the Cooperation of Energy Regulators
CB	Consortium blockchain
CCR	capacity calculation regions
CIA	confidentiality, integrity and availability
DERs	distributed energy resources
DR	demand response
DS	distribution system
DSO	distribution system operator
EC	European Commission
EEM	European electricity market
ENTSO-E	European Network Transmission System Operators for Electricity
ESP	energy sharing provider
EV	electric vehicle
GDPR	General Data Protection Regulation
ICT	information and communications technologies
IEM	internal energy market
LTC	local trading centre
LTM	local trading manager
MAS	multi agent system
MG	microgrid
P2P	peer-to-peer/prosumer-to-prosumer
PET	peer-to-peer energy trading
PETCON	P2P energy trading consortium blockchain
RE	renewable energy
RES	renewable energy resource
RoR	rate-of-return regulation
RR	Round Robin
SDG	sustainable development goals
SO	system operator
TS	transmission system
TSO	transmission system operator
UN	United Nations

Motivation

Throughout the last few decades, the issue of global warming due to depletion of natural resources has increasingly gained political importance. Owing to the advancement in information technology and digital transformation, electricity usage has rapidly increased and is still rising as shown in *Appendix 1*. On the flip side, this technological development also introduces great potential to positively impact the operation and management of utility networks. By employing new technologies such as smart grids to deploy renewable energy sources (RESs) and match supply with demand, energy loss along the distribution chain can be reduced significantly. Along with the paradigm shift towards a digital era comes the necessity to innovate existing networks and adjust its governing structure. Here, the task of policy makers and regulators is to provide all market participants with transparency and sufficient support to increase investments in improving the local infrastructure and engage citizens in local trading. However, the question arises as to how new technologies can be utilised to achieve the best result working towards reaching the goal set by the European Commission to reduce emission and become carbon-neutral (EC 2019).

Introduction

In recent years, the development of smart cities has gained popularity in the face of emerging global challenges. The core structure of the smart city concept is built on six pillars, some of which are in accordance with the sustainable development goals (SDG) defined by the United Nations (UN). These are (1) smart economies which focus on entrepreneurship to increase competitiveness, (2) smart people with the aim to promote social and human capital, (3) smart governance participating in diverse decision-making processes by enhancing transparency in public and political affairs, (4) smart mobility through the incorporation of information and communications technologies (ICT) in infrastructure to improve accessibility for citizens, (5) smart environment targeting sustainable resource management and environment protection, and lastly (6) smart living with the goal to increase the quality of life by raising the significance of health, education and safety objectives (Pieroni et al. 2018: 299-300). In other words, the essential purpose of a smart city is to boost inter-connectivity and employ technology-based infrastructure to enhance economic efficiency, and promote social, urban and cultural development. Thus, smart cities aim to provide an attractive and friendly environment for businesses.

Leaning on the philosophy driving the smart city movement, this thesis is centred around smart grids the target of which works in accordance with both the pillars of the smart city concept and the sustainable development goals of the United Nations (The Global Goal 2019). To be specific, smart grids integrate ICT and expand access to networks (4) which enhances competitiveness (1) and contributes to innovation in the industry and improves infrastructure (SDG 9). Using the high processing power to rapidly process information can help reduce information asymmetry on the consumer side and thus works towards reducing inequality (SDG 10). Subsequently, smart grids could induce responsible production and consumption (SDG 12) while providing affordable and green energy (SDG 7), which overlaps with the sustainable resource management and environment protection pillar (5) (Pieroni et al. 2018: 299-300, The Global Goal 2019).

This thesis sets out to provide a solid foundation of available regulatory instruments, the structure on the energy market and various technological tools to find answers to the following research questions, based on which recommendations for regulators will be discussed.

- How can the distributed generation of RE and the employment of energy storage systems reduce CO_2 emissions and electricity price while leading to a socially better outcome?
- Which regulatory mechanisms can be adopted to encourage competition and investment in innovation of technology?
- How can smart contracts add value to P2P electricity trade and what role will it play in the future energy market?

By comparing different regulatory mechanisms under consideration of evolving technologies such as smart grids, blockchain-based technology and smart contracts, this thesis aims to establish guidance to find regulatory measures that can foster positive change towards greener energy generation and distributed energy supply. Furthermore, this thesis endeavours to examine the effect of micro-grids in urban areas on efficiency and stability of the main grid. In addition, it pursues the goal to find out whether the incorporation of electric vehicles (EVs) and battery storage systems might improve the distribution and the energy flow to counter the fluctuating demand throughout the day. The goal is to provide law-makers with recommendations of how to use available technologies to improve the current power network with regards to security of operation and energy efficiency, as well as low prices for end-customers. While there are a great number of RESs out there, this thesis is primarily focusing on solar energy source due to the easy availability and more established application. However, on the larger scale, the outcome and discussion are applicable for various types of RESs.

This thesis is divided into six parts, with the first chapter laying the foundation of regulatory theories explaining why it is so important to regulate the power market. Chapter two offers a more in-depth insight of the electricity market, its actors and their roles on the current market. Chapter three accounts for the evolution of the electricity market towards a digitalised future, new business models and shifting responsibilities of market participants under the impact of technological disruptions. Chapter four introduces technologies applied in the smart grid, such as necessary ICT, blockchain based smart contracts which enhances operations efficiency and adapts to the redesigned energy market and its players. After discussing the key aspects and some regulatory tools and their impact on the energy market in chapter five, chapter six concludes and gives answers to the research questions and adds recommendations for regulators of how to best use emerging technologies to positively impact the economy and society.

1 Theory of economic regulation

Public utilities often display characteristics of a natural monopoly that is, when due to structural reasons, it is cost minimising to produce one or several goods in one firm instead of having them produced in several firms separately. Then, this unique position enables large companies to misuse their power and charge users immoderately high prices. Therefore, it is often advisable for governments to intervene and prevent such a misconduct from happening. The following chapter explores the reasons as to why regulation is essential for achieving market efficiency by explaining the network structure behind a natural monopoly and, thereafter, introducing different regulatory mechanisms, such as rate-of-return regulation (RoR), price cap regulation (RPI-X), yardsticks competition and benchmarking.

1.1 Natural monopoly

Firms in the public utility industry are likely to inhibit innovation, operate cost-inefficiently, which, therefore, inherently leads to market failure. Hence, it is paramount for governments to interfere and impose guidelines to steer the natural monopoly towards a more efficient production path.

1.1.1 Definition of a monopoly

The term ‘natural monopoly’ has undergone various changes over the course of history. Today, a natural monopoly is a firm exhibiting a sub-additive cost structure that allows it to produce a certain level of one or more products in the cheapest way possible. In other words, there is no other output combination produced by any other two or more competitors that reveals lower cost of production (Baumol 1977: 809). Other typical characteristics of a natural monopoly include the huge investment in equipment and infrastructure that is not only location-bound and highly specified, but conventionally extremely capital-intensive. This means that, once purchased or built, the investment made is irretrievable and cannot be easily liquidated, and thus characterised by *sunk costs*. In addition, its fixed costs of operation are also typically relatively high with rather low variable costs. In the single product case, the average costs will, therefore, oftentimes decrease, which is a phenomenon known as *economies of scale*. This phenomenon must exist for a certain output level, but not necessarily for the entire production line or the complete product portfolio of the naturally monopolistic firm.

Traditionally, the notion of natural monopoly was restricted to a firm producing just one single product or offer one single service. Yet, there are also firms in some industries that can produce two or more related commodities more cost-efficiently than multiple contenders separately. Here, the cost structure must reveal characteristics of subadditivity along the ray. Together, both, "the strictly declining ray average costs and that of transray convexity" are sufficient conditions for subadditivity of costs in the multi-product company (Baumol 1977: 810-812). A textbook example for this is the telecommunications industry, in which it is, maybe, most cost-efficient for one single company to provide both landline service and mobile connection due to the vast investment in the infrastructure. In this case, the cost-efficient production of two or more products also involves *economies of scope* (Baldwin 2012: 444-446).

In short, depending on the size of the market, it can be said that a natural monopoly can exist in that market, if its cost structure exhibits subadditivity, and for to a certain level of production, it can produce under economies of scale and economies of scope. However, as natural monopolies often are associated with a high level of investment and sunk costs, they require special attention regarding cost recovery. However, having the monopolistic market power and being protected from new market contestants, a monopolist rarely finds the motivation to improve service quality or reduce cost of production without additional, external pressure. Hence, the model of a contestable market might give ideas to scrutinise and find tools that incite productive and allocative efficiency.

1.1.2 Monopoly in a contestable market

Perfect competition and contestable market models are seemingly similar concepts, and due to this reason, they are often used interchangeably, by mistake, although both perfect competitive and contestable markets allow for free entry and products sold by competitors on the market are considered homogenous and thus perfect substitutes. Furthermore, both theories work based on the assumption that customer loyalty is negligibly low or non-existent and that information symmetry is given on the market. Moreover, in a perfect competitive market, it requires a sufficiently high number of market participants so that the decision made by one single firm does not affect the decision making of the others and is thus neglectable. While the perfect competitive market can be used as a reference to understand and explain how participants interact on a free market to form prices and create market equilibrium, the contestable market theory comes in handy to make sense of the behaviour of a natural monopolist under the mere threat of competition. One of the key characteristics of a contestable market constitutes the free entry to and costless exit from the market, meaning there are no entry barriers in form of sunk costs or information asymmetry; and all investments in equipment and operational plants can be liquidated without loss. Additionally, the theory of contestable market postulates that new entries have access to the same technologies as the incumbents. Under such market conditions, it is not possible for firms to charge exorbitantly high prices and gain supernormal profit due to the risk of 'hit-and-run' entries. That is, in a market where entry is free and exit free of charge, potential competitors could enter the market, undercut the price of the incumbents and leave before those can adjust accordingly. In this case, regulation is unnecessary as the mere threat of entry would force incumbent monopolistic firms to behave appropriately and set competitive prices (Baumol 1982: 3-5, Bailey & Baumol 1984: 112-118).

Nevertheless, there are some issues that might get in the way of regulators to maximise allocative and dynamic efficiency. While the former focuses on maximising economic welfare, the latter concentrates on enhancing production technology and decreasing the average cost of its products. Here, the focal point is placed on creating incentives for firms to improve their production techniques to both increase quality and decrease costs. Firstly, in a rapidly changing environment, firms are reluctant to invest if there is too high an uncertainty that those investments cannot be recovered. Secondly, if a monopolist holds market power, chances are low that contestants could enter the market to compete with and challenge the incumbent firm. Consequently, the market succumbs to technical inefficiency, innovation inertia and bad management of the firm displaying monopolistic attributes (Decker 2014: 24-25). In either case, end-users are the ones suffering from low quality services or overpriced charges. In those cases, it might be necessary for governments to intervene and level the playing field to protect consumers. That is to set a framework that encourages investments and ensures their cost recovery; one that allows for prospect competitors to enter the market under fair conditions, giving them access to the same technologies and market conditions while protecting the incumbents from cherry pickers whose goal is to enter the market, serve only the most profitable customers, and leave before existing firms can adjust accordingly. Under these competitive circumstances, end-users would benefit from a reasonable price for their indispensable services (Decker 2014: 19).

There is a standard formula for regulators to restrict the number of market participants to one single firm and impose additional conditions that should lead to maximised 'economic welfare', but it is seldomly used nowadays. The goal is to set a common price that equals marginal cost of production to achieve the maximal level of 'total surplus' for a given output level. This is often called the 'first-best' price (Decker 2014: 20).

However, there are cases in which a firm has a high amount of fixed cost to recover and, at the same time, is obliged to set a price that equals marginal cost for a certain product. This marginal price setting would be unsustainable in the long run, as the firm is unable to recover their fixed cost of production. Hence, there are other approaches that could also lead to economic efficiency, such as peak-load pricing and Ramsey-Boiteux pricing. Ramsey pricing is also known as 'second-best' pricing as it includes a mark-up that reflects the inverse demand-elasticity and the first best price (price equals marginal cost). In the multi-product case, this generally means the more elastic the demand, the lower the mark-up, and conversely, the less elastic the demand, the higher the mark-up (Baldwin 2012: 450). This would, sometimes, contradict regulators' objectives to provide affordable services to the poorer population whose absolute demand elasticity is usually lower due to the inability to switch to another means. In addition to the information asymmetries and fairness concerns, its application is not wide-spread (Decker 2014: 20-21).

Economic regulation can be described as a process of governing a specific industry by imposing rules and restrictions to guide behaviour of market participants towards a desired goal, often in forms of financial incentives (Decker 2014, Berg and Jamison 2019). There are two opposing views on economic regulation, with the first one, also known as the "public interest", introducing the idea of governmental intervention in the market to make corrective adjustments in order to achieve a maximum of social welfare. For example, this is the case in a natural monopoly. In contrast, the "interest group" theory supports the notion that public policy is primarily shaped by stakeholders with the largest profit, these are often large corporations with massive impact in the industry (Laffont and Tirole 1991: 1089).

Generally, it can be said that the effectiveness of regulation mainly depends on the completeness of information about the true cost of production and the total market demand. This should be kept in mind when choosing the suitable regulatory tools which are presented in the following sections.

1.2 Rate-of-return regulation

Rate-of-return regulation (RoR), sometimes also known as 'cost of service' regulation, sets an overall price level that accounts for accounting cost and cost of capital of the regulated firm. This method is the so-called 'cost-plus' pricing (Baldwin 2012: 476). This, on the one hand, allows firms to recover investments and gain some profits, while making sure that consumers are not over-charged. The revenue level of the firm is calculated using the following formula:

$$R = Opex + s \times (\text{rate base})$$

The total revenue R is composed of Opex and s times the rate base. While Opex represents the operating expenses of the firm to produce the goods or services including depreciation and tax, s displays the allowed RoR. 'Rate base' describes the firm's financial investments minus the accumulated depreciation (Decker 2014: 104).

RoR is readjusted in a rate case process reflecting the true cost of operation of the regulated firm. The usual interval between rate cases runs from one to five years and is always fixed in advance. However, a reassessment can be requested by the firm or consumer group anytime given a reasonable justification which is usually the changing costs of production. During this hearing, different stakeholders can present their cases and bring forward financial evidence supporting their arguments or even consulting experts' opinions. Thereafter, the regulatory agency will determine the overall revenue requirement so that the costs of capital investments made by operators can be recovered during the next period. The last step is to establish a set of tariffs with specific prices that can be charged for different types of consumers or products (Decker 2014: 105; Berg and Jamison 2019).

Applying RoR regulation enables, in principle, price settings to achieve allocative efficiency, such as Ramsey-Boiteux (second-best) pricing. However, once the RoR is set, it will be valid until the next assessment, which means that there could be a time lag for the adjustment of prices according to changing market conditions. Decker (2014: 108) argues that the advantage of RoR regulation is that the operators do not have to bear imprudent losses, nor will they be able to receive monopoly profits. Another positive aspect is the public hearing process for the readjustment of the RoR that allows for all opinions to be presented and thus considered. Moreover, this regulatory approach ensures that the prices charged are set in relation to the production costs incurred. Also, as financial investments will be fully recovered, there are limited incentives for firms to reduce or increase service quality. Hence, production efficiency may stagnate, since any decrease in operation costs will directly translate into benefits for customers such as reduced prices, leaving little to no reward for the company. On top of this, the imbalanced information received by regulators results in a regulatory lag, which creates a loophole for firms to increase their profit in case of decreasing costs until the next rate case. Another quite prominent critique towards RoR regulation is the Averch and Johnson (1962) effect which demonstrates the negative impact of this approach on productive efficiency. Since RoR mainly considers the capital costs instead of true production cost which also encompasses labour costs, the capital-labour ratio is distorted. This means that the production may be more cost-efficient given a lower capital-labour ratio. Another drawback of this regulatory method is the slow response time of firms compared to competition in the market due to the long process of rate case assessment (Decker 2014: 109-111).

1.3 Price cap regulation

Price cap regulation, or also known as RPI-X regulation, is a pricing mechanism that sets a ceiling for what firms are permitted to charge for their services, which allow firms to break even, but not to gain monopoly profits. The main objective of this mechanism is to simulate market conditions under competition to benefit consumers with minimised prices (Bernstein 2000: 64). As for producers, the only approach to maximise their returns is to find ways to reduce production costs and increase their productive efficiency. To put it differently, producers must increase the difference between the ceiling price and actual production costs to gain profit. The price cap is set based on the so-called ‘building block’ procedure which is a streamlined forecasting model regarding the financial aspects of the regulated firm. It considers various price levels and how they affect the demand of the services under regulation and the resulting output level and the production cost of the firm (Baldwin 2012: 480-481; Decker 2014: 116). The price cap, i. e. the set ceiling, can be calculated as shown below:

$$P_{(t)} = P_{(t-1)} \times (1 + RPI - X)$$

$P_{(t)}$ represents the price for the current period, $P_{(t-1)}$ for the previous one. RPI is the inflation factor, and X denotes the offset factor. The former refers to a portion by which the price charged by the regulated firm must shrink. The X-factor is readjusted every three to five years (Bernstein 2000: 63). During this period, firms are incentivised to improve their performance, innovate their production process to reduce costs and gain additional profits, since any profit generated until the next readjustment of the X-factor belongs to the producer. Therefore, it is crucial for regulators to let an appropriate amount of time pass between two reassessment periods. When the time between the two resets of the X-factor is too short, firms lack incentives to increase productive efficiency. Similarly, if prices diverge too much from average costs, consumers will not benefit from efficiency gains, which thus leads to allocative inefficiency (Decker 2014: 116-117). The goal of price cap regulation is to benefit end-consumers with lower prices while accounting for input price inflation (Bernstein 2000: 66).

Advantages of price caps are clearly the incentives set for firms to seek for better technological inventions to minimise production costs, as any reduction of cost directly translates into producer's profit. Here, the information asymmetry is not as significant and relevant for regulators to set the perfect X-factor. Moreover, it eliminates the need to micromanage a firm's performance as opposed to an RoR method, since the firm's behaviour will reveal its true costs in the long run. Furthermore, as the capital investment is not guaranteed to be reimbursed, there is no incentive for firms to overinvest, and thus, there is a lower risk of facing the Averch-Johnson effect as in the case of RoR regulation. An additional benefit of the price cap approach also lies in the shift of the risk associated with the demand volatility from user to producer, who is in a better position to balance this effect. Lastly, the simple application of this method reduces costs for both regulators and regulated firms regarding the information gathering and calculation of an optimal rate or even in the monitoring process. Nevertheless, there are also downsides to this approach. In the case of a large divergency of average revenue and costs, the price will not reflect the input in any way, and this discrepancy will result in allocative inefficiency. Sometimes, to reduce cost of production, firms do not necessarily increase productive efficiency but simply deteriorate production quality to save costs instead. Even if they had discovered a more efficient way to deliver the same service quality, they would want to delay the implementation of this advanced technique till after the reassessment of the

X-factor to gain more profit. This way of postponing the new technology to the next period is known as the ‘Ratchet effect’. Besides, the freedom to set the price at any level below the ceiling could lead to anti-competitive prices to drive competitors out of the market and cross-subsidise different products within the company. Furthermore, as there is no guarantee for investments to be recovered, firms under RPI-X regulation are reluctant to invest causing productive efficiency to suffer. This problem is coined as ‘Achilles heel’ or ‘commitment issue’ (Decker 2014: 125-127).

To account for some of the drawbacks mentioned, adjustments of regulations have been introduced. For example, the ‘efficiency carry over mechanism’ provides a solution for the Ratchet effect, which allows for firms to continue yielding a profit from increased efficiency in the production for a specified time in the following period after readjusting the X-factor (Decker 2014: 127).

1.4 Yardstick competition and benchmarking

In a real-world scenario, in which regulators lack the knowledge of the actual production cost of the firm to be regulated, the ‘yardstick competition and benchmarking’ method presents itself most practical. This method regulates the firm’s price and profit levels which are directly linked to its performance by comparing firms in the same sector that have similar cost structure. Comparing the average cost and price of all firms helps to determine the most efficient way of production and to establish a ‘benchmark’ against which regulated firms will be compared (Jamasb & Politt 2001). Yardstick competition, furthermore, will set the market price equal to the average price of all companies, completely detached from their actual operating costs. In this vein, firms that have lower costs gain more profit, and vice versa, those with an inefficient production would suffer losses and may have to exit the market in the long run. This yardstick competition and benchmarking approach, therefore, increases the dynamic efficiency on the market without subsidies. Under the assumption of a competitive market, the risk of collusion is neglectable due to the increasing coordination cost with the rising number of firms. The benchmarking process only works assuming that firms are sufficiently similar in terms of their operation environment, which restraints the validity of this approach to very few industries (Decker 2014: 135-136).

All considered, it can be said that the afore-mentioned methods to regulate public utility firms only serve as a rough guide to the matter. This short treatise should provide a guideline as to which issues could occur and how to account for them instead of employing plug-and-play solutions. As the market is constantly evolving owing to various factors, it is nearly impossible to find a formula that accounts for every single eventuality. Therefore, these regulatory approaches should, instead, be considered cooking recipes that need adjustment according to taste, industry and environment.

2 Europe's current electricity industry

Being part of indispensable essentials of the modern society in developed countries, the power industry displays unique characteristics rendering it more sophisticated to manage than other public utility industries. Its production chain and infrastructure can be divided in distinct sections each of which exposes different attributes with different actors requiring appropriate regulatory measures to achieve an optimal outcome. This chapter deals with the clarification and presentation of the special characteristics of the electricity market in general, and the European electricity market (EEM) in particular, its participants, their roles and responsibilities.

2.1 Structure of the electricity market

While electricity is considered a tradable commodity like any other, its value fluctuates unlike anything else on the market. Storage in large amounts is coupled with disproportionate costs and, therefore, it needs to be consumed in near real-time. Price is time-dependent and varies greatly. Its transportation requires a highly costly transmission line which is subject to a safety flow limitation. Exceeding the said limit may cause collapse of the entire grid resulting in severe consequences. Therefore, electricity is location-bound and has different prices depending on the area of consumption. Since power generation cannot be easily controlled, steep demand fluctuation could lead to grid failure if not balanced efficiently. Resultingly, the power market is divided in numerous sequences with different frequency and voltage that need to be synchronised and managed systematically to avoid failures and outages. To simplify the coordination of supply and demand, the electricity market is subdivided into different trading areas, namely, energy only, transmission capacity, reserves/flexibility until the final load to end-customers in real-time as displayed in *figure 1* (Meeus & Schittekatte 2018: 2-4).

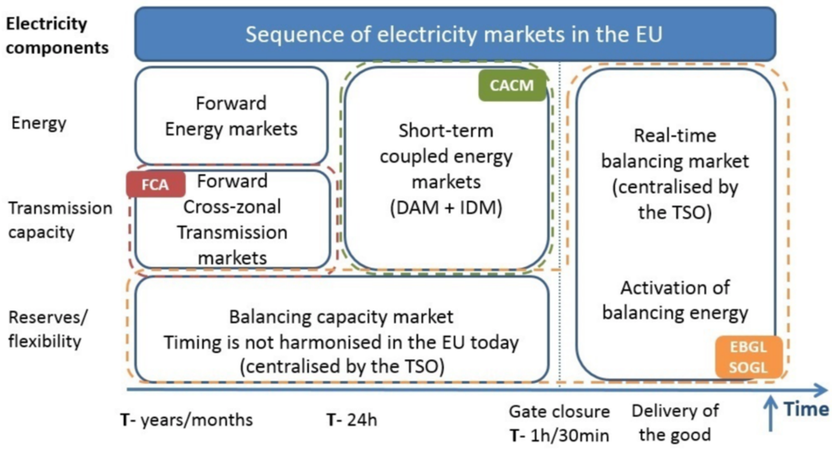

Figure 1: Sequence of electricity markets in the EU (Meeus & Schittekatte 2018: 5).

On the power market, the trading process can take place several years before the actual delivery of the commodity. This happens on the *long-term forward market*, where supplier and consumer can secure their position using an auction mechanism. Here, *forward energy contracts* and *forward cross-zonal transmission right*s are traded independently. Up to 24 hours before load time is when short-term markets open which encompass day-ahead, intraday, and (near) real-time trading. While day-ahead is self-explanatory, intraday market allows participants to make corrections to their biddings right until *gate closure*, which is usually 60 to 30 minutes before the energy delivery. After this point, the real-time balancing market takes over in which only the transmission system operator (TSO) can adjust loads and feed in from energy storages or draw on balancing mechanisms given incongruence in the supply and demand. The *balancing market* is, again, comprised of the *capacity market* and the *energy market*. While the former refers to the contractual readiness to either produce or consume energy in real-time, the latter is where participants can make bids and offers to feed-in or feed-off the grid. Sometimes, the involvement in the energy balancing activity requires an existing balancing contract, which can be acquired from one year up to one hour prior to the real-time balancing market (Meeus & Schittekatte 2018: 5-6).

In the day ahead market, in which the auction opens at noon 24 hours before delivery, there are three possible bid formats: simple, block and complex bids. The first and also the simplest form is placing bids in pairs of price-quantity, the second, block bids allow producers to bid several price-quantity pairs in one go, and lastly, the complex bidding option enables bids for multiple parts at once. The optimal simple bid strategy for the selling parties would be to bid their marginal cost, as bidding below their marginal cost would always lead to losses should they get accepted. The opposite case in which energy generators bid a price that is above the marginal cost and the bid is not accepted, they will lose out on the opportunity in which they might have made some profit (Meeus & Schittekatte 2018: 24).

Due to the almost non-storable characteristics of electricity, the energy generated needs to be consumed in near real-time. Another specificity of the electricity network is also the interconnectivity and high dependency of different parts of the grid. This is, failure such as surplus or shortage somewhere along the power generation chain could not only cause an outage in that specific area but would, in some cases, lead to a breakdown of the entire system. Hence, the balance of supply and demand in the network is of paramount importance to keep the stability of the electricity grid. According to Decker (2014: 223) inefficiency in the electricity market can impede economic growth up to 2%, which is the reason for a closer examination in the next chapter.

2.2 Value chain & market types

For understanding the role of different actors on the market, it is crucial to grasp the underlying structure of the value chain. This chapter sheds light on the specifics of power generation and highlights the distinctive characteristics of the diverse market types.

The production chain consists of three distinct parts, upstream, midstream and downstream. Upstream activities involve generation of high voltage electricity that is usually sold on the wholesale market. Midstream productivity includes storage and transmission of high voltage electricity to local nodes that act as load centres, from where the downstream chain starts. This downstream process is characterised by sales of the commodity, which incorporates the distribution of the now converted lower voltage electricity on the retail market in local areas to finally supply end-users. This last step in the supply chain, in which the electricity is drawn from the socket, is referred to as the 'load' (Decker 2014: 225).

Energy generators are categorised by their operating patterns, namely, base-load, peak load, and hybrid. Base-load plants are those that operate for an essential period throughout the year at low variable costs, like nuclear or fossil power plants. These are good at a constant output level, however, inapt for variable production. On the opposite, there are peaking plants that are employed at peak demand periods and are, therefore, flexible.

They fire up and be shut down quickly – however, at higher costs – very much like energy storages that have a limited capacity. The intermediate plants work somewhere in the middle; they are employed more often than peaking plants but less often than base plants. They can, on the one hand, be fired up easily and generate large amounts of energy and shut down quickly. On the other hand, they do not always operate at command due to their weather dependency (Decker 2014: 226).

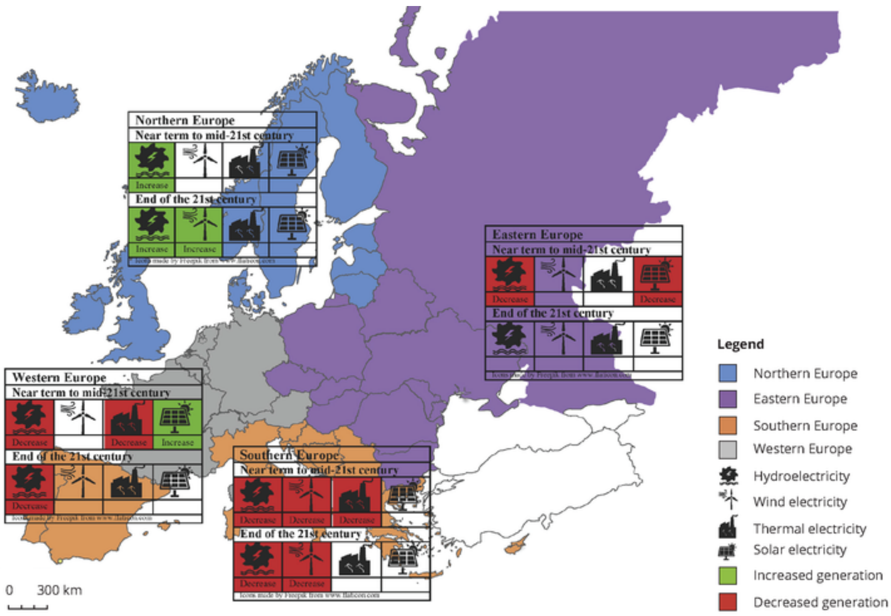

Figure 2: European wholesale markets divided in four regions (European Environment Agency 2017)

In *Figure 2*, the composition of energy plants and their development in Europe is on display. It is subdivided in four distinct regions, namely, (1) Northern Europe, consisting of Great Britain, the Nordics (Denmark, Norway, Sweden, Island) and the Baltics (Estonia, Latvia, Lithuania), (2) Eastern Europe, consisting of Russia, Belarus and other Eastern European countries, (3) Southern Europe, consisting of Spain, Portugal, Italy, Greece, Croatia, Cyprus and the Balkans, (4) Western Europe grouping the rest. While in Northern Europe, there seems to be an increasing trend towards hydroelectricity and wind electricity, the opposite is true for Western and Southern Europe (European Environment Agency 2017).

Another issue is the energy losses caused by the dissemination of electricity from generators to end-users, which can account up to 7% (Decker 2014: 226) to which the distribution network contributes a major part (Jenkins et al. 2015: 417; Kang et al. 2017). Generally, the rule of thumb applies that "the longer the distance that electricity is transmitted, and the lower the voltage, the larger the losses, and the higher the level of transmission costs that need to be recovered through [higher] charges" (Decker 2014: 228). While physical proximity of the generator to the customer plays an important role, the physical constraints of the network, namely, the transmission capacity must not be neglected either. These make up a significant amount of the price which the end-user must bear. Even if the power generation was carried out at low cost, exorbitant transmission costs would drive the electricity price up to an unreasonable level. Therefore, the transmission constraints might prevent power generated in a region to be transported to another region so that the available generators in that region become crucial for satisfying local demand. As a result, they can overcharge for their marginal units produced during these peak times (Decker 2014: 226-227). However, if the energy to be transmitted from one location to another exceeds the capacity of the provided power line, the independent system operator can decrease the price of the feed-in energy of the former and increase the price of the latter to avoid congestion. This task is also known as congestion management, which is fundamental to a smoothly running power grid (Skantze et al. 2004: 293).

As the large amount of sunk costs invested in the local infrastructure needs to be recovered, distribution networks are entitled to charging high prices. Hence, they possess power comparable to a natural monopoly despite the increasing number of companies on the distribution level. Considering this, it seems necessary for regulatory bodies to break up this structure and allow more competitors to enter the market, which enables the infrastructure costs to be borne by several parties to maintain affordable prices for end-users (Decker 2014: 227-228).

Within the electricity industry, market participants can do business on various types of markets, such as, energy only markets, capacity markets and balancing markets. Enabling the trade on these markets requires an independent third party for the task of balancing the supply and demand in order to satisfy requests. This transmission system operator (TSO) possesses the ability to incorporate a power reserve with a very short reaction time to stabilise the grid for a short amount of time in emergency cases. While the energy-only market is a space for trading the electricity produced, on the capacity market, one can monetise the mere capacity or readiness to generate energy on request.

With the intervention of the TSO, the energy-only market can supply the market flexibly tailored to the expected demand. As a result, it reduces over-generation and eliminates negative energy prices that often occur due to the inability of large power plants to adapt to the changing demand. In addition, the peak-load installations, which serve as an insurance policy, are only in use for a short period of time throughout the year, in which the peak-load prices can be realised. Compared to the long planning time and large sunk costs coupled with a rapidly changing market, the energy-only market's rate of return does not attract many investors. This is also known as the 'missing money problem' (Next Kraftwerke 2019).

Besides trading in an organised manner employing the market mechanism, it is also possible to do a direct over-the-counter (OTC) trade employing a bilateral contract. While the former provides transparency of exchange processes with uniform prices, as well as balancing services by the TSO, the latter offers more flexibility regarding the time of exchange and price settings (Meeus & Schittekatte 2018: 4).

2.3 Interplay of markets, grids and actors

The following chapter clarifies the interlink between the market infrastructure and the grid structure to roughly explain the role, task, and responsibility of the actors involved using the EU Network Code.

While the *market structure* comprises processes of trading, bidding, offering, and price calculation, the matching of supply and demand, i. e. the balancing of capacity and usage, as well as securing the smooth transmission, belongs to the *grid structure* and its management. Therefore, the concept of zonal pricing has been introduced to permit different bidding zones which operate with their own wholesale market prices. Bidding zones are linked via cross-zonal interconnectors which allow price levels of those zones to converge, given free capacities of the connector. In this case, these 'markets are fully coupled'. If, however, the cross-zonal interconnectors are congested, the markets of those two zones are split resulting in diverse wholesale prices for the said period. Transmission system operators will seize the price difference between those two zones, which is also known as the *congestion rent*, for the ownership of the network enabling the interconnection (Meeus & Schittekatte 2018: 7).

Any outcome of the market is called 'nominations', for producers and consumers alike (Meeus & Schittekatte 2018: 7). Within one bidding zone, the energy to be transmitted could exceed the transmission capacity and, hence, TSOs need to take measures to prevent this scenario from occurring, such as changing the grid typology correspondingly. In the long run, this would be more cost-efficient than any curative, short-term actions to countertrade or to redispatch. As in the case of re-dispatching, a TSO will have to command the production of one area to stock-up while curtailing the other to match the local demand without transmitting the required electricity through the main grid. Here, differential costs are to be calculated according to network tariffs. If, however, this manoeuvre cannot be executed, due to the limited capacity of local production, for instance, the TSO would have to reduce the capacity for the cross-zonal trade and compensate transmission rights' holders accordingly (Meeus & Schittekatte 2018: 33).

Although bidding zones and control areas often appear together, they are, nevertheless, two very different concepts that are too often confused as synonyms. The correct definition, according to Meeus and Schittekatte, is the following:

> *"A control area is defined as a coherent part of the interconnected system, operated by a single system operator. The system operator is responsible for maintaining the operational security of its control area. In Europe, the TSO is the entity which operates the transmission system and manages and owns the transmission assets"* (Meeus and Schittekatte 2018: 8).

While there are countries that incorporate only one control area and one bidding zone like Belgium, there are other countries in which there are more control areas than bidding zones, such as Germany, where the control areas are operated by four different TSOs that bid in the same pool as Luxemburg and Austria. Yet again, Sweden has one single control area that aligns with its national borders while having four separated bidding zones (Meeus & Schittekatte 2018: 8-9).

Therefore, a good communication between regional TSOs and bidding zone borders determines the accuracy of the optimal calculation of capacity that is to be traded on the market. This coordination, again, depends on the designated capacity calculation regions (CCRs) which, normally, include several bidding zone borders that are geographically grouped together. Regional regulatory authorities can approve of suggestions put forward by institutions. Should, however, no consensus be found, the Agency for the Cooperation of Energy Regulators (ACER) will have the final say. Their goal is to create one common

European CCR for a better use of its synergy (Meeus & Schittekatte 2018: 9). For the same purpose, the European Network Transmission System Operators for Electricity (ENTSO-E) has proposed the Common Grid Model, whose goal is to create a common database to enhance the coordination between various bidding zones throughout Europe, thus allowing a faster retrieval of data to calculate the optimal capacity for all the different markets (ENTSO-E 2016).

Another important actor is the Regional Security Coordinator (RSC), who belongs to the TSO, and whose role is to carry out regional coordination activities like coordinated capacity calculation. “RSCs will be active in one or more CCRs and have five core tasks, mostly related to grid security”, while TSOs take responsibility for the security of their control area (Meeus & Schittekatte 2018: 10).

Since the balancing task takes place almost in real-time, there is no better suitable candidate to carry out this task than the TSO due to its comprehensive overview of the interconnected parts. In Europe, the Internal Energy Market (IEM) makes up the largest unit which consists of five synchronous areas. A synchronous area, also known as a pool, interlinks various TSOs are divided as follows into Continental Europe, Great Britain, Ireland-Northern Ireland, Nordic and the Baltic. On the other end, the smallest unit is a *scheduling area* which is comprised of one or more *control areas*. A scheduling area is essential for the balancing system, as it constitutes the lowest level of energy control and management. All these notions are important for the requirement of reserve dimension. Since the bigger the geographical area, the faster and larger the storage must be to be able to react to adverse events (Meeus & Schittekatte 2018: 11-12).

There are two activation methods for energy reserves: reactive and proactive. The former kicks in to remedy the effect on the real-time balance market and is highly dependent on interactive market participants, while the latter is already in place before the real-time market even starts. Both operate on the premise of the expected deviation. The reactive system requires strong incentives to engage balance responsible parties in the balancing act, while the proactive one necessitates TSOs to be fully aware and responsive to occurring circumstances. Even though the proactive approach is assumed to be more reliable in terms of grid stability, especially for less integrated markets, there are successful implementations of a hybrid system making use of both – in Denmark, for instance (Meeus & Schittekatte 2018: 69).

2.4 Electricity regulation in the European Union

The following chapter recounts the chronological introduction of regulatory approaches attempting to reduce monopolistic power, liberate the market to attract new entrants and increase investments in new technologies to ultimately improve market efficiency.

Regulations applied in the public utility industry are originally applied to protect natural monopolists, whose production can efficiently satisfy market demand, from new entrants. However, these regulated and other state-owned firms with a vertical integrated structure are prone to be inefficient as they are not subject to any outside pressure to innovate or invest in improving their services (Joskow and Noll 1981: 16). While non-competitive activities such as providing network access for electricity transmit is best served by one single provider, competitive activities like generating and retailing would benefit from competition on the market. Therefore, vertical separation has been applied to prevent inefficient operation and discrimination against newcomers and force those who cannot operate competitively out of the market (OECD 2001). Besides this market liberation, some additional regulatory tools are necessary to ensure productivity growth and foster competition to enhance dynamic efficiency for the benefit of consumers.

One of the milestones for the modernisation of the electricity sector has been set by the Directive 2009/72/EC of the European Parliament and the Council which creates the foundation for the unified European electricity market (EEM) and enables seamless trading across borders. Furthermore, this directive provides consumers with a stable electricity grid with a high degree of security of supply at a reasonable price. The aim of the European Parliament and Council is to establish a well-functioning market that sends the right signals to encourage producers to expand the network to include the underserved population in rural areas and invest in new power generation technologies. This internal market should increase transparency in retailing and provide consumers with information so that they can take agency of their consumption behaviour and make the right choices to save energy costs. To achieve this outcome, the European Commission (EC) stipulates national regulatory authorities to open-up borders and allow diverse renewable energy suppliers to enter the market (EC 2009; Erbach 2019).

The first step towards this end is the ownership unbundling, which coerces the separation of network provision from the generation and the rest, namely transmission, distribution and retailing. This unbundling process promotes dynamic efficiency, as there is no longer a vertically integrated firm that possesses monopoly power and thus an advantage over its peers. Hence, all contenders on the market must strive for higher productive efficiency to ensure their competitiveness (EC 2009; Erbach 2019). However, as Moreno et al. (2012: 312) discovered, depending on numerous factors, the price of electricity can even increase despite market liberalisation and a rising number of RESs. Since they are costly and require a vast amount of investment, these costs are often carried by end customers. The authors show that an increase of 1% in integration and utilisation of RESs results in an increase of 0.018% in the household electricity price. Therefore, to prevent these negative externalities from occurring, regulatory bodies are recommended to impose additional rules to further the development of RESs.

To take it a step further, the EC proposed the establishment of the Cooperation of Energy Regulators (ACER), which unifies the regulatory forces and uses their synergies to provide better services. Previously, electricity markets used to be separated, and thus, synergies between different countries could not be used. However, as the potential advantages of a unified EU energy market had become obvious, the EC and ACER made efforts to integrate the fundamentally different market structures into one single common grid. These advantages are security of supply, higher grid stability due to the joined force in the balancing task, and many more. To achieve this harmonised state, clear guidelines and a strict code of conduct are essential. Therefore, the EU network code that has been effective since 2017, is legally binding and directly applicable without the need to transpose it into local law. While codes usually include a detailed description of tasks to do and steps to take, guidelines require a methodology to be developed and thus leave room for interpretation and flexibility in their final application (Meeus & Schittekatte 2018: 2-3). On top of this, the European Network of Transmission System Operators for Electricity (ENTSO-E) was established with the outlook of providing the EEM with an elaborated code of conduct and thorough guidelines to collaboratively work towards the vision of the EU. The task of ENTSO-E comprises developing common standards for grid coordination and power exchange, as well as safety and emergency procedures (EC 2009; Erbach 2019: 2).

After the integration of the energy market, the 'Green Energy for all Europeans' Package of 2016 followed, in which the EC has stipulated a 'New Regulation for Risk Preparedness' and overhauled the 'Regulation on the Agency for the Cooperation and

Energy Regulators' to facilitate the incorporation of more RESs, empowerment of consumers, and enhanced management of power stream within the EU. The goal set by the EC is to become the world leader in RE generation and accomplish net zero emission by 2050. Hence, the only way to approach this goal is to eliminate power sources which emit high volumes of CO_2, like traditional power plants. Therefore, it is crucial to create a solid foundation on which sustainable energy systems can thrive and consumers are provided with enough protection. This paradigm shift moving away from centralised electricity generation to a decentralised system entirely relying on renewable power resources requires the market to adapt. Besides, it will provide the best conditions that allows for new entrants and investments in power reserves and demand response (DR). This results in increased efficiency of coordination, and thus improves the overall performance of the electricity grid. This additional adjustment intensifies the emphasis on the development of consumer protection and engagement. Especially, with the outlook of smart meter roll-out by January 2020, consumers are given more transparency and agency in their energy consumption, and thereby offered real choices, not only to change to a more suitable tariffs but also to switch their power provider should they wish to do so (EC 2019).

With all these changes in mind, the next chapter looks at the transition from the traditional network and market towards a future market with the outlook on carbon free energy generation and consumer empowerment, as well as the changing roles and responsibilities of market participants.

3 Evolving energy market

This section examines requirements for the market by comparing the infrastructure of the past and the future to identify structures that need to be adjusted. After defining new modes of transactions on the market including its participants, the focus shifts towards assigning tasks and responsibilities to all actors involved.

3.1 Past vs. future market

Conejo and Sioshansi (2018: 520) highlight the importance of renovating the current electricity markets as these were designed three decades ago, at a time when electricity generation and demand were significantly different to today's usage pattern. Back in the 1980s, a change in the system was required to enhance the productivity and capability of the electricity grid management. Through this process, risks and costs were shifted from consumers to investors, which improved the end-users' position significantly.

The rapid evolution of solar photovoltaics (PVs) and other technologies that enable more efficient generation of renewable energy have developed negative side effects such as operability issues and grid disruption. Traditionally, grid systems were created for unidirectional electricity flow from generator to consumer only, and, therefore, issues of "harmonic distortion, voltage spikes and power output fluctuations" can occur when households start transmitting electricity in the reverse direction (Parag & Sovacool 2016: 4).

While in the past electricity solely came from the upstream transmission system, prosumers, nowadays, have the possibility to feed their excess electricity into the grid. Consequently, the thermal voltage band of the grid infrastructure and the permitted voltage band might be violated. However, there are numerous ways to prevent this scenario from occurring, such as expanding the current network, employing adjustable power transformers, and deploying electricity storage as a buffer (Pereira et al. 2018a: 428).

Originally, the power system was driven by a small number of thermal generators with high dispatchable capacity. However, with the ever-growing need for energy and the resulting CO_2 emissions, which are forecasted to be 110% higher than the stabilisation level, a more sustainable solution is required to take up this challenge and meet the market demand. Owing to decreasing costs of harvesting energy from RESs, an increased awareness for ecological issues and guidelines, as well as support schemes provided by the EC, the energy market has experienced a drastic shift toward demand and supply of green energy throughout the last decade, in a continuous effort (Conejo & Sioshansi 2018: 520).

However, with all the remedial effects of RE, come the negative aspects, which entail a decreasing dispatchable amount of energy and high volatility due to weather dependency. To balance out this fluctuation in the energy generation, also known as the duck-curve effect, the system requires a balancing agent with a high degree of flexibility to avoid curtailing the output range of RESs (Conejo & Sioshansi 2018: 521).

The traditional day-ahead and its corresponding real-time markets are relicts of the past, when the only sources of energy were steam turbines or nuclear reactors, which required planning hours or days ahead to be able to supply the requested demand or to balance out occasional errors. Operating on this outdated market design that does not reflect today's demand and supply properly, the retail market of today cannot satisfactorily deliver the most efficient outcome for market participants. In contrast to the traditional market design in which active participation had little to no effect on the energy market, the current market design is shifting towards a new model that not only encourages pro-active engagement but strongly relies on it. By taking part in relieving the grid during peak times, customers' demand response have become an inconceivably essential part of today's energy market. Therefore, the market calls for a fundamental make-over, since small adjustments to patch errors in the outdated system will no longer suffice (Conejo & Sioshansi 2018: 521).

The rapid evolution of technology advancement has transformed markets and customers' behaviour. Therefore, business models need to change and regulations need to adapt accordingly (Lesh 2010). Hence, the development and attributes of the future market will be the subject of analysis in the following chapter.

3.2 Characteristics of prosumers network and market

The rise of new technological advancements in the field of electricity production and storage results in decreasing costs of solar panels, batteries and other means. In addition, the imminent roll-out of smart meters on an EU-wide scale will increase transparency and facilitate the incorporation of small producers to the power grid. New technologies, such as smart home systems with automation and integrated energy management, enable a more transparent and conscious electricity usage in households. This development points towards a rapid transformation of the current electricity market with new roles and functions (Parag & Sovacool 2016: 1).

While in the past the focus was placed on the integration of the EEM, current efforts steer towards promoting the development of a balanced local supply and demand. It is imperative to restructure and adapt current infrastructures to prepare a pathway for the upcoming microgrids and to introduce distributed small capacity energy sources (DESs). This new type of market participant, the so-called *prosumers,* who not only consume but also produce, can be divided into *autonomous* or *contributing* groups. The former describes those who produce, consume and manage their own energy production completely disconnected from the grid. The latter refers to those who take part in supplying the grid with their excess energy. The goal of policy makers is to utilise prosumers' potential to maximise social welfare and to minimise losses (Parag & Sovacool 2016: 1-2; Zhang et al. 2018: 1).

The key question here is how to best involve prosumers to employ their balancing capacity for the benefit of all. As Zhang et al. (2018) have found out, incentive tariffs, which lower electricity prices for those who actively feed-in the local grid, could encourage participation. This result is also backed up by the example of Vandebron (2019) in the Netherlands, which showcases a platform allowing direct trading between numerous autonomous generators (Zhang et al. 2018: 2). This online platform enables sellers to list the amount of energy which they want to sell at a specific price; buyers can then browse through and find a suitable offer. After placing their bids, which can happen a few months ahead of time up until the gate closure, which is usually one hour before the transaction takes place, DSOs will sort through all orders to either accept, if constraints allow so, or otherwise reject them. During the half-hour window, DSOs will actively try to balance the traffic to maintain stability of the network. The cost of this balancing act is then recorded along with the amount of energy produced and consumed during this time frame. Those who could not fulfil their bids (production or consumption) for the said time of transaction either pay a penalty in form of money or they will have to accept less favourable conditions for the next bidding. Concerning the calculation of price for this peer-to-peer/prosumer-to-prosumer (P2P) market, they (ibid.) suggest procedures like those in the whole sale market (Zhang et al. 2018: 3-4).

The P2P trading model stems from the concept of the shared economy, the core substance of which is to share the ownership of certain products, which in this case is electricity by using an internet-based platform. Hamari et al. (2016) discovered various reasons that explain the (in-) active participation of actors in P2P trading or in the shared economy. Motives range from awareness of ecological sustainability, enjoyment of the act itself, upholding reputation, gaining economic benefits to simply following unspecified personal motives.

Based on this ground, Parag and Sovacool (2016) present three types of prosumers integrated grids that are a P2P trading model, prosumers-to-grid (P2G) and organised prosumer groups (Parag and Sovacool 2016: 2).

Regarding the former, being formed by the bottom-up approach, its structure is comparably loose, which is why sellers and buyers can directly interact via an online platform to trade for electricity, energy storage or other services without a third party. This market model involves a fair number of individuals who produce and sell power at a small scale (Parag and Sovacool 2016: 2).

The P2G system is more structured with a brokerage system connecting prosumers within the microgrid (MG), which can either be connected or disconnected from the main electricity grid, completely isolated. While the former mode incentivises customers to maximise their power generation, as any excess energy can be fed into the grid for monetary reward, the latter requires a higher level of self-management regarding the electricity generation, due to the limitation of storage possibilities. In either case, prosumers are to act on their own, either on the smaller scale of the MG or interacting directly with the main grid to adjust their prosumption behaviour given certain market signals (Parag and Sovacool 2016: 3).

As for the organised prosumer groups, instead of acting on the individual level, the aggregator will represent the entire group as one single unit combining all their prosumptions and trade as a virtual power plant. The single revenue stream will be shared fairly among all participants in the network, according to their respective contributions. One of the main advantages of this model is a higher risk diversification among participants, which encourages participation. Furthermore, grid operators benefit from the streamlined pattern of supply and demand with respect to capacity and flow management. Moreover, to attract prosumers to partake in the MG support systems, such as facilitation of the integration and balancing of supply and demand, or revenue generating activities in form of pooling resources to create profit for participants, could be of advantage. Aggregators and service companies that are willing to invest in the infrastructure to yield financial benefits from the energy savings could act as incubators for the advancement of prosumers (Parag and Sovacool 2016: 4).

Furthermore, it is important to note that the electricity market design originally made use of a balancing mechanism to match supply, based on the assumption that demand was completely static, price-inelastic, and inapt to react to the changing market signals, in the short run. However, this assumption no longer holds true and market designers have acknowledged the power residing in the ability to move the peak load. Therefore, there has been a growing desire to engage prosumers in the demand response to deploy this capability. A pilot study discovered that the active participation in the demand response (DR) can save household around 100kWh annually and facilitate the balancing task of network operators using the higher flexibility and capability to shift the peak load (Conejo & Sioshansi 2018: 525).

However, it is often the case that commercial customers with high demand tend to participate more actively in the wholesale energy ancillary service and capacity markets than smaller, private customers. The latter can only participate through a third-party aggregator, if they wanted to which limits their direct impact notably (Conejo & Sioshansi 2018: 526). To counteract the rigidity of the traditional electricity market model with day-ahead markets, the authors (ibid.) advise to employ a successive auction mechanism with a time frame of 15 minutes approach. The ability to adjust offers and demand continuously help reduce uncertainty moving closer towards the delivery time adds to the advantage of this approach (Conejo & Sioshansi 2018: 529).

Prerequisites for these types of transaction can be categorised in three distinct groups of agents. These are (1) enforcers of nominations which are substantial for the trading process, (2) correctors of frequency deviations and (3) auxiliary agents for structural and administrative obligations. Furthermore, home gateways or smart home management systems can act as mediators and match-makers between energy production, demand and storage of the household and the supply on the market (Parag & Sovacool 2016**:** 4). Transactions between multiple partners happen in between the low voltage and high voltage market places with an ambassador that takes responsibility for balancing out the unmet requests or surplus supply in the local market (Parag & Sovacool 2016: 5).

3.3 Roles and responsibility of actors & regulators

In recent years, the distributed generation of low voltage power, which is directly connected to the distribution network, has taken off and poses challenges for the current interconnection standards and the role of DSOs (Decker 2014: 229).

For the integration of P2P networks and MGs to the main power grid, new actors are required to provide prosumers with a marketplace, a prosumption brokerage system, and rules facilitating an orderly transaction, as well as a feasible congestion management. Here, prosumers on the grid play an essential part on the distributional level when communicating their electricity demand and production to the grid operator, partaking in the DR and reaping the entailed benefits. To ensure a functioning system, the online marketplace will be responsible for balancing the network by using optimising mechanisms, governing energy and financial transactions, and settling disputes in case of discrepancy or disagreement (Parag and Sovacool 2016: 3).

The future electricity market is expected to encompass two key characteristics that may pose a challenge for network operators and the current market design. Firstly, the growing number of RESs results in a proportional increase of variability of the power output. Secondly, due to a higher employment of batteries in the form of EVs, consumption variability creates peak demand that might cause instability of the grid. Therefore, Conejo and Sioshansi (2018: 526) suggest designing models that include various statistical distributions to forecast and approximate future output to provide SOs with scenarios and prepare them for all possible eventualities. Furthermore, with the help of artificial intelligence which can consider various sources of information in combination with machine learning algorithms to do advanced analytics, predictions will become more accurate every day (Negnevitsky et al. 2009).

However, to keep pace with the current development in the electricity industry, it is natural for market participants to reposition themselves accordingly to remain relevant and reap the desired benefits. In the same vein, Ruester et al. (2014) highlight the ongoing change in the power structure caused by the increasing penetration of distributed energy resources (DERs), which results in challenges for DSOs, and consequently, for regulators. With the incremental number of DERs in the energy market, local demand could easily be satisfied without drawing from the upstream electricity production.

Also, Lesh (2010) urges the industry to start assessing and adjusting their way of doing business, as 'disruptive changes' are about to shake the current market considering the technological advancements in the recent years. Contrary to this position, Parag and Sovacool (2016: 5) claim that a significant number of consumers and homebuilders do not share this opinion, which fuels their reservations against the adoption of PVs to harvest RE. While investors fear that the return on investment would not recover the costs, consumers assert that the switching costs compared to the benefits gained do not pay off the hassle. However, Parag and Sovacool (2016) agree on the fact that the current market, indeed, lacks innovations, and the prevalent information asymmetry is hindering the progress of the green energy movement further. Therefore, Lesh (2010) strongly believes that regulations should support the evolution of firms by reducing risks associated with their investments and provide appropriate support schemes. Besides these remarks, Lesh (2010: 43) emphasises the important role of regulators and their power to improve the status quo, even if they had to do so by trial and error. Additionally, Lesh (2010: 44) also supports the notion that cross-subsidisation does not inevitably lead to unfair pricing mechanisms and advocates its necessity to level out the cost. In her (ibid.) opinion, cross-subsidisation among different types of customers might even be the enabling factor of affordable service prices. On the other hand, Haber (2018: 309) argues that the absence of incentives to innovate and improve their performance would lead to inefficient operation. Lesh (2010), however, reasons that decoupling of services along the distribution chain could prevent providers from operating cost-inefficiently, and instead, to rethink their costs and therefore improve the allocative efficiency and allow additional services to be offered.

Contrary to the wide-spread belief, Ruester et al. (2014) report that, in some regions during a specific period, the renewable energy (RE) generated even exceeds the demand and thus can be fed to the main grid. This development necessitates a bidirectional power flow and requires a higher effort of DSOs to balance the supply and demand. Consequently, the costs of maintaining the stability of the network and enhancing distribution services would increase disproportionally. However, in this challenge also lies the opportunity to use excess energy generated to compensate for underproduction in other locations by simply redirecting the electricity flow. Moreover, there are possibilities to incorporate thermal storages such as water heating or space heating systems to convert the overproduction of RE into energy storage with a high marginal utility (Zhang et al. 2018: 5).

Compared to imposing strict regulations at the EU level, directives and guidelines accompanied by supervision and monitoring of practices would achieve better results. Additionally, sharing the lessons learned with other states gives them support and incentives to improve their national structures. In the same fashion, remunerations schemes and standardisation of infrastructure, lowering of entry barriers as well as distributed grid management are key to success. To overcome the uncertainty of future development in this space, smaller DSOs could cooperate and join forces to invest and expand their network for mutual benefits enhancement and risk reduction. Ruester et al. (2014: 236) conclude that the task of regulators is, first and foremost, to define the role of DSOs including their boundaries and responsibilities. This will facilitate the coordination between DSO and TSO manifolds. Moreover, regarding tariff prices, they suggest including the cost of generation and transmission for companies to be able to work sustainably.

Furthermore, as balancing the network can be costly, it might be wise to set incentives for market participants to correct their errors and level out their feed-in and feed-off quota in the intraday market to facilitate the process. In other words, balancing charges should be set so that sellers and buyers are inclined to behave in their best interests and to the best interest of the power grid. Meeus and Schittekatte (2018: 62), furthermore, conclude that a price that equals *marginal* cost for balancing activities is considered optimal regarding resource allocation, whereas, a price that equals *average* cost could create undesired behaviour of balancing responsible parties, for deviations from original contracts might increase their profits.

Employing these insights, the following section attempts to assemble these elements and lessons learned into a framework facilitating participation in sustainable power generation of the future electricity grid to keep pace with the smart city development.

4 Market redesign

Owing to the increasing computational power and enhanced ICT that allow for better interactions at lower cost, there are new algorithms for matching supply and demand that deliver a better market clearing price. Hence, the energy market requires regulatory tools that enable and encourage DR. This chapter introduces some general technological foundations that assist energy trading in the new era, such as data hubs, blockchain technology, smart contracts, and how they contribute to a more efficient framework, followed by tasks for regulators.

4.1 Incorporation of demand response

For a smooth adaptation of the new market design and its accompanying changes, proper IT foundations and stable network connections must be ensured to enable DR. In line with this view, Ehrenmann et al. (2019) work on a make-over for the single intraday coupling to fulfil the requirements imposed by the EC. The goal of this is to find a congestion pricing mechanism that reflects the real operation cost while promoting seamless cross-border trade and respecting the first-come-first-served allocation method for transmission capacity. Following this approach, any newly released free capacity after the allocation process would be assigned free of charge.

Regarding the engagement of the demand side to maintain a balanced power grid, Annala et al. (2018: 1140) strongly contend that DR resources "constitutes a largely untapped potential in Europe". Issues which end-users are currently facing are numerous, ranging from the lack of incentives to the lack of standardised technologies, such as smart meters that enable momentarily adjustment of energy consumption and, in the long run, users' behaviour. In their view, DR embodies these unrealised possibilities to raise competitiveness of RESs over the incumbent electricity companies. In their belief, market-ready and emerging technologies can assist TSOs and DSOs in reducing their costs and increase reliability of the network. As load prices are wholesale market driven, DSOs' load management could, by decreasing peak loads, reduce network congestion and thus, increase the profitability of retailers (Annala et al. 2018: 1140).

Experts' opinions on the topic conjecture that the reasons for the slow adoption of DR solutions were among others, the "small economic benefits, […] lack of standardised interfaces between different data systems, […] and also lack of motivation among customers" (Annala et al. 2018: 1143). Furthermore, the absence of clear rules and regulation in the sector are believed to cause a feeling of unease among DSOs who are the one committing to acquiring the technology at high costs without an outlook to recover those, while retailers reap most of the benefits. Hence, unless roles of actors including their responsibilities are clear, there will not be enough incentives for DSOs to invest in DR development and promotion. From the retailers' point of view, the effect of DR on balancing the network remains an unknown variable which is why they request regulators to compensate for the damages and costs incurred by applying DR to their business model. Furthermore, they argue that the increasing number of switches necessary for demand matching will cause the system to wear down faster, and hence, they mandate a standard set of rules for the controls in order to ensure fairness (Annala et al. 2018: 1143).

The result of a survey conducted by Annala et al. (2018) also backs up the above-mentioned aspects (represented in *Figure 3*). In addition, it adds stakeholders' insights displaying other causes leading to the slow adoption of the DR.

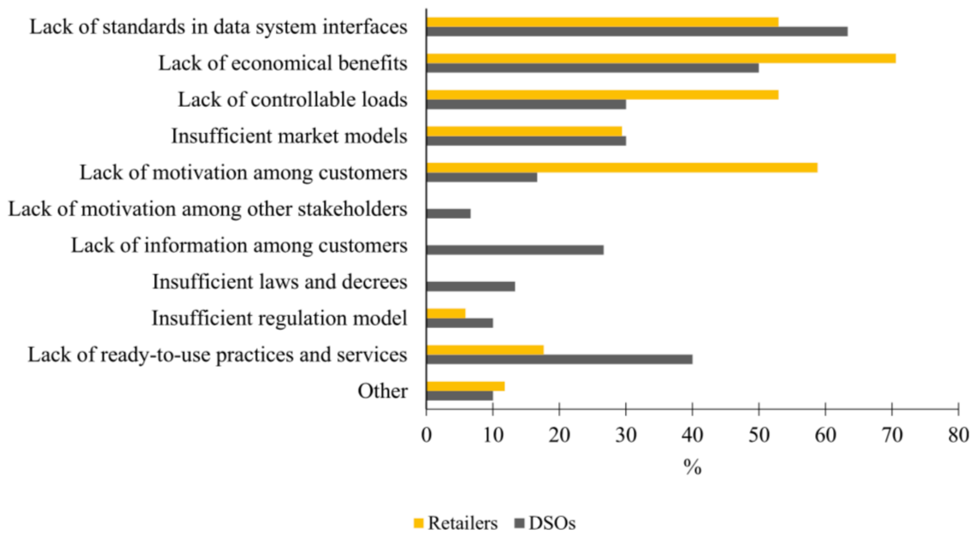

Figure 3: Barriers to employing DR successfully (Annala et al. 2018: 1444)

As shown in *Figure 3*, one can observe that there are some discrepancies between how retailers and DSOs perceive the situation. While retailers believe the lack of motivation among customers (68%) to be a key issue following the lack of economic benefits with 72%, DSOs do not consider the former to be as important with merely 15%, however, they do agree that the latter, indeed, plays a crucial role. Nevertheless, both retailers and DSOs are of similar opinion that DR lacks standard data system interfaces and that there are insufficient market models.

Among the major issues restricting the development of DR systems such as the lack of consumers' willingness to engage and adapt their consumption behaviour is perceived by most as a key hurdle. Moreover, issues concerning data transfer and security also hinder the acceptance among the population. Therefore, the development of new businesses and services around DR is deemed rather difficult. Additionally, heavy subsidies on the current electricity market render cost control unclear (Annala et al. 2018: 1145).

In the follow-up retailer survey, when asked about how regulators should enhance current regulations and support schemes to increase the number of participations in the DR, the figures show that an hourly varying electricity price would provide the best incentives, among others, to engage customers. The outcome of the survey is summarised in *Figure 4*.

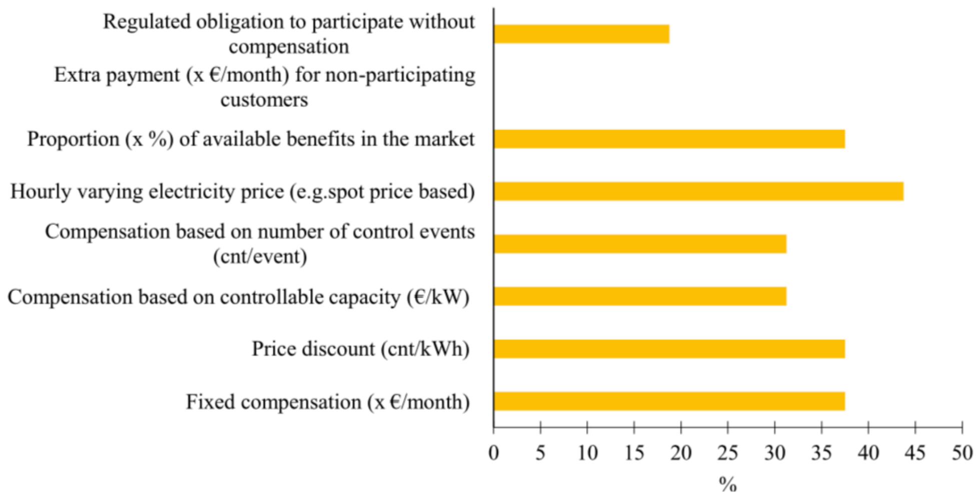

Figure 4: Most welcome pricing models and other mechanisms to engage customers in DR (Annala et al. 2018: 1145)

The first step is to abolish price caps and fixed cost tariff and instead introduce an obligatory hourly pricing to advance the transition to a more flexible power market (Annala et al. 2018: 1146). Furthermore, it is argued that, with the standardisation of products and services, DSOs and DR could "improve the efficiency of operating and developing their networks" (Annala et al. 2018: 1147).

Furthermore, regulators are asked to create incentives for DSOs to offer power-based distribution tariffs, i.e. to charge network usage in proportion to the power usage. There are also voices claiming that the introduction of flexible DR could take place without the explicit inclusion of end-customers. In general, a seamless transition to the new market design would encourage active participation and change their behaviour to reduce electricity bills (Annala et al. 2018: 1145).

In line with the proposed normative approach, gamification was put forward to engage users in the DR. Some voices prefer giving consumers the agency and choice to act via smart phone notifications to inform them about the amount of money they would save by adapting their momentary consumption. On the contrary, there are contrasting opinions in favour of the automation of DR instead of wasting effort to animate users' participation. Below the line, they request the public sector to invest in automated DR and lead by example (Annala et al. 2018: 1145). To be able to do so, it requires a universal data standard, interoperable systems and an appliance interface. This package would provide a solid foundation which is a non-negotiable prerequisite to optimally deploy the advantages of DR. The following *Figure 5* sums up the proposals and groups them thematically including the listing of relevant stakeholders for each solution.

Institutional and thematic classification of the proposed solutions.

Solution	Institutional framework			Relevant stakeholders
	Regulative	Normative	Cultural	
MARKET ACCESS				
Reducing the minimum bid size in backup power and reserve markets	✓			TSO
Allowing aggregators in reserve markets	✓			TSO
Cross-border trade of DR	✓			TSO, market operator (Nord Pool Spot)
BUSINESS MODELS AND SERVICES				
Selling electricity as a service, not a product, easy total service packages to end-users		✓	✓	Retailer, new actors
New business models and services, e.g. virtual energy services to utilize DR and solar PV		✓		Retailer, DSO, new actors
Gamification of DR		✓		New actors
END-USER INCENTIVES/OBLIGATIONS				
Removal of price caps in electricity markets	✓			Market operator
Consumer pricing based on wholesale market price		✓		Retailer
Abandonment of TOU (day/night) tariffs		✓		Legislator, DSO, retailer
Prohibiting fixed electricity pricing/mandatory hourly pricing for end-users	✓			Legislator
Selling electricity distribution as "power band" with defined maximum power		✓		DSO
Energy regulatory authority to create incentives for DSOs to introduce power-based distribution tariffs	✓	✓		Legislator, Regulator
DR incentives in the electricity tax	✓			Legislator
Classifying the levels of supply security and pricing based on the chosen level	✓	✓		TSO
Investment subsidies for households	✓			Legislator
Mandatory participation for households (with electric heating)	✓	✓	✓	Legislator
Regulation on DR, energy saving and power-based pricing in public buildings	✓			Legislator, public users (municipalities etc.)
INFORMATION/EXAMPLES				
Informing end-users about times when changes in consumption are needed and about the impacts on electricity costs		✓		Retailer, DSO
Informing building owners about the opportunities and encouragement to the use of new technology		✓		Public bodies
Encouraging households to use appliances with DR interface	✓	✓		Retailer, DSO
Regulation on ownership of energy consumption data	✓			Legislator
Public sector could lead the way and open their consumption data		✓	✓	Public users (municipalities etc.)
Public sector could encourage transition to DR by starting the investments		✓	✓	Public users (municipalities etc.)
ATTITUDES				
Change in consumer attitudes, courage to invest			✓	Public bodies
Change in the attitudes of electricity professionals			✓	Educational institutes, professional communities
TECHNICAL ISSUES				
Automation of end-users' response		✓		Appliance manufacturers
Forcing regulation to make gadgets and systems communicate, Standardized interfaces for appliances	✓			Legislator, appliance manufacturers, builders
Wireless technology to facilitate automation in old buildings		✓		Appliance manufacturers, builders
Electricity plan of building and documentation of installation prepared for DR infrastructure	✓	✓		Legislator, builders, designers (of electrification)
Guidelines for electricity planning and installation in buildings to prevent demand peaks caused by large simultaneous loads	✓	✓		Legislator, builders, designers (of electrification)
Incorporation of energy and material efficiency and DR into building codes	✓	✓		Legislator, builders, designers (of electrification)
Removal of energy efficiency certificate scheme	✓			Legislator
Regulation to forbid undersizing of pumps	✓			Legislator
Smart electric vehicle charging systems		✓		Charging system providers

Figure 5: Proposals for regulators grouped thematically (Annala et al. 2018: 1146)

Furthermore, the four types: pricing, bargaining, auction and contract theories could help to understand the demand side and its management. Based on this categorisation, "a cloud-based vehicle-to-vehicle energy exchange framework and an optimal contract-based electricity purchase scheme" can be employed to offer an efficient charging service with reduced transmission cost. This low cost stems from the fact that, instead of drawing electricity from static energy sources, which are usually transmitted over long distances, the vehicles will simply draw energy from the one in close proximity. This theory has been put to test in simulations and the results have proven its applicability (Abdalla and Shuaib 2018: 7).

To provide a level playing field for all market participants, especially for newcomers to enter and compete under fair circumstances, it is important for DSOs to offer satisfactory conditions concerning the network access (Ruester et al. 2014: 231-231).

Additionally, TSOs and DSOs must have well-defined tasks and hierarchical reporting structure to assign responsibility accordingly. Services offered by either of those require coordination to ensure a smooth operation and avoid conflict between them. Especially, when the products provided differ not only in technical characteristics but also in location and time of delivery, an arrangement would lead to better results in terms of timely consumption on the demand side, and thus ensure system stability while guaranteeing product and service security (Ruester et al. 2014: 234).

Besides, since stakeholders' rights and responsibilities are not yet clearly defined, the question of investment commitment is left unanswered. The result of the survey clearly demonstrates that there is a need to reassess the rules and regulations currently applied to the market to find pertinent requirements and set the right incentives for the incorporation of DR in the future business models (Annala et al. 2018). Hence, the subsequent chapter is dedicated to addressing these issues with a focus on the technology side to enable a better-connected energy system.

4.2 ICT and smart grids

A successful implementation of DR requires regulators to introduce tools that encourage active participants and "investments in enabling technologies", such as smart grid infrastructure. Since social or cognitive barriers, like "low awareness" are as important as institutional ones, it is crucial to shed light on the benefits of ICT and smart grid systems to eradicate uncertainties about its implementation (Bauwens et al. 2016: 138; Annala et al. 2018:1140).

4.2.1 General application and benefits of the smart grid

ICT enables smart energy grids and the integration of a high number of RESs employing the simplified and standardised processes to provide users with a plug-and-play level ease of use. Along with benefits as mentioned before, these smart grids enhance the accuracy when detecting power losses and improve the speed in diagnosing issues in real time on the transmission and distribution lines. This feature aids in reducing latency time and prevents severe damages from happening, which could save the network a great amount of money. To monitor power losses and conduct diagnosis in real-time, which, again, improves load factors and reduces system losses. In further instances, the information gathered will contribute to improve stability of the operation on the grid owing to an improved balance of supply and demand sides. As overproduction of electricity often results in frequency jumps and the underproduction leads to frequency drops, reoccurrences of these fluctuations have negative consequences on both producer and consumer sides, which, eventually, could bring about a power blackout. Being highly dependent on extrinsic factors, the grid stability would suffer from the intermittent characteristics of RE. As this factor is not controllable, RE generation would greatly benefit from the integration of smart grid technology (Pieroni et al. 2018: 300-301).

One major difference between a traditional power grid and a smart energy grid is the flow of electricity. While the traditional grid can only carry upstream energy to end-users, one directional, the smart grid allows for energy and information flow both ways, which is its main characteristic. Moreover, the ability to monitor power plants' generation details and to record preferences of the users' side makes the decentralised P2P trading possible (Pieroni et al. 2018: 300).

This P2P distributed energy trading (DET) enables a more open access to energy trading by allowing the household level to join the network without the need for a utility company (Abdella & Shuaib 2018: 1). However, for P2P DET to work properly several prerequisites must be fulfilled, namely, the existence of an optimised demand response, power routing, a public energy market, a money transaction mechanism and efficient communication networks. Due to the high volatility of RES, demand response is more sophisticated and requires more complex mechanisms than the existing load scheduling operated by one central authority (Abdella & Shuaib 2018: 2).

The concept of a smart grid was coined by the European Technology Platform in 2006 (Jenkins et al. 2015: 412) and is defined as a network that exhibits the capability to autonomously take actions to achieve the best outcome for all network participants based on their preferences and restrictions. Furthermore, it reduces environmental impact by integrating RESs and facilitating communication between different actors in the network. On top of this, by gathering information available, effort for maintenance of the network can be reduced considerably (Jenkins et al. 2015: 414). Additionally, smart grids possess the ability to balance upstream and downstream activities. Besides maintaining stability of the power grid, it also matches local supply and demand in a more economical manner than the incumbent operators. Moreover, it enables greater flexibility in DR and allows prosumers to modify their consumption in near real-time and thus contributes to a more efficient pricing mechanism (Parag & Sovacool 2016: 2).

4.2.2 Smart grid structure

The role of ICT in the new market structure is not only to facilitate the communication and data exchange between different parties but also to help detect irregularities to predict future issue to find solution for imminent issues. *Figure 7* exhibits a structure of how a smart grid works.

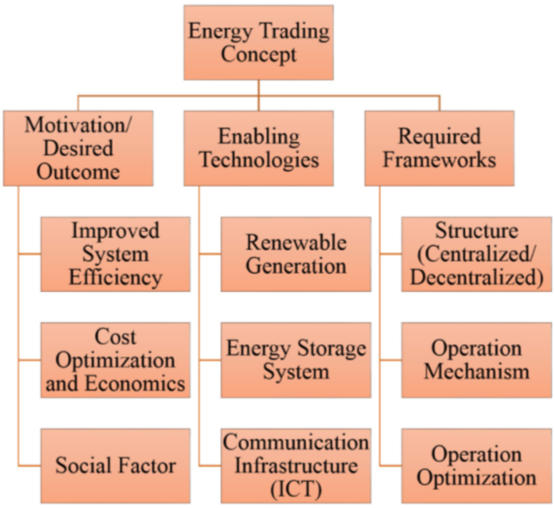

Figure 6: ICT enabled energy trading concept (Jogunola et al. 2017: 3)

This new trading concept is built upon three elements, (1) desired outcomes which includes improved system efficiency, cost optimisation, and social inclusion, (2) enabling technologies, such as RE generation, storage system and communication infrastructure, and lastly, (3) frameworks that entail either centralised or decentralised structure, trading mechanisms and operation optimisation (Jogunola et al. 2017: 5).

As the desired outcomes have been discussed in the previous chapter, there is no need to repeat it here. Concerning the second pillar, enabling technologies, smart controls and smart meters play a key role in establishing a functioning ICT. Smart controls are programmed to reduce human interaction with the system and to automatically take actions according to inhabitants' preferences, they also function as some sort of gateway to communicate directly with the power supply, such as PV, battery or energy utility (Han and Lim 2010: 1419). Among other benefits of a smart meter, the recorded energy production and utilisation gives users a better overview of their spending leading to more conscious consumption behaviour and reduced electricity bills. Additionally, with the help of smart meters, power congestions and issues related to the grid can be located faster and more accurately. Traditionally, an outage was localised depending on phone calls made by customers who experienced the issue. Using the smart meters on the smart grid, breakdowns can be determined within a shorter amount of time. Therefore, infrastructures which were originally built to serve as backup systems are no longer needed due to the higher visibility. This could further enhance current capacity, improve the system reliance and transparency as a secondary effect (Jenkins et al. 2015: 419).

As for the framework required, there are two types: decentralised in form of direct P2P communication and trade; and centralised control in which interactions are bundled through a centre unit responsible for the coordination and correct transmission (Jogunola et al. 2017: 12).

Again, two major distinctions are important to make between the decentralised and centralised energy management systems. While in the former prosumers form a smart grid that is physically constrained to a neighbourhood or organisation, the latter is a virtual construct that goes beyond any physical restrictions and fuses various RESs or storage options to one federated system. Acting as a cluster, this central unit strives to achieve its community's goal which is to optimise energy expenditure (Jogunola et al. 2017: 13-14).

Moreover, smart grids that work based on smart meters are expected to carry out simple tasks fully automatically, such as connecting consumers and disconnecting them in case of late payment, or automated billing. This would not only be more cost-efficient but also reduces the possibility of human error. With these new technologies, new services can be adopted to increase consumer (self-) management, which, in turn, would facilitate the P2P trading (Pereira et al. 2018a: 435). The following *Figure 7* provides an example of how such a smart grid structure could look like.

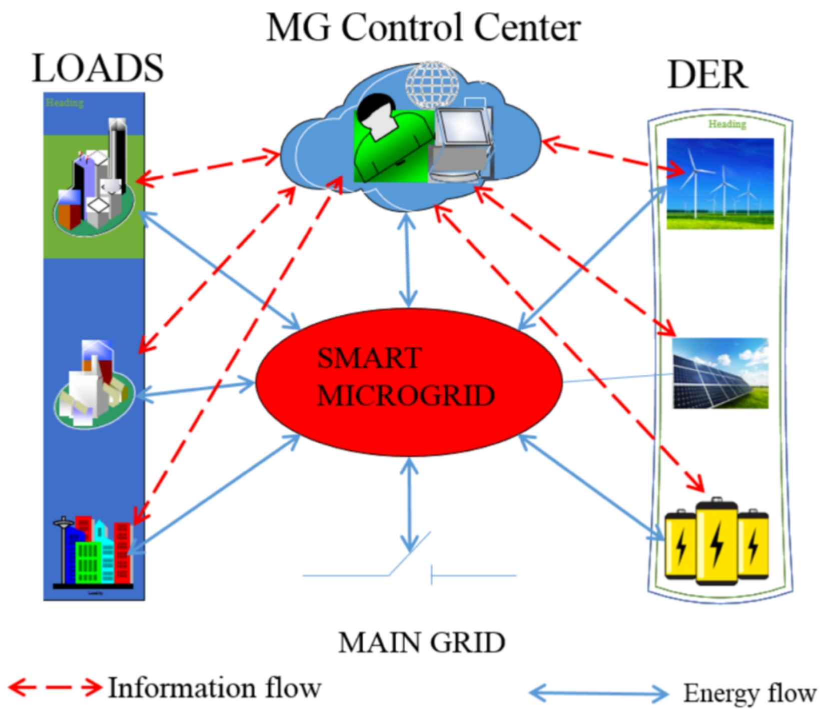

Figure 7: A smart microgrid (Jogunola et al. 2017: 5)

Within the smart grid, energy can flow from DERs (distributed energy resources) to the grid and the same for loads, while the information flows from DERs and loads to an MG (microgrid) control centre. A smart microgrid constitutes the smallest element of an electricity grid and can consist of only one self-sufficient household that produces and consumes energy on its own while having a storage system to stock power for later use, in case of overgeneration. The household appliances are interconnected via an MG network directly, while the information flow is managed by an agent, the so-called MG controller. The communication often happens over a wireless network using sensors, which collect and transmit data. This MG controller also assumes the responsibility to balance supply and demand on the MG in the most efficient way, similar to the task of a network operator for the main power grid (Pieroni et al. 2018: 301). The most significant difference here is that the smart MG controller is usually not a real person but a computer program which reduces reaction time and works almost instantaneously.

In the same manner, a microgrid could be expanded to incorporate numerous households to form a local microgrid that communicates with each other using the MG controllers. There are three distinct levels of trading: intra microgrid, inter microgrid and on the distribution level as illustrated in *Figure 8*.

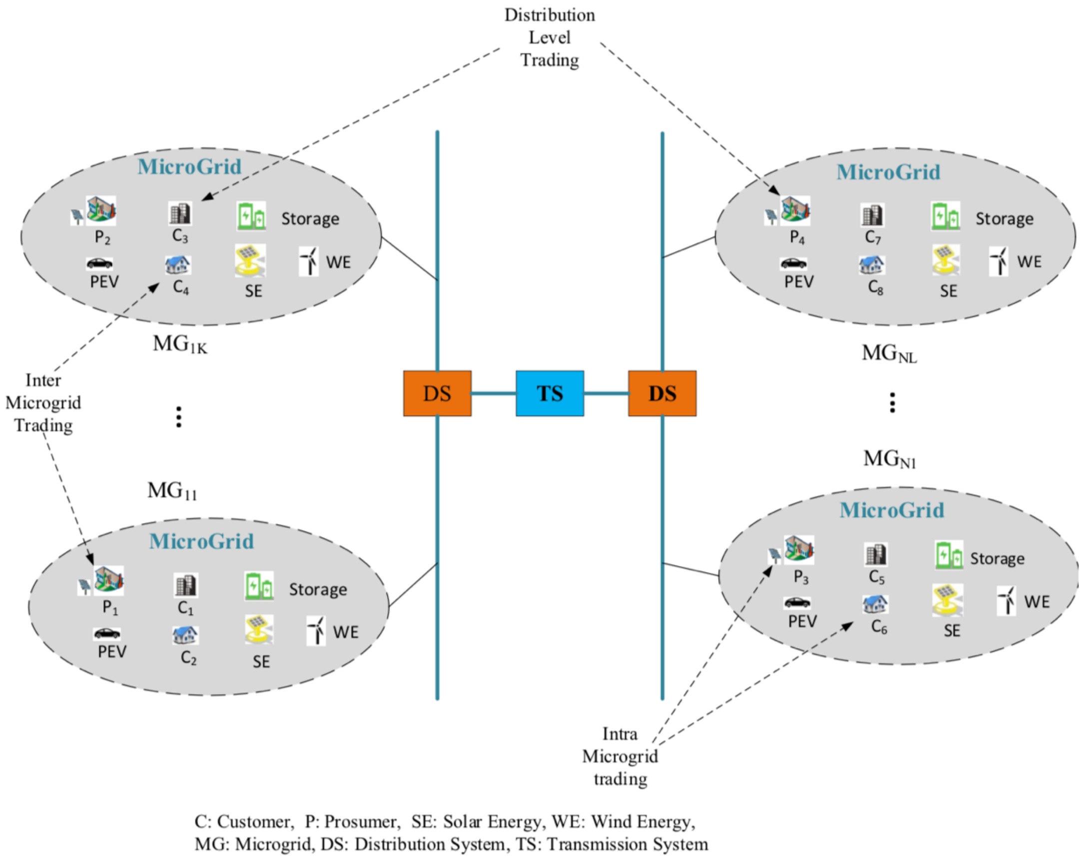

Figure 8: Hierarchical structure of microgrids and distribution systems (Abdella & Shuaib 2018: 5)

Intra-grid trading is referred to when actors within the *same* MG communicate with each other. These actors could include consumers, prosumers, home users or even industry users. As for inter-MG trading, it requires MGs to be connected to a distribution system (DS) which allows for this external communication, outside of the MG. The highest level would be the distribution level trading which requires a transmission system (TS) to enable the communication and power exchange, which is not the focus of this analysis.

Corresponding to the framework proposed by Parag and Sovacool (2016), the cooperative-based models proffer a base station aggregating electricity production of a prosumer cluster, which communicates with the main grid to sell excess energy in time of overproduction and to buy when the need exceeds the generation, using coordinated multi-point communication. The cooperation of the smart grid and the base station aims to manage the two-way power flow and strives to minimise the operation and transmission costs for all prosumers in the cooperative (Abdalla and Shuaib 2018: 7).

Traditionally, there was one single control centre that acted as the mediator that was responsible for the load scheduling to ensure the balance and stability of the grid. However, with the growing number of distributed RE generators, it becomes increasingly difficult to manage the load schedule due to the high uncertainty of production that depends on weather conditions. In this system, the central unit will collect data from all users and aggregate their production/consumption patterns to calculate the best distribution of the generated electricity (Abdalla and Shuaib 2018: 6).

Abdalla and Shuaib (2018) also give account of attempts to realise the concept of the decentralised energy trading of two microgrids, both of which operate disconnected from the main grid. The goal of this simulation is to enable P2P trading by using a central unit as controller to minimise costs of production and transmission while satisfying local demand. This model also proposes a local trading manager (LTM) who sets the power price on the MG with the outlook to make it more attractive and beneficial for MG users compared to prices on the main grid.

SonnenCommunity provides a good example of P2P using a central control unit. The membership costs around 20 Euros a month and gives its members access to ancillary services, such as weather forecasts, optimised energy management to match the consumption with the predicted production, and low-price energy. SonnenCommunity entirely relies on the power generation of its members and is completely disconnected from the central power grid. According to their website, excess energy from weather situations, e.g. storm, are collected and stored in a virtual pool of sonnenBatteries to be used later, when the weather conditions are not as favourable. Instead of investing in expanding storage capacity, sonnenGroup came up with a business model using their sonnenFlat-Box to encourage households to participate in relieving the peak by sharing their battery storage with the community. As compensation for allowing the sonnenGrid to access their battery storage for a few minutes each week, sonnenFlat members can consume a lump sum of energy depending on their contracts free of costs. This system only works with a sufficiently high number of participants within an adequate range of production and consumption to keep the balance, which is why the sonnenFlat-Box are only available to four countries Germany, Austria, Switzerland and Italy. Despite both the cost advantage for community members and the capacity advantage for the DSO, this communistic approach might not be to everyone’s liking (SonnenCommunity 2019).

Bauwens et al. (2015: 138) detect that locals' attitudes towards the cooperative model are much dependent on whether an established trend already exists, in which case, people would be more inclined to join the cooperatives. They explain that the awareness of the structure and its resulting benefits would convince new consumers to consider their participation, whereas, in areas, where this concept is rather unexplored, potential users might be even more hesitant and cautious due to the low awareness and lack of information thereof.

4.2.3 Operation and optimisation mechanisms

Another approach to promote the implementation of RES generators is the application of incentive-driven mechanisms to encourage contribution in the form of demand response. Actors should be motivated to offer their excess energy to others in exchange for the use of energy in a later time of need. The trading will happen between numerous participants, simultaneously (Abdalla and Shuaib 2018: 7).

With the help of an ACS/DC/ACs converter called "Digital Grid Router" the synchronised, high voltage grid can be split into smaller, asynchronous grids that communicate with each other via multiple IP addresses. The energy flow on the main grid is dependent on the impedance of the grid structure. Hence, adding RESs would increase its complexity and fluctuation due to the volatile nature of those energy sources. Therefore, the smart grid design aims to solve this issue of high volume of RESs integration to the main grid. Considering power routing which is the process of transferring electricity from producers to end-consumers who live in different areas, algorithms similar to routing data packets can be employed. Here, the physical distance from transmitter to receiver, which constitutes the highest amount of electricity loss in the process, must be kept at a minimum to achieve higher transmission efficiency. Moreover, future power router must adopt the ability to convert energy from diverse sources and forms into the required one to improve the grid performance and allow for its full integration (Abdalla and Shuaib 2018: 9).

Regarding the optimisation question, there are two approaches, the first one being the adjustment of consumers' and producers' behaviour to the price set by the LTM, and the second one being an algorithm through which the LTM can calculate a price that maximises the benefits of all parties on that MG. As an extension of this model, several actors are added. There are a utility company, a local trading market and a local trading centre (LTC) that is divided into two sub-categories: non-profit and for-profit LTCs. While the former operates to boost the profit of local grid users only, the latter focuses on maximising its own profit and benefitting other stakeholders along the way (Abdalla and Shuaib 2018: 6).

Furthermore, various forms of game theoretical mechanism and algorithms have been employed and tested to find out the most viable approach for the optimisation problem among traders. The trade, in general, has been facilitated by the improved data transmission structure, such as 5G wireless networks. This 5G technology contributes substiantially to finding new solutions for information and energy exchange between different stakeholders. As coordination of market participants is increasingly important for an efficient match making and balancing of supply and demand, a common standardised interface and language for the communication is of vital importance. While current energy trading platforms do a good job in match-making, the ever-growing number of distributed energy sources requires a highly expandable and scalable framework with strengthened stability and reliability in the long run (Jogunola et al. 2017: 14).

The smart microgrid structure discussed previously provides a solid foundation for a P2P market structure, as it requires a stable and fast communication between different agents in the network for exchanging of information about generation, demand and status. The more accurate and reliable the information, the more efficient the transaction. There are several algorithms that can be used in a multi-agent system (MAS) for information exchange. A multi agent system is a software technology which connects multiple components, also known as agents that act autonomously towards a common goal. These different agents can process the data collected from the sensors and communicate within their network to efficiently exchange information in almost real time. The information provided by all agents will help the system arrive at an optimal decision of how to best solve the task it has been set out to resolve (Cook et al. 2006). However, as their performance varies greatly, it is a challenge to find the right one. For instance, the graph-theory-based solution created by the so-called Ziegler-Nichols method which is applied on electric vehicles (EVs) exhibits that "information exchange [indeed] improves the system performance" (Jogunola et al. 2017: 10). The Ziegler-Nichols method is a mathematical model that provides heuristics to improve the reaction time of an automatic control circuit. A control circuit can be a feedback-based control-loop mechanism that collects and calculates input variables to find the right outputs which, again, will be the input for the same system. For instance, instead of computing the exact response based on the inputs, the Ziegler-Nichols method only calculates the ratio of the data points and induces proportional responses (Ziegler & Nichols 1942).

Another system simulation is based on the Round Robin (RR) technique. Round Robin is a routing algorithm used in the wireless network that features the clustering method to reduce the amount of data transmission and thus saves transferring time. It often functions as load balancer that allows parallel streams of data to be loaded at the same time (Nam & Min 2007: 54). The basic idea behind RR is the equal distribution among all participants according to the first in-first out principle, meaning that the first one that finishes will queue up and wait its turn. This method has proven to be very useful in routing network packages in parallel so that waiting time can be reduced remarkably (Van Steen & Tanenbaum 2017: 113). However, working with an increasing number of agents in the network proves to be unscalable due to the increasing steps required to establish the communication.

Yet, another approach using a minimum-spanning tree for the agent-based communication was proposed. That is, to find the path with the lowest edge weight which will deliver the shortest route for the communication between the agents. It employs the minimum path formation to transfer the messages. However, the interaction can only take place after the tree formation is finished. On top of this high latency, this reformation of the tree is necessary every single time a new agent joins the network, which renders it also impractical. There is another solution based on intelligent physical agents that not only requires fewer steps with a higher response rate but is also less complex compared to the algorithms mentioned previously. The only drawback of this model is that it demands an *even* number of participants for a functioning communication (Jogunola et al. 2017: 10-11).

Regarding optimised DR, the introduction of an energy sharing provider (ESP) might be a possibility to solve the balancing of supply and demand with a small mark-up on the net power price for the broker task. However, in addition to introducing communication delay due to an additional actor, this creates dependency on an ESP (Jogunola et al. 2017: 12).

As for storage possibilities, Lüth et al. (2018) find that the incorporation of batteries in P2P trading, indeed, increases energy savings up to 31% owing to the flexibility gained. Although the results of their simulation show that the battery usage is impacting P2P trading positively, the market design remains the main driver for a higher electricity cost saving (Lüth et al. 2018: 22-23). The investigation of the difference between private battery usage and to the community one reveals that the total savings of the former is 7% higher compared to the latter (Lüth et al. 2018: 22).

One of the most popular grid-friendly solutions to balance out the peak load is to add EVs to the equation. Due to their decent power storage capacity, they could contribute to the demand side management (Pereira et al. 2018a: 428). While Abdella and Shuaib (2018) report plugin EVs to be a key challenge to P2P DET, Kang et al. (2017) perceive the ability of (hybrid-) EVs to charge and discharge a great amount of electricity as an advantage. As the development of EVs charging stations has been ongoing for a while and is continuing, this could be a possibility for network providers to expand their business model and contribute to the DR management, as old business models would soon become outdated.

Regarding the optimisation mechanisms for the trading procedure, several bidding algorithms are examined most of which rely on game theoretical concepts. Here, it is crucial to distinguish between cooperative and non-cooperative game theoretical approaches. Cooperative games are those in which players can communicate with each other and their interlacing dependency strongly influences the pay-off functions of other players involved. As the outcome is an agreement that renders players involved at a better position than without the agreement, there is no incentive for players to deviate from this so-called Pareto optimum with their best interests in mind (Moulin 1995: 5-6). Whereas, in non-cooperative games, players have no means of communication to exchange information or collude. Due to this reason, their decision-making process is highly independent from those of the other players. In this case, the strategy of a player can only be formed relying on assumptions of how others might react by backward deducting from their pay-off function. Therefore, it can be said that while the former focuses on the outcome of the coalition of two or more parties, the latter merely considers the outcome of each individual and derives at a strategy to optimise that outcome. In a non-cooperative game, a Nash-equilibrium presents an optimal outcome for multiple players provided that each player knows the pay-off of the opponents, in which case, no other possible strategy could yield a better result. Therefore, this proposed algorithm delivers the optimal pay-off (Zhang et al. 2018: 5).

Among various game-theory-based models proposing how to manage the business transaction between sellers and buyers, Abdalla and Shuiab (2018) report about a trading algorithm that enables consumers to buy from their neighbours at a lower price than at the market. The price can be arbitrarily set by sellers, while buyers can play a game to choose the seller with the best outcome for themselves. The selection process is based on electricity prices and transmission costs, which vary depending on the physical distance from sellers to buyers, and the given grid transmission capacity. The simulation displays a positive result concerning cost optimisation for both sellers and buyers (Abdalla & Shuaib 2018: 8).

Another, also game-theory-based model designed by Marzband et al. (2018) utilises the Nikaido-Isoda Relaxation algorithm to arrive at the optimal outcome. Nikaido-Isoda relaxation theory describes an approximation of a strategy to achieve a Nash equilibrium in a multi-player game in which players face coupled constraints. Namely, the pay-off functions of the players are unknown, except for the pay-off of one player. This relaxation method only works under the presupposition that the history of previously taken steps of all players are known and that they will continue playing like they did in the past. At each step, the player with the known pay-off function will take the optimal response for his position assuming the others will continue applying their chosen strategies. Ultimately, the outcome of this algorithm will converge towards the Nash equilibrium (Krawczyk & Uryasev 2000: 66). The advantage of this model compared to the others is the unlimited number of participants. These are divided in three groups of players, namely, generators, consumers and retailers. Here, the issue of generation volatility and demand fluctuation is included and represented using statistical models. Outcomes of test runs reveal that this model allows market clearing price to be reduced by 4%. While consumer engagement in the DR doubled, the local generation of RE has become three times as high (Marzband et al. 2018).

Also, game-theory-based cooperative and non-cooperative strategies have been applied to match sellers with buyers in an auction game in which the number on both sides are equal. Based on an optimisation mechanism called particle swarm model, researchers have created a negotiating agent to support the electricity trading process (Jogunola et al. 2017: 11). The particle swarm is an optimisation mechanism established to understand birds' social behaviour regarding how they can regroup so quickly and achieve the synchronous movement despite sudden changes of directions. Experts conclude that the key to the synchronous movements is obtained by adjusting the interspaces to reach an optimal distance between individuals. There are two approaches that lead to the same goal. The first algorithm measures the movement vector of the nearest neighbour and adjusts the speed of the agent in question accordingly so that all end up moving synchronously. To increase the complexity of the system to simulate real birds' unpredicted behaviour, a "craziness" factor is introduced. After each iteration, it adds a random variable to the position and velocity of a stochastically chosen agent. The second model iteratively adjusts the current position by calculating the best possible momentary change for an agent. The present location is documented in an array that collects the coordinates of all group members which is available to the entire group. This accumulation of the optimal positions reflects the group's optimal destination that, in this case, represents a cornfield. These simulations also describe how information is spread among group members that enable birds to find the most recent food sources (Kennedy & Eberhart 1995: 1943-1944). The application of this optimisation technique in the auction mechanism has been reported to have achieved great results provided there is a well-established communication channel to spread the knowledge about the optimal outcome (Jogunola et al. 2017: 11). Additionally, simulations validate that the increased diversity in the microgrid greatly reduces power exchange with the main grid resulting in lower effort for the balancing responsible party (Zhang et al. 2018: 11).

Even though the application of ICT in the smart grid entails many advantages, there are still loopholes preventing the population from employing these new technologies. For this reason, the next chapter takes a closer look at these concerns and puts forward a possible solution.

4.3 Blockchain technology-enabled solutions

Even though the benefits of local trading on smart micro grids are proven, there are still doubts refraining prosumers from participating on the local market. The most prominent reason for all this is that they must rely on a trusted third party for coordinating and managing the trading. Disadvantages of the current system include overload of servers due to the ever-increasing amount of transactions, which could inflict a bottleneck on the market. Furthermore, the risk of being attacked and thus posing a single point of failure renders the current intermediary role of platforms a rather insecure one and deters many from partaking in the local energy exchange. However, the blockchain technology might be able to address all those weak points and provide more reliable interactions between market participants (Kang et al. 2017: 3154; Pieroni et al. 2018: 302).

4.3.1 Public and private blockchain

The blockchain technology is a distributed ledger system, in which each ledger is an identical copy of the others in the network. This feature renders it impossible to tamper with information stored in these ledgers, as they are backed up manifolds. All previous transactions are stored in form of blocks with time stamps, so that they cannot be altered retrospectively. Each block is linked with the previous one by a unique hash value to form a chain. Each block can be created by any computer with enough computational power to solve a cryptographic mathematical task which only works one way. In other words, these cryptographic hash functions create a hash output which is impossible to reverse-engineer within the short time window before the next block is generated. A tiny change in input would lead to an output which differs greatly from its previous input and thus is considered collision-resistant (Andoni et al. 2019: 145). Before each transaction, a verification process that seeks consensus of all nodes in the network is triggered to ensure the authenticity of users using the proof-of-identity concept to match with the data stored in all ledgers. This consensus mechanism is based on an algorithm that is called proof-of-work, which lies at the heart of the blockchain technology and secures its integrity. It requires all active nodes to solve a numerical task that demands high computational power. This process of creating a new valid block is called ‘mining’. The first one to crack the mathematical code will become the miner and obtains the right to execute the next transaction, and gains a token (a sum of money in digital currency) in return. Every time a new block is being added to the chain, ledgers held by all users will be updated to maintain the single point of truth. Also, the network will only execute a transaction if it was initiated by an authorised person who is also the real owner of the ledger. Here, the authenticity of information on the ledger that requests a transaction is matched with all other ledgers on the network. If consensus is reached, the transaction will be carried out; in case of discrepancy, however, the transaction will be cancelled (Boucher et al. 2017: 5). Hence, the blockchain technology can take over the verification process, carry out transactions and store all transactional records, thus making a centralised party redundant.

In the pilot project ‘Brooklyn Microgrid’, blockchain technology is already employed as the main ICT (Mengelkamp et al. 2018). Similarly, the project ViertelZwei which is still ongoing could provide the proof of concept for this approach in the Austrian market. Currently, the number of participants in this pilot project is rather small. However, over this longitudinal data collection might be able to answer some questions regarding the fluctuation of solar energy generation and consumption of Viennese inhabitants throughout the day as well as seasonal changes. However, they are still at the very beginning of this venture. Currently, they are collecting data of energy generated by the solar roofs, the amount of energy stored in the battery and the amount being exchanged between members in the community. While the price of the community energy is currently lower than the one from the grid, these prices are not variable but fixed by Wien Energie. Since their objective is to create the infrastructure and figuring out the presumption pattern of the residents, there is not yet a focus on finding a suitable pricing mechanism. As of the time of writing this thesis (2020) they are merely at the stage of consolidating and broadcasting energy consumption of the households to the blockchain, according to an insider source.

The reason as to why adding new information in form of a new block to the blockchain is rather costly is due to the resource intensity of the proof-of-work mechanism that requires all nodes in the network to join the verification process. Each node holds the right to create the next block in the public, also known as permission-less, blockchain. In its counterpart, the private blockchain, only specified validator nodes are entitled to write the next block as opposed to the permission-less one, where every node has this right. While the public blockchain is fully transparent and decentralised, the private blockchain is submitted to the control of its creator which undermines its transparency and decentralised characteristics. In other words, the public blockchain is deemed more secure because more nodes need to be overwritten at the same time to manipulate its content, whilst the private one is subjected to the control of its creator which might increase the risk of collusion; the great number of nodes that requires checking and matching results in the need for a higher power source while private blockchain can limit the proof of work to a certain number of nodes, which reduces the power usage significantly and thus enhances its speed. This means that the financial advantage or transactions must be limited so that it does not incentivise collusion or external attack. Besides, despite the 'small' number of participants in the network, the computational power necessary to compute the answer to receive the permission to write the next block is still relatively high so that it still requires a computer with a super powerful processor to fool all the individual computers in the network collectively. Leveraging both advantages and disadvantages of both models, there is a hybrid-model that combines the best of both worlds named 'consortium blockchain' (CB) which will be the focus of the next chapter (Pieroni et al. 2018: 302; Andoni 2019: 147).

4.3.2 Consortium blockchain

CB lies in between the public and private blockchain and has a semi-decentralised infrastructure. It is neither fully accessible by anyone with internet access like the former nor under the control of one single enterprise or individual like the latter. The application of CB could be collaboration of multiple cooperation in certain areas to draw on their synergies and shared resources in the development process (Kang et al. 2017).

CB works based on a consensus mechanism whose shared ledger consists of multiple authorised nodes with lower costs compared to a public blockchain. Its application in the energy sector works as follow: authorised nodes act as local aggregators (LAGs) that collect all transactional records and publicly verify and share them with all the distributed ledgers, completely without involving a trusted third party (Kang et al. 2017: 3156).

Incorporating the **Con**sortium Blockchain for the **P**2P **e**nergy **t**rading (PETCON) uses a different consensus algorithm which means that, instead of involving every single node in the network, the consortium blockchain only works with the designated ones to save energy caused by the overly high computational power required for the process (Kang et al. 2017: 3156).

PETCON's structure consists of three components: a transaction server, an account pool and a memory pool. The tasks of the transaction server include controlling switches from the charging poles to its destination, while the memory pool is responsible for storing all transaction records in the consortium blockchain (Kang et al. 2017: 3156). Addressing security questions, Kang et al. (2017) go into more details regarding characterising the blockchain, such as the dismissal of a trusted third party, immunity to hacker attacks due to the hash values integrated in distributed ledgers. Moreover, the additional audit will ensure the authenticity and the integrity of all parties involved. The result of the simulation of over 1000 cases proves that a double auction algorithm indeed helps both bargaining parties to yield the best outcome. It works by determining the ideal amount of energy that should be sold at a specific price level and thus maximises the social welfare (Kang et al. 2017: 3155, 3163). In the double auction, both sellers and buyers simultaneously place their bids which include the asking or bidding price and the number of units to be sold or bought, respectively. Lowest asks and highest bids constitutes the clearing price and the number of units placed in the bids get sold. In the next round, sellers and bidders must lower or raise their bids to get their match. By using this double auction mechanism, the outcome provides an optimal allocation of resources as both asking and bidding prices represent the true value of the good sold in the transaction (Liu et al 2009).

While CB has its advantages such as reduced computational power, it is not fully decentralised as prove of work can only be done by authorised nodes. This limitation renders it less trustworthy as it is more inclined to be corrupted. CS would make a good platform for enterprise cooperation but is not quite suitable to become the backbone of the energy transition towards a fully automated and decentralised grid operation for the public. The next chapter introduces another blockchain based technology that offers the possibility to include everyone in the process.

Taking the advantage of the blockchain technology a step further and utilising its full potential, which is to reduce manual interaction with the system to a bare minimum to eliminate human errors, smart contracts might provide itself useful. Hence, the next chapter is dedicated to the employment of smart contracts and its contribution towards a completely decentralised electricity system.

4.3.3 Smart contracts

There are various reasons as to why smart contracts are going to be the key to the future of decentralised energy trading. Decentralisation distributes the power from the few to the many which might enable individuals to take control over their decisions which, in turn, could improve their consumption behaviour and influence the market price positively. Increased autonomy leads to increased agency and broken monopoly or oligopoly power structures which ultimately lead to a more balanced market and resultingly a more dispersed market power. Increased information gathering process gives individual the direct power to influence their electricity bill while influencing the market price, it reduces the power position of big players. Consequently, the dynamic efficiency will increase as the more participants contribute, the lower the price will drop, according to the basic market mechanism.

First of all, as discussed previously (Chapter 2 and 3), the complexity of the energy market requires extended knowledge of the field and comprehensive understanding of the law and regulations of the local market. Secondly, to set up contractual relationships often demands some trusted third parties like a notary or similar middlemen to make contracts legally binding and ensure its reinforcement. Thirdly, it is not easy to keep track of the fast-changing prices of the strongly fluctuating commodity such as electricity. Hence, small-scale prosumers are deterred from joining the power exchange without the provided affinity towards the subjects or reliable tools that help them facilitate the decision-making process to arrive at the right one. Therefore, this chapter will discuss some aspects of smart contracts and address the mentioned issues.

Cornelius (2018: 10) declares that smart contracts merge "electronic contracting and cryptography" and constitute a "legitimate binding self-contained document", which means that smart contracts include the same commitments as a hard-copy contract, whilst also offering a higher level of security and encryption. The content verification and transaction records take place in a decentralised manner, matching previous actions and data with multiple distributed ledgers, and thus rendering it trustworthy without requiring a notary or other similar institutions to prove its validity (Boucher et al. 2017: 14). This not only saves time as it can happen anytime and at a considerably higher speed.

However, the immutability which counts as the core value of this system is, at the same time, a vulnerability thereof, as mistakes abide by the same rules (Boucher et al. 2017: 14). Hence, regulators must intervene to ensure a satisfactory conduct to protect users. Additionally, intervention can see to it that tax rules and other consumer protection laws are properly adopted and integrated in the code to avoid misuse of power (Boucher et al. 2017: 15; Cornelius 2018: 10-11).

The smart contract triggers transactions of goods and payment once the pre-programmed conditions are met. In other words, only if the amount of energy can be generated and successfully transferred, and the buyer has enough tokens, the system native currency to pay for the service in question, will the contract be carried out. Boucher et al. (2017: 14) recommend applying this type of contract in a repetitive environment, in which similar transactions take place every day for the high effort invested in the set-up to be worthwhile. An additional advantage of employing smart contracts is also the anonymity of actors involved in the transactions allowing them access to real-time feedback of their energy usage and energy production (Pieroni et al. 2018: 303).

On top of this, Boucher et al. (2017) advise policy makers to draft a new law to clarify the position and application of smart contracts so that, in case of unpredicted events and unresolved conflicts, national law enforcement can intercede and settle the disagreement to protect consumers at a weaker position (Boucher et al. 2017: 15).

Ryan (2017) examines the social relationship which, she claims, makes up a substantial part of the contracts before the digital age. Before the digitalisation, partners entering a social contract usually knew each other in person and thus trusted that the other party will deliver exactly as agreed upon. Since privacy and security in the internet era have become the focal point, anonymisation of trading partners in these smart contracts is very welcome, as it uses the zero-trust approach which ensures authentication of users relying on the internal proof-of-work concept. By matching the previous hash value with other nodes in the network, it will take the new input data to create a new hash that will then be shared with other nodes. Due to its immutability, once a hash is created, it will become a historic value that can only be read but not altered. However, this very feature makes the settling of disputes and law enforcement difficult in adverse events to trace back to the person behind the pseudonym used for the online trade.

However, the innate characteristics of a blockchain based smart contract prohibit these adverse events from happening in the first place despite anonymity of trading partners. Consider the example of P2P trading in which a seller offers a fixed amount of energy for a given amount of system native crypto currency. This information is coded in a smart contract that is published on the blockchain that is accessible to anyone with connection to the internet. A buyer wants to accept the offer and sends a smart contract that includes the amount of crypto currency asked for the entity to be sold plus the transaction fee for the miner who will check for validity of the information, also known as *proof of work*, in the smart contracts before executing the code to write a new block which is then added to the chain. Once the state of the blockchain is changed, all the nodes in the network will automatically update themselves to include the most recent piece of information which provides the reference for the next *proof of work* to be checked against. Therefore, it is not possible for a buyer to consume the good and not paying or vice versa, there is no case where the seller takes the payment without delivering the good. Once, the contract is written and broadcast to the blockchain, the good is locked in the contract until the offer expires or the good gets sold. Either way, the seller will surely receive either the good back or the money asked for it, minus the transaction fee for the executioner of the contract (ibib.).

Concerning initiatives for DR and how to remunerate participation in relieving peak loads, Conejo and Sioshansi (2018: 529) assert that since DR will play an increasingly important role in the future energy market, it is essential to explore possibilities to automate this process, for instance, by using smart contacts. According to them (ibid.), consumers prefer fixed prices over the flexibility of varying prices. It is argued that the effort put into finding the right offer and, afterwards, to adapt their consumption behaviour accordingly, does not pay off. Therefore, a smart home system that can record inhabitants' consumption behaviour and autonomously act on their behalf would bridge this gap and encourage consumers to participate in DR (Conejo & Sioshansi 2018: 524). To foster this development and eradicate the disadvantages of current electricity trading systems, a blockchain-based smart contract presents itself as highly useful (Pieroni et al. 2018: 302).

Although smart contracts can facilitate and automate daily transactions such as in the energy trading by eliminating the middlemen which can result in reduced cost and time for sellers and buyers, it could pose some challenges for the regulatory authority. These start with the lack of infrastructure and knowledge of the technology to provide incentives for its adoption. The lack of awareness for its existence might let its advantages go unnoticed. Therefore, authorities are the key to bridge this gap and provide an enabling environment in which market participants are encouraged to experiment with and make use of these new technologies. That is to create a fostering framework that accounts for unforeseen circumstances and provide the participants with security and support necessary to engage in the digital transformation. Therefore, the next section focuses on regulatory mechanisms facilitating changes on the electricity market.

4.4 Regulation and support schemes

This chapter focuses on the development of energy directives and regulations that are currently active and attempts to find solutions for future changes. The first steps in setting incentives for the innovation and integration of RESs is a tax levy on “fuel for lighting, heating, and power used by business consumers including those in industry, commerce, agriculture, public administration and other services” while exempting RESs (Jenkins et al. 2015: 415).

Experts have acknowledged that the limitations of current regulations prohibit innovations and developments of the smart grid (Pereira, et al. 2018b: 8). Moreover, Pereira et al. (2018a) address the grid disparity in the supply side concentration across Europe. Opposed to Germany, where there are 880 DSOs operating, Ireland, Portugal and Lithuania still have only one single DSO that holds the monopolistic power despite the unbundling directive in the Energy Package released by the European Commission in 2009 (Pereira et al. 2018a: 428). Facing the risk of stranded investments, grid operators with monopolistic power have no incentives to invest in research and development to improve or expand their existing network without external motivation (Pereira et al. 2018b: 9). However, as smart grids would offer the benefit of an easy integration of RESs into the existing network to expand the current capacity without a system upgrade or increased overhead expenses, regulators should promote their adoption more vigorously (Pereira et al. 2018a: 428).

According to a survey, 62.1% of the experts on this topic have backed the establishment of an independent regulator focussing on the transition to the smart grid framework (Pereira et al. 2018b: 12-13). Furthermore, they have acknowledged the important role of DSOs as facilitators of services providing a platform and other services. They recommend policy makers to take this aspect into account when creating incentives for DSOs to invest in a nourishing ground allowing for new players to enter and contribute to the dynamic efficiency in the energy market (Pereira et al. 2018b: 17). Another possible approach to encourage operators to innovate their business and improve their performance is to simulate competition by comparing key performance indicators (Pereira et al. 2018a: 428). In addition to adjusting the existing structure to become future-fit, new tasks could be imposed upon DSOs, such as to act as a data hub for compliance with the General Data Protection Regulation (GDPR) as well as to provide a platform or marketplace for exchanging services and ensuring a correct conduct (Pereira et al. 2018b: 11).

The probably most widely applied approach is the rate of return (RoR) and incentive regulations. Cambini and Rondi (2010) have examined both approaches regarding investments made to improve the infrastructure and increase the quality of service provided. Since delayed investments can result in huge losses of social welfare, it is essential to encourage timely investments. In their work, Cambini and Rondi (2010) thus investigate the sensitivity of investments to certain regulations in order to answer the ownership question of the RE generators, as private ownership is correlated with a higher investment rate. The results display a higher tendency of investment under incentive regulation than under RoR. However, the X-factor influences the investment rate in the EU energy utility negatively. Furthermore, it is important to note that the concurrent Averch-Johnson effect is often present where firms with monopolistic power position invest heavily to increase their asset base without improving their productive efficiency, exactly as forecasted in theory. When using a price cap, firms are incentivised to improve productive efficiency, as they can keep the entirety of the increased profit. However, as elements of RoR regulation and fixed price incentives are employed, the resulting effect cannot easily be associated with any one single tool (Cambini & Rondi 2010: 2-4).

The integration of RESs into the conventional power grid causes various issues and uncertainty due to external factors. Additionally, this variability on the generation side can cause prices to fluctuate, and thus renders the market unattractive for risk-averse investors and drives risk-premiums towards the higher end. Therefore, it is mandatory for regulators to intervene and address this missing-money problem by promoting DR solutions and raising awareness of their advantages. The type of support scheme chosen has a great impact on "the degree to which renewables influence the market" and thus plays an essential role in propelling the green energy movement forward (Winkler et al. 2016: 157).

Among approaches to promote the integration of RESs in the main grid such as investment grants, feed-in tariffs (FITs), feed-in premiums (FIPs) and green energy obligation (GO), also referred to as the “quota scheme” and capacity-based support schemes, FITs and FIPs are the most popular ones. Fixed FITs consist of a constant payment towards the power generator for each unit of RE produced. The downside of this scheme is that plant operators are incentivised to produce at their maximal capacity disregarding the actual market demand. Therefore, the more efficient tool of FIPs are introduced, in which RE generators are rewarded with a fixed or variable premium added to their regular revenue. This approach encourages energy generators to produce just enough to satisfy the market demand instead of overproducing, since the FIP only covers the opportunity cost if the demand turns out to be below the expected level (Winkler et al. 2016: 158). Moreover, Jenkins et al. (2015) report that the calculation of the feed-in tariff rate uses the retail price index with a degression variable which already accounts for the decreasing costs of RESs. As the price for its technology drops, the feed-in tariff would shrink as well. In the long run, the subsidy level is expected to converge towards zero. To include the real technological development in the calculation, this tariff is being readjusted every three months (Jenkins et al. 2015: 417). However, as monetary rewards for the capacity-based scheme disregard the actual output, it could lead to inefficiency regarding the installation of capacity, leading to an issue similar to the Averch-Johnson effect. It should be kept in mind that this subsidy could, however, create an undesirable side-effect which is production maximization disregarding the market signals (Winkler et al. 2016: 158-159).

Regarding the quota scheme, following recent developments on the EEM and the Renewable Obligation imposed by the EC, the so-called ‘green energy certificate’ was introduced. For each produced MW/h within a period of 15 years (in the case of Norway), operators will receive a green certificate. As electricity producers and some industrial consumers must fulfil the green certificate quota, operators with an excess number of certificates can sell them on the certificate market to increase their revenue in addition to the income generated from producing and selling electricity on the energy market. This secondary source of income constitutes a support scheme that should encourage investment in RESs and reduce governmental spending on subsidising green energy. It can be claimed that these certificates, when issued, aim at reducing the risk faced by distributed energy generators, especially wind power developers. As this support scheme should mitigate commitment issues, investments in RESs are expected to increase accordingly (Jenkins et al. 2015: 414). Furthermore, CEER (2018: 8) reports that FIPs contribute the most to the growing number of RESs integration.

However, in their analysis, Hulshof et al. (2019) reveal the lack of transparency in the certificate market. They, furthermore, add that the volatility of the certificate price decisively adds to its inefficiency and, thus, leads to low adoption. Besides, the churn rate has been reported to be rather low. The authors surmise that this effect is the result of the missing international standard and that its volume would rise if they introduced one. Also, they suggest to increase transparency in the certificate market by improving the accessibility of information available. This step would not only facilitate research on the RE market but also raise the liquidity of the certificate market (Hulshof et al. 2019: 707).

In addition to the support instruments mentioned, the priority treatment of RESs regarding network connection and electricity dispatching exists (CEER 2018: 8). The former means that, whenever RE is produced, network operators will guarantee free access to feed-in to the grid while the latter ensures their preferential order of dispatch in case of low transmission capacity (CEER 2018: 32). Moreover, regarding congestion management, RES generators are to be compensated first and curtailed secondary to fossil power plants (CEER 2018: 33). However, the merit-order effect resulting from this approach could, in the long run, lead to a sustainable price. While this low price is beneficial for consumers, it might deter investments in RES schemes due to the inability to cover investment costs without additional support (Winkler et al. 2016: 159).

Besides direct support schemes and priority treatment of RESs, there are also indirect methods to relieve small-scale RE producers, like tax exemptions for self-consumption. It is argued that these small-scale RE generators and their integration at the distribution level would, in near future, drive Europe’s energy system. Also, they will substantially contribute to the consumer empowerment and to reaching Europe’s goal to become the frontrunner in green energy production (CEER 2018: 37).

To enable the contribution of the said small scale RE generators, the new market will require elements that allow for the storage of excess energy, which need to be taken into consideration when designing new regulations and pricing schemes (Lüth et al. 2018: 3). An appropriate price, on the one hand, needs to be competitive, and, on the other hand, must generate enough return to attract prosumers to invest and conduct business in the local market.

In short, the regulatory tools discussed above would provide a solid and enabling framework for future developments in the EEM. After detecting issues and weak spots of the current regulators, it is time to design a more suitable EEM to pursue its goal. Shifting the focus from increasing grid efficiency towards maintaining its stability due to the high volume of RESs is best supported by employing demand response. Hence, the most important step is to increase awareness of the ongoing transition on the electricity market. Clearly, the focus has been shifted from expanding and increasing capacity to integrating small RESs to utilise their DR potential to stabilise the grid facing the rapidly growing volume or RE plants.

Furthermore, to take advantage of the ongoing trend in the direction of digital transformation and integration of advanced ICT such as blockchain based smart contracts it might be necessary for authorities to increase awareness of its existence by promoting the possibility of its applications through workshops in which uncertainties can be addressed and resolved. This also provides the stage for communication and ideation of new solutions.

5 Discussion

Since traditional power grids are designed to dispatch a large amount of energy from rather centralised power plants, the incorporation of a high number of RE generators poses a hurdle and requires large investments to expand the existing infrastructure. The European Commission has put much effort into the establishment of a European Electricity Market with support of new institutions such as ACER and ENTSO-E. Together, these institutions have achieved to introduce a common code of conduct and standards to guide Member States towards the goal of becoming the global leader in green energy production.

The fast development of ICT has driven the digital transformation of various areas in our daily lives. Along with rapidly decreasing costs for RESs deployment on the small scale, we are gradually moving towards a new era, in which prosumers are becoming a fundamental part of the new electricity market, thus taking over the role of DSOs to balance the grid. Due to smart technologies such as smart meters and smart grids, energy efficiency and performance of the power grid has improved manifolds and is steering towards the decarbonisation and zero-emission target.

Heading for a more sustainable energy future, disruptive changes in the infrastructure and utilities are mandatory. Due to the intermittent characteristics of natural energy resources, these require a more flexible, close to real-time trading scheme, which possesses the capability to respond quickly to unpredictable supply. For these reasons, new regulatory measures and appropriate incentives are necessary to encourage investments in enabling technologies and active participation of prosumers, both of which are fundamental for the establishment of platforms facilitating the direct P2P trading. This form of trading has proven to be the most effective solution for this highly volatile environment. Here, the double auction mechanism provides the best results in terms of pricing and the amount of energy to be traded.

As the P2P network is growing at a rapid pace and ICT is becoming more capable, current centralised transaction management might develop into a liability concerning security, which, in turn, might compromise the grid's performance and stability. To overcome these limitations, the blockchain technology presents itself as an ideal candidate fulfilling all three core values of the CIA principles, namely, **c**onfidentiality,

integrity and **a**vailability. In other words, access is given only to those authorised; the data stored cannot be manipulated and is always available. Using the distributed ledger data structure, not only is the trusted third party eliminated but also the risk of having a single point of failure, rendering it a rather robust transaction system. To take this system a step further, the blockchain-based smart contract could be employed to automate transactions completely without human interaction. This simplification should expand the access to energy trading and attract more market prosumers to take part in the process. However, as this technology is not yet market-ready, policy makers adapt current legal systems to reduce uncertainty and safeguard consumers' position and rights against misconduct.

Within the next ten years, a considerable amount of money will be invested in upgrading the current network to make it fit for the digital era (Andoni et al. 2019: 144). Hence, it is recommended that incumbent networks and energy providers invest in expanding their business model and provide ancillary services as well as trading platforms for future P2P trading, as a big revenue generating sector will break away once the prosumers take over the electricity market in full. Therefore, network providers would be well-advised to extend their network to provide charging stations for EVs as this new business field might be substantial for their survival in the era of electrified mobility.

Moreover, it is advisable to establish a regulatory body that specialises in digitalised business models with the incorporation of smart contracts to ensure a safe environment for conducting businesses, especially in the coming age of the internet of things. During the transition period, traditional electricity producers need to be encouraged to diversify their product portfolio by looking for new business fields to invest in. Despite new technologies like hydrogen cars, which could be more energy efficient, heavy investments made and the involvement of numerous stakeholders are securing the future of EVs. Hence, including them in the balancing process is proven to have an immensely positive impact on relieving peak loads. However, due to the inefficiency of energy storage capability and resource intensity in the production of current batteries, it will take a few years' time for this solution to be fully realised and to benefit the power grid regarding its operation's reliability and stability.

The future energy market can be self-sufficient by relying on micro grids to supply small local areas. Since an optimal number of households – a number that is large enough to compensate for each other's deficiencies, and small enough for the power loss to be kept at near zero – participate in the network, its stability can be ensured as demonstrated by the examples of *sonnenCommunity*, *Brooklyn Microgrid* and *Vandebron*. Furthermore, since the energy loss in long transmission distances could provide a small local area with enough energy, it makes sense to rethink the scale in which electricity is being transferred. Instead of expanding transmission lines to transmit energy generated from Northern Europe to Southern Europe, capital might be better invested in adjusting existing infrastructure to enable a bidirectional flow that allows for local P2P trading. Additionally, future-ready technologies, such as artificial intelligence and the internet of things, could draw on information from various online sources as well as on recorded behavioural patterns to improve the exchange of energy on the P2P scale. In particular, they could support individuals in accurately predicting their future production and consumption, so that the network operator can compensate for the disparity with minimal effort.

Since externalities and social costs of fossil energy are not included in the electricity price when compared to RE, the comparison is skewed and does not entirely reflect the real cost. This social cost consists of health and environmental costs which eventually must be borne by the entire society (Owen 2004: 128). Therefore, it might be more purposeful to recalculate and include the externality costs in the final energy prices for a more correct display thereof. Furthermore, it is also important to bear in mind and compare externality cost between producing batteries for EVs and supplying energy from fossil sources. Depending on the battery type in use, the carbon emission level of its production might nullify the positive effect of RE generation (Majeau-Bettez et al. 2011).

Smart grids and their potential to relieve transmission lines and SOs to balance supply and demand, especially for the highly volatile RESs, could provide *a* good solution for the future of the energy industry. Combined with the emerging blockchain-based smart contracts and smart home solutions, the smart grid can provide a fully automated and efficient tool to approach the green energy transition. To facilitate the establishment of these new technologies, regulators are required to set the right incentives for investment to keep monetary subsidies as low as possible, such as by relieving taxes on RE generators and increase those of fossil sources for big players. Another approach that might set the direction for big players in the field to follow suit is to simply lead by example and invest in new building projects and establish a positive trend to increase the acceptance in society. On the side of the end-users, however, it might require initiatives that allow small communities to join resources as the risk is spread evenly among and borne by all the co-owners. Furthermore, this method enables nearly everyone to jump on board and be part of the energy revolution.

In addition to harvesting solar energy, other sources such as wind, hydro or even thermo are still under investigated. Adding new ways of extracting energy from diversified sources is perfectly in line with the idea behind the theory of decentralisation the focus of which is to shift the power position from the few key energy generators and main grid owners towards smaller players and seize the potential to empower individuals to take control of their presumption. One of the possible results might be increased awareness towards energy consumption which, in turn, could lead to proactive DR of individuals. As DR has been declared to be one of the key factors in relieving peak load and congestion of the grid infrastructure, engaging participation on the household level could have a significantly positive impact on the network structure. To reinforce this effect even further, prosumers could engage in energy exchange to even out the demand and supply on the local scale and become more self-sufficient using DERs.

6 Conclusion

This thesis started out to cover some of the regulations known to the public utility and went on to describe the market structure of the traditional electricity industry and changes it has undergone in the last two decades. The consequent chapters made the transition of the current energy market the subject of discussion and put forward approaches and optimisation mechanisms in support of adjustments that scholars deem necessary for the digital era and energy evolution that is currently taking place. Afterwards, concrete technologies such as blockchain-based smart contracts were introduced and their advantages highlighted with respect to facilitate peer-to-peer trading of renewable energy from distributed sources, followed by recommendations for regulatory authorities to improve adoption of this new strategy. Returning to the question posed in the introduction of this thesis, the next paragraphs will emphasise some of the prominent aspects relevant to each of the topic.

- How can the distributed generation of RE and the employment of energy storage systems reduce CO_2 emissions and electricity price while leading to a socially better outcome?

The European energy market currently constitutes of five main pools that collectively supply the entire Europe. Due to this division, cross border transmission has become the key means to compensate for the supply and demand of energy in form of congestion management in certain regions. Hence, energy often flows across Europe to get from the generation site to its final destination which is highly inefficient due to the physical constraints. Here, the heuristic applies: the longer the distance the higher the loss. Therefore, distributed generation of renewable energy paired with the employment of smart storage systems can balance out the peak production and compensate for the usage at a later time. This would enable prosumers to become more self-reliant in terms of energy production and become less dependent on and thus undermine the power of the main electricity providers. This increased agency of their own production renders prosumers self-sufficient and raises the awareness of their consumption behaviour which provides them with insight and internal motivation to adjust and contribute to DR. This would, in turn, help simplify the congestion management and reduce network operators' cost which is reflected in energy price consumers are paying for. In this regard, investments in expanding the network beyond the borders is no longer required once the focus of the power generation is shifted to the regional context, which would bind less financial resources from the network operator's point of view.

- Which regulatory mechanisms can be adopted to encourage competition and investment in innovation of technology?

As the current energy market lacks the enabling infrastructure required to fully exploit the positive aspects of smart grids and its implications, regulatory authorities are in need of new mechanisms to encourage competition and investment in technology. In order to attract those wanting to participate, strong signals must be sent, starting with raising awareness of RE solutions. As DR has been highlighted as a major contributor to relieve congestion management and stabilise the grid, it is becoming increasingly important to engage small-scale producers to invest in RE generators so that they become less reliant on the main power grid. For instance, by lowering taxes on RE generators, regulators can be incorporated in the house building process. However, to invite individual to become part of the prosumers community, local authorities need to provide an infrastructure that enables and simplifies participation such as guidance and support concerning new technologies.

- How can smart contracts add value to P2P electricity trade and what role it will play in the future energy market?

Blockchain-based mart contracts can boost the implementation of distributed RESs even further due to the numerous characteristics that have been proven to be highly useful, especially in online trading as discussed in chapter 4.3.3. One of its best-selling points is the elimination of trusted third party and self-reinforcing characteristics which saves time in signing agreements and later in its execution. As conditions are recorded in form of algorithms and code which will ensure that the contracts will exclusively be executed once all required conditions are fulfilled from both parties. The immutability of the underlying blockchain ledger technology safeguards it from ill intentions of one of the trading parties, which renders middlemen like notary services redundant. Furthermore, the ability to gather information from diverse sources from the internet and collecting consumption data, smart applications can support end-users in making informed and thus better decisions. Computers can process huge amount of information that is unimaginable to human beings. Therefore, provided with the right sources and residents' preferences, the integration of smart contract will be able to empower prosumers and facilitate the peer trading process which will benefit their community and the society at large.

To conclude, the energy future requires active participation on all levels which starts with the change of the mindset. Game theoretical approaches coupled with ICT translated into regulatory measures is one sure way leading to success. Furthermore, it can be said that one of the best approaches to find out the right fit for each local market is to design simple models based on suggestions given by experts and directly apply them to different local communities. By observing the resulting effect on specific market, adaptive changes can gradually be added and to address the deficiencies and finally arriving at the best solution for the given circumstances. However, human behaviour is only predictable up to a certain extent, there is no one-size-fits-all solution which can be universally applied and achieve the same result. Therefore, the best one can do is to pick the method that has been successfully applied and tailor it to the need of the community in question based on its preferences and restrictions.

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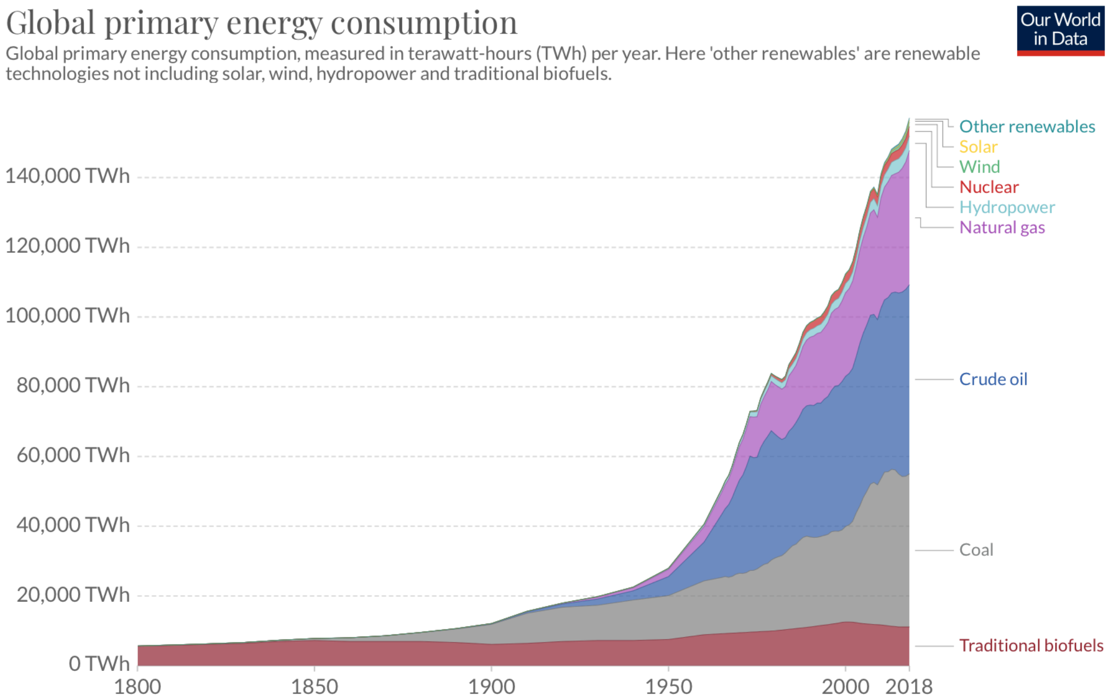
Abstract

The long overdue redesign of the European power system requires a break-up of the main energy pools into smaller, regional and distributed energy generators. This small-scale on-site production of renewable energy can contribute positively to demand response, which will help to relieve congestion and thus to reduce cost. Owing to blockchain-based smart contracts, prosumers are encouraged to get involved in direct trade using the peer-to-peer network. This technology can provide users with insight, eliminate third parties, increase users' agency and undermine the market power of the main providers. Applying the appropriate regulatory mechanisms can accelerate this transformation. All of this can facilitate the participation in green electricity generation and contribute towards a more sustainable power grid.

Zusammenfassung

Die längst überfällige Neugestaltung des europäischen Stromnetzes erfordert eine Aufteilung der Hauptenergiepools in kleinere und regionale Energieerzeuger. Die Vor-Ort-Produktion von erneubaren Energie kann einen positiven Beitrag zur Entlastung der Stromnetze leisten und damit die Netzstabilität erhöhen und die Kosten senken. Darüber hinaus ermutigen blockchainbasierte Smart Contracts Prosumer dazu, sich über das Peer-to-Peer-Netzwerk am direkten Handel zu beteiligen. Die dadurch geschaffene Transparenz eliminiert Intermediäre, erhöht die Entscheidungsfreiheit der User und verringert die Marktmacht der Hauptanbieter. Mit den passenden regulatorischen Maßnahmen kann diese Transformation beschleunigt und vorangetrieben werden. All dies kann eine breitere Beteiligung an der Ökostromerzeugung erleichtern und zu einem nachhaltigeren Stromnetz beitragen.

Appendix



Appendix 1 Rising global energy consumption (https://ourworldindata.org/energy#all-charts-preview) Retrieved on May 22nd 2020