Blockchain Potential in the Energy Sector

A Qualitative Analysis of the Peer-to-Peer Energy Ecosystem
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I. Definition of Abbreviations and Term

Term	Description
AC	Alternating Current
BNetz	Bundesnetzagentur - German Federal Network Agency for Electricity, Gas, Telecommunications, Postal Services and Railways
BEV	Battery Electric Vehicle
BSI	Bundesamt für Sicherheit in der Informationstechnik – German Federal Office for Information Security
DC	Direct Current
DER	Distributed Energy Resources
DSO	Distribution System Operator
Ecostructure	Ecosystem Infrastructure
EV	Electric vehicle
P2P	Peer-to-peer
PHEV	Plug-In Hybrid Electric Vehicle
PV	Photovoltaic System
TSO	Transmission System Operator
V2G	Vehicle-to-grid
V2X	Vehicle-to-X

II. Abstract

In the 21st century, technological advancements and policies regarding climate change have facilitated a big transformation in the energy sector. The key driving forces of this transformation are decentralization, decarbonization and digitalization. Blockchain and distributed ledger technology have the potential to remove centralized actors and intermediaries to achieve efficiency gains. Therefore, blockchain could also help address the decentralisation and digitization challenges of the energy sector. The purpose of this study is to discover the biggest challenges and the greatest opportunities for blockchain in the energy sector. Our focus is the potential of blockchain-based P2P energy trading within the energy sector. We will analyse the P2P energy ecosystem in terms of its current technological maturity, its present market readiness and the state of the German regulatory environment. We examine the advantages, disadvantages and main challenges of current business trends in this sector by interviewing the most important actors and associations. Besides the energy industry, we will also touch on the e-mobility industry, because we highly believe that electric vehicle batteries will act as a storage buffer for energy in the future and electric vehicles will be active participants of the energy sharing ecosystem.

1. Introduction

In the beginning of the 21st century, a huge transformation started in the energy sector. This transformation was triggered on one hand by the international policies addressing climate change and, on the other hand, by technological development in terms of power generation and IT. The three key driving forces of this transformation are: decarbonization, decentralization and digitalization[1]. The decarbonization trend strongly supports the shift

[1]Lawrence, O. et all (2019) Transactive Energy. A New Approach for Future Power Systems. Viewed at: 11:56, 10.02.2020 https://exergy.energy/wp-content/uploads/2019/03/TransactiveEnergy-PolicyPaper-v2-2.pdf

from traditional fossil fuels and nuclear energy toward solar and wind power. Decarbonization has resulted in large declines in the cost of renewable energy infrastructure. In addition to renewable energy's inevitable potential, it is also creating problems for electric power systems, because the power grid is not designed to integrate large volumes of renewable power. The decentralization force is driven by the fact that more and more residential customers are installing rooftop solar and household batteries. Customers prefer renewable energy and individual households are switching to distributed renewables as the cost of renewable infrastructure rapidly declines. Even though various challenges of balancing the demand and supply with these new, local renewable energy resources exist, there are opportunities for the operators, because with the help of intelligent devices, the local energy and the household batteries can be utilized as distributed energy resources. Finally, we want to address the digitalization aspect: experts predict that by 2040 there will be 11 billion smart devices actively participating in the electricity system[2]. This trend will create multiple opportunities for consumers, such as to reduce their energy bills, to participate in energy trading markets and to provide other valuable services to the grid. At the same time, future consumers will demand smartphone access to their energy consumption and production anywhere, anytime and they will want smart connected products (e.g. smart meters, intelligent home systems, thermostats, smart lighting).

The core problem of today's energy sector is that the old assumptions are no longer valid, and the sector requires new governing mechanisms. Previously, the increasing presence of renewable energy operators assumed that demand is fixed, supply is controllable, and that the energy ecosystem can be governed in a centralized way. However, in today's world we have an increasingly variable energy supply, a flexible demand and increasing residential investment in energy producing infrastructure[3].

[2]International Energy Agency, Digitalization set to transform global energy system with profound implications for all energy actors, 06.11.2017 Digitalization set to transform global energy system with profound implications for all energy actors - News

[3]Tapscott, D. Tapscott (2016) A Blockchain Revolution. New York, New York, Penguin Random House LLC.

The increasing distributed manner of the energy grid system and the digitization efforts to make the grid smarter will highly support the necessity of blockchain solutions in this segment. Blockchain technology enables decentralized energy resources to act autonomously by utilizing smart contracts, which are applications run on the network; a potential fit for the energy sector, with its auditability- and security requirements and its ability to remove central management. No wonder, there is a big interest from different energy operators, startups, financial institutions, governments and academia around this technology. But what is blockchain technology, where exactly can it be utilized and how can it contribute to the energy sector?

1.1. What is Blockchain?

We live in a world where the internet has become an important part of our everyday life. Most of us check email, use social media and make payments over the internet every day. Many people utilize the internet in order to use the advantages of big data, cloud computing or even the Internet of Things. It has never been easier to search or exchange information or collaborate with other people. Moreover, digitalization infused intelligence into our home, our cars, even to our clothing and wallets. However, we are still not able to reliably verify one another's identity, so we need third parties, like banks or the government to identify our business partners when we want to sell or buy something. What if there was a technology, which could provide "trusted transactions directly between two or more parties that don't know each other, authenticated by mass collaboration and powered by self-interests, rather than by large corporations motivated by profit". This is how Tapscott defines blockchain technology in his book[4]. The good news is that this technology is not just already available today but also improving continuously.

More than 10 years passed since the Bitcoin network was created by a pseudonymous Satoshi Nakamoto. His whitepaper describes a novel technology named blockchain[5]. In

[4]Tapscott, D. Tapscott (2016) A Blockchain Revolution. New York, New York, Penguin Random House LLC.
[5]Nakamoto. S (2018) A Peer-to-Peer Electronic Cash System. Viewed at 10.48, 17.02.2020 https://bitcoin.org/bitcoin.pdf

these years, blockchain has developed different variants and use cases in different sectors. Blockchain is a distributed ledger technology. That is to say, individual computers (nodes) in a network seek and find consensus regarding a sequence of valid transactions. Transactions can be monetary value, data or any other kind of information. At its core a blockchain consists of a ledger that can be updated without a central intermediary. Blockchain is special because the database consists of a continuously expandable list of datasets (blocks) which are chained together via cryptographic procedures. A record that has been added to a chain becomes immutable, meaning that it is not possible to ever delete or change it. Blockchains can thus provide a more secure, cheaper and oftentimes faster information exchange between any kind of participants without intermediaries. Each network user can crosscheck for themselves if a transaction is valid, which provides increased transparency and trusted, tamper-proof records[6].

Some blockchain protocols are enhanced with so-called smart contracts, which function as a transaction layer that can trigger actions, such as a data transfer or payment. Smart contracts are written in code, executed and monitored automatically in the blockchain. Smart contracts ensure higher contractual security and lower costs than paper contracts. For example, if you are a solar energy producer and you have a smart contract with your neighbor or your operator, you would receive automatic payment for your energy supply from the buyer. Likewise, your car could make an auto payment for a charging station in exchange for the power. The payment can happen either in fiat currencies or in cryptocurrencies. The democratization of the energy market, the increasing number of smaller market players and the penetration of e-charging stations could benefit highly from cryptocurrencies, as they often use transaction-based business models and microtransactions could be efficiently processed via blockchain technology. Blockchain permits multiple users to add transactions to the ledger and the ledger's valid state is reached through the consensus mechanism, therefore smart contracts can speed up

[6]dena Multistakeholder study. Blockchain in the integrated energy transition. Viewed at 14:49, 14.02.2020 https://www.dena.de/fileadmin/dena/Publikationen/PDFs/2019/dena-Studie_Blockchain_Integrierte_Energiewende_EN2.pdf

contracting processes among multiple participants and decrease administrative burdens and costs[7].

As we can already see in recent years, blockchain is becoming a new form of data storage and transaction exchange. Many people think that blockchain will entirely change how people live and interact with each other. But in order to use blockchain effectively, we must understand thoroughly how it can be utilized for the transformation of the energy ecosystem.

1.2 Blockchain use cases in the energy sector

The German Energy Agency (dena) has multiple studies about the potential of blockchain technologies in improving the efficiency of current energy practices and processes[8]. They also mention the technology's acceleration potential in the development of IoT platforms, P2P energy trading and decentralized power generation. In addition, they report that blockchain technology can significantly improve customer services and internal processes services and can decrease costs for energy enterprises and utility companies. Atoni and his team[9] collected several energy use cases and they claimed that blockchain technology could be used in the following domains: automated billing, tailored sales and marketing based on consumer energy patterns, trading on wholesale markets, commodity and green certificate trading, peer-to-peer trading, grid management, data transfer among smart devices, and sharing use cases (e.g. electric vehicle charger sharing).

The Energy Web Foundation also collected and analysed over 100 use cases. They found that blockchain technology is the most useful in those cases where it can anchor trust, provide proof and establish multi-party consensus. Based on this, the two most valuable use cases are *"enhancing energy sector traceability and unlocking grid flexibility from*

[7] Atoni M. et al (2019) Blockchain technology in the energy sector: A systematic review of challenges and opportunities Renewable and Sustainable Energy Reviews, Volume 100, February 2019, Pages 143-174
[8] dena Multistakeholder study. Blockchain in the integrated energy transition. Viewed at 14:49, 14.02.2020 https://www.dena.de/fileadmin/dena/Publikationen/PDFs/2019/dena-Studie_Blockchain_Integrierte_Energiewende_EN2.pdf
[9] Atoni M. et al (2019) Blockchain technology in the energy sector: A systematic review of challenges and opportunities Renewable and Sustainable Energy Reviews, Volume 100, February 2019, Pages 143-174

customer-owner resources." The former is about providing market participants the capability to buy a variety of green commodities, like low-carbon fuels, certifications or green electric vehicle chargers, while the latter is about enabling the entry of residents to the electricity market with their own distributed, renewable energy infrastructure in a cheap, trustworthy and scalable way. They also suggest that blockchain should not replace but complement existing legacy systems[10].

This study is focusing on the second use case. The first pilot in this topic happened in 2016, in Brooklyn, New York. The idea behind that solution was the following: In spite of the increasing demand for local, renewable energy and an increasing supply of renewable energy from solar panels and windmills, most homeowners and business entities were still required to buy energy from the utilities. These consumers must pay full retail price for renewable energy generated by their neighbours, who may be located just across the street. Locally generated power and community microgrids could provide resiliency for the grid and reduce the costs of customers, while promoting efficient electricity storage options and renewable energy for the community[11]. That's why a start-up, called LO3 Energy, made it possible for the customers to buy and sell energy to each other and for them to select their energy mix via a blockchain based platform. This was the birth of the peer-to-peer energy trading ecosystem.

2. The Peer-to-Peer Energy Trading Ecosystem

– Analysis of the Building Blocks

We will start our review with the vision of the IOTA Foundation on smart energy[12]. They believe that in the future we will use electric vehicles and we will produce our own

[10] EW-DOS: The Energy Web Decentralized Operating System. An Open-Source Technology Stack to Accelerate the Energy Transition. Viewed at 21:07, 16.02.2020 https://www.energyweb.org/wp-content/uploads/2019/12/EnergyWeb-EWDOS-VisionPurpose-vFinal-20191211.pdf
[11] Tapscott, D. Tapscott (2016) A Blockchain Revolution. New York, New York, Penguin Random House LLC.
[12] Smart energy. Viewed at: 12:36, 10.02.2020 https://www.iota.org/verticals/smart-energy

renewable energy by using rooftop solar panels and windmills. With the help of smart devices, we will make sure that we use all that power that we generated. To make this happen, we will need a machine economy, where different smart devices will be able to communicate with each other and, moreover, they will be able to make or receive payments for their services. It will all happen in a seamless way and people maybe won't even notice that these devices are working hard in the background.

Maybe your car will be able to charge itself from the solar panels of the neighbouring school while you work from home. Later, in the evening, you can power the lights in your house with the energy stored in your car's battery. While you are sleeping, the windmills located nearby can again refill the car batteries and in the morning, you can leave to work with a fully charged vehicle. In the future, these transactions among devices will increase exponentially. For every exchange between these devices, you need to calculate both data and value in order to successfully automate the process. The current approach, namely centrally registering all electricity exchanges and then paying through the bank, might not be the most appropriate for these kinds of microtransactions. Distributed ledger technology is more suitable, thanks to its secure, transparent and peer-to-peer manner. You can also connect cars, windmills and solar panels to the same distributed ledger network and let them to sort out the transactions and their related payments themselves. In the following sections we will analyze piece by piece the most important parts of this ecosystem.

2.1. The Energy Trading Market

The digitalization and decentralization trends brought new kinds of use cases to the wholesale energy markets. Originally, wholesale electricity trading has been only available for large power plants. However, renewable energy resources are heavily supported by governments, especially to act against climate change. Once the funding period is over, governments will be still incentivized to ensure the production of renewable energy. In order to do so, the emergence of a new kind of wholesale trading platform is needed where smaller energy producers can participate as well. Blockchain solutions could

support these platforms with up to 90% cost savings and drastically lower the market entry barrier for smaller producers. Also, the potential for automation of energy trading is very high[13]. There is a grand vision that, in a couple of years, every node in the power system will be able to join peer-to-peer networks for power production and distribution, resulting in a blockchain-enabled smart microgrid available for everyone.

Four years ago, LO3 energy made the first paid transaction via blockchain in New York using a peer-to-peer energy transaction platform[14]. They created a microgrid, where residents could buy and sell energy to each other. By using blockchain technology they made it possible to log every unit of energy created by one of these homes. Smart contracts made these units of energy available for the local community to be bought and sold in an open market and payment happened through online money transfer. Users could set their energy requirements and choose exactly whom they wanted to buy the energy from, and the system automatically controlled the process. LO3 Energy is also tried doing German pilots with local partners[15]. These projects were set up in Lazarettgarten in Landau and in southern Germany, in the Allgau region. The LO3 platform could offer ways for early adopters of solar technology to benefit from their investment in renewables even after the expiration of their feed-in tariff period, allowing them to buy and sell energy directly in their community.

At the same time, other participants, like the Wuppertaler Stadtwerke[16], are experimenting with similar things. On the “Tal.Markt” trading center, customers can buy their electricity from local green electricity suppliers and put together their own energy mix. Blockchain technology ensures that no kilowatt hour of solar or wind power can be sold twice.

[13]Dena: Multistakeholder study. Blockchain in the integrated energy transition. Viewed at 14:49, 14.02.2020 https://www.dena.de/fileadmin/dena/Publikationen/PDFs/2019/dena-Studie_Blockchain_Integrierte_Energiewende_EN2.pdf

[14]The USA`s first consumer energy transaction begins `power to the people`revolution in New York. Viewed at: 12:07, 10.02.2020 https://lo3energy.com/usas-first-consumer-energy-transaction-begins-power-people-revolution-new-york/

[15]US start-up LO3 Energy begins two German projects. Viewed at: 12:20, 10.02.2020 https://lo3energy.com/us-start-lo3-energy-begins-two-german-projects/

[16]Wuppertaler Stadtwerke starten ersten Blockchain-Handelsplatz für Ökostrom . Viewed at: 12:32, 10.02.2020 https://www.wsw-online.de/unternehmen/presse-medien/presseinformationen/pressemeldung/meldung/wuppertaler-stadtwerke-starten-ersten-blockchain-handelsplatz-fuer-oekostrom/

2.2. Metering Infrastructure

One of the core prerequisites of an energy trading platform is to have devices which are able to measure electricity usage in real time. For this use, people need widespread digital electricity meters with associated secure databases. Also, the EU requires its member countries to equip homes with smart meters for at least 80% of all households. In Germany, the Act of the Digitalization of the Energy Transition was already passed in 2016, however the rollout only started in January 2020 with three certified smart gateway vendors (Power Plus Communications, EMH metering and Sagemcom Dr. Neuhaus)[17]. The act allows the rollout of modern measurement devices and intelligent measurement systems. A smart meter consists of a digital meter and a secure communication unit. These devices will allow the flexible integration of renewable energy sources into the electricity grid.

Smart metering is also a significant prerequisite for using blockchain technology in the energy sector. Smart metering allows secure verification and representation of different assets. There are multiple blockchain use cases linked to smart meter usage. Please find below a table summarizing some of them:

Use cases	Description
Electric Vehicle (EV) driven congestion management in electricity distribution grids (e-mobility)	EV penetration and especially increasing usage of household chargers will increase capacity problems in the grid. Blockchain based congestion management systems could potentially avoid capacity problems by load balancing
Energy services for buildings & industrial processes (maintenance)	Maintenance and services activities stored on a blockchain in a transparent, immutable way and can be charged via smart contracts
Registration of installations in the core market data register (MaStR)	Blockchain based automatic registration and verification of power generation and storage systems through smart meter gateway with a built-in crypto chip

[17] Certified products. Smart metering systems. Viewed at 15:19, 14.02.2020 https://www.bsi.bund.de/EN/Topics/Certification/certified_products/SmartMetering_Systems/Smart_Metering_Systems_node.html

Certificates of origins	Verification and blockchain-based authentication of the origin of the energy
Billing of electricity fees and reallocation charges	Consumption data registered to the blockchain and used as a basis of invoicing. Verified and transferred values also written to the blockchain. It can be also used for validating e-mobility roaming charging fees.
Termination and switching suppliers (electricity) operator	Registration by the new supplier, deregistration by the old supplier and the grid operator
Electricity wholesale trading (OTC)	Anonymous trading between two participants, which is only visible for the trading parties. Registration by the new supplier, deregistration by the old supplier and the grid operator
P2P trading between customers of an electricity supplier	The electricity trade is allowed among customers of an electricity supplier via an online trading platform, while the supplier remains responsible for load balancing. Local suppliers can sell their energy, while consumers can select their energy mix.
Trade and allocation of grid capacities (electricity)	Automatic adjustment of grid usage fee based on forecasted utilization. Monetary transaction exchange via smart contracts, recorded transactions on the blockchain.
Landlord-to-tenant electricity supply	Blockchain based interaction between the tenant and the landlord to maximize the local consumption of the produced clean energy.

Table I. Smart meter use cases for blockchain technology[18]

Most of the above-mentioned use cases are needed to achieve a full-fledged peer-to-peer energy trading system. You need to register all devices, which are measuring produced or consumed energy. You need to prove the origin of the energy with certificates of origin. Finally, you need to do proper billing and charging processes and, of course, you want to use the maximum renewable energy that you produced, even if it means allowing energy usage by the tenant. The auditability and transparency aspects may facilitate the property owners' willingness to invest into renewable energy infrastructure. But in order to let more participants act and trade, you must create a professional grid that is balanced by the incentivization of the participants through accurate forecasting of energy usage. In many

[18]dena Multistakeholder study. Blockchain in the integrated energy transition. Viewed at 14:49, 14.02.2020 https://www.dena.de/fileadmin/dena/Publikationen/PDFs/2019/dena-Studie_Blockchain_Integrierte_Energiewende_EN2.pdf

countries, like Norway, different tariffs exist to motivate consumers to delay or bring forward their consumption of energy (e.g. washing or electric vehicle (EV) charging). In Germany, the Federal Network Agency (BNetzA) has so far rejected the idea of variable grid fees. However, there is a threat of potential capacity problems caused by the emergence of electric vehicles, which obviously need to be prevented. Therefore, variable grid fees might come back as a mitigation option.

2.3 The Energy Grid

There are several factors challenging the current energy system. One of them is the threat of future capacity problems resulting from the increased usage of electric vehicles. A more current threat is the integration of distributed, clean energy resources. By its nature, renewable energy from windmills or solar panels is always dependent on current weather conditions. Successful integration of these resources requires the electricity grid to be able to respond flexibly to fluctuations.

Based on the merit order, available sources of energy can be ranked based on their marginal costs, and the ones with the lowest marginal costs will be used first. Usually that means that variable renewable resources come first. However, it is harder to forecast the production of renewable resources than it is to forecast the energy supply of nuclear and traditional power plants.

At the same time, power systems' frequency regulation must be in balance at all times, meaning that supply and demand of active power must always be equal. Imbalance can happen in either direction and both scenarios need to be avoided. If generation is greater than demand that is overcapacity, which can severely damage the electrical system. Likewise, shortages can lead to dangerous brownout effects. This balance (i.e. the frequency regulation) is managed in real-time by system operators who utilize reserves whenever needed. They need information about the actual electricity generation and the actual consumption of both individual households and commercial buildings. Then they maintain the balance between supply and demand mostly using large generation plants

and by providing reactive power support to the electricity network. But large generators are costly and have fairly slow response times. Some storage devices, like batteries, combined heat and power plants or pumped hydro storages can improve response times. Out of these options, batteries are currently the most promising candidate for the regulation of supply and demand, because of batteries' cost and fast response times. The cost structure of big power plants can be divided into three main parts: capital, infrastructure and operating costs. Capital cost is the cost of preparing the plant for operation, while operating cost is the cost of generating a unit of electricity and it consists of labor costs, fuel costs, water and other utilities. When using batteries, capital cost and operation cost can be avoided. This scenario brings electric vehicle batteries into consideration, because they can be controlled independently by each vehicle, which would provide a flexible scalability option. Eventually, the growing electric vehicle market and increasing charging station penetration will bring diversification to the energy market[19].

2.4. The e-Mobility Market

The electromobility (e-mobility) market is mainly driven by the goal to achieve the European Union's climate targets. In order to do so, drastic reduction of CO^2 emission is needed. The EU`s ambition is to reduce greenhouse gas emissions by 80%. That would mean that both energy generation and transport need to be almost emission free. That is impossible with combustion engine cars, but renewable energy generation and electric vehicles could significantly improve the situation[20].

The German Federal Government's original target was to have one million electric vehicles on the roads in Germany by 2020[21], however the number of registered electric

[19] Renewable energy world, When Will Electric Vehicles Act as a Grid Resource Under the V2G Paradigm? https://www.renewableenergyworld.com/2018/07/06/when-will-electric-vehicles-act-as-a-grid-resource-under-v2g-paradigm/ viewed at 10:44, 14/02/2020

[20]Gnann, T. et al (2017) Market Diffusion of Electric Vehicles in Germany. Viewed at 13:08 17.02.2020 https://www.isi.fraunhofer.de/content/dam/isi/dokumente/cce/2017/Market-diffusion-electric-vehicles-Germany-Vortrag.pdf

[21]German Federal Government`s National Electromobility Development Plan. Viewed at 13:20 17.02.2020 https://www.bmvi.de/blaetterkatalog/catalogs/219118/pdf/complete.pdf

vehicles was only around 220.000 on the 1st November 2019 as per the Verband der Automobile Industry[22]. At this time there were around 20.650 public and partially public charging points and 12% were fast charging points. The German government has several initiatives to support electric vehicle penetration. Since 2016 there has been a 2.000-euro subsidy on BEV purchases and 1500-euro subsidy on PHEV purchases with an emission level below 50g CO^2/km. Since 2019, new electric vehicles used as company cars have reduced taxes. The electric vehicle charging infrastructure is also subsidized on the national, regional and local levels[23]. It is also a positive sign that the country will require all gas stations to provide electric vehicle charging[24].

2.5. Vehicle-to-Grid (V2G) Technology

As the result of growing electric vehicle (EV) penetration, Distributed System Operators (DSOs) have started to realize that electric vehicles are not just a potential burden to their networks. In fact, electric vehicles can also be used as distributed resources for the grid, as per the vehicle-to-grid concept. Too many charging positions at a single location can certainly burden the current distribution network, but the V2G capability of the EVs located in that area can help in congestion mitigation. The battery of the electric vehicle is a mobile energy storage opportunity that can support the grid with distributed energy resources (DER). In order to do so, EVs need to be equipped with bidirectional chargers. These chargers allow energy flow in both directions (from the grid to the vehicle and from the vehicle to the grid). To maximize efficiency, EV batteries should be charged when there is surplus energy in the grid and the energy should be utilized when the grid has high energy demand[25].

[22]Electric Mobility. Viewed at 14:45 17.02.2020 https://www.vda.de/en/topics/innovation-and-technology/electromobility/Electric-Mobility-in-Germany.html
[23]Finally catching up: What powers the EV uptake in Germany? Viewed at 15:39 17.02.2020 https://theicct.org/blog/staff/germany-ev-uptake-market
[24]Germany requires all gas stations to provide EV charging. Viewed at 15:39 15.06.2020 https://electrek.co/2020/06/04/germany-requires-all-gas-stations-to-provide-ev-charging /

[25] Renewable energy world, When Will Electric Vehicles Act as a Grid Resource Under the V2G Paradigm? viewed at 10:44, 14.02.2020 https://www.renewableenergyworld.com/2018/07/06/when-will-electric-vehicles-act-as-a-grid-resource-under-v2g-paradigm /

Vehicle-to-grid technology was developed by Prof. Willett Kempton at the University of Delaware in the 1990s. The first real world tests started in the US in 2008, while in 2011 the Fukushima nuclear tragedy encouraged the market to develop bidirectional charging capability in order to balance load demand. Japan had 130.000 plug-in vehicles by 2016 and Mitsubishi, Nissan and Toyota were working on V2G before 2011. However, Fukushima brought a different kind of urgency to develop this technology[26]. By 2018, more than 50 V2G pilot projects existed in parallel[27]. One of the recent projects was piloted by Nissan and asked how EVs can stabilize the power supply in Hagen, Germany. A Nissan Leaf was qualified as a power plant to comply with all regulatory requirements and it was able to act as a transmission system operator (TSO). It was equipped with bi-directional charging capability, which enabled the battery of the Batter electric vehicle (BEV) to act as a mobile energy storage buffer. The charging process was controlled based on the grid frequency. The car was able to absorb surplus energy from the grid when it was needed, and it was able to react really quickly in order to feed the grid within just a few seconds. The test showed that integrating electric vehicles to the energy ecosystem as a power control and storage mechanism makes sense both technologically and economically. But obviously there are still obstacles to efficiently do it, especially when it comes to regulations and the price of the technology[28].

There are also some peer-to-peer (P2P) pilots involving electric vehicles. For example, Toyota is piloting the world first of its kind P2P energy trading pilot including Plug-in Hybrid Vehicles (PHEVs) as a distributed power supply. Toyota works together with TRENDE and The University of Tokyo. The idea is to test a P2P electricity trading system connecting EVs, companies and homes equipped with solar panels and batteries to check the system's economic feasibility. This trial also uses AI for the electricity management of the companies and the households in the following ways: the AI automatically buys and sells electricity based on the forecasted production of the rooftop solar panels and the

[26]How Electric Vehicles Provide Relief for Japan`s Delicate Grid? viewed at: 13:16, 14.02.2020 https://www.fleetcarma.com/electric-vehicles-relief-japans-grid/
[27]V2G global roadtrip: Around the world with 50 projects, viewed at: 12:38, 14.02.2020 http://everoze.com/app/uploads/2018/10/UKPN001-S-01-H-V2G-global-review-compressed.pdf
[28]Nissan V2G project in Germany shows results, viewed at: 12:04, 14.02.2020 https://www.electrive.com/2019/01/29/v2g-project-in-germany-shows-results/

entity`s electrical consumption needs. It also calculates the electricity demand of the electric vehicles. The goal is to minimize the consumer bills throughout this project[29].

Finally, there are a few companies, like NewMotion, who are already working on the further developed version of vehicle-to-grid technology and they call it V2X (vehicle-to-everything). V2X puts greater emphasis on availability and accessibility. It has a smaller size, it is more lightweight, it is simpler to install, and it even has a user interface where customers can gain insights about their charging sessions and about potential earnings[30].

2.6. Machine Economy

Machine economy is the vision that in a couple of years' time millions of smart devices will be able to sense, measure, share data, communicate, buy and sell their own electricity or pay for and offer their services without any human intervention. Blockchain technology has the potential to facilitate IoT devices to collaborate and do value (e.g. energy, time, money) exchange. Based on shared information it will even be possible to automatically configure production processes and supply chains. A lot of different actors could benefit from the machine economy, starting from homeowners who could produce their own solar energy and sell it via peer-to-peer networks to big corporations. The latter group could benefit highly if every power pole becomes smart and reports its status, such as alerting the operator in case repair is needed. Such processes would be cheaper, safer and simpler than today's processes. The smart pole could generate an incident report, share its location and notify the maintenance team, but it could also reassign its responsibilities to other poles nearby, which could result in less downtime and faster response time[31]. Of course for such scenarios a high quality, secure internet connection is inevitable. Luckily, many companies (such as devolo and Kiwigrid[32]) are building high-speed powerline and

[29]Toyota to launch 'world first' P2P trading pilot with V2G capability, viewed at: 11:18 14.02.2020 https://www.current-news.co.uk/news/toyota-to-launch-world-first-p2p-trading-pilot-with-v2g-capability
[30]The future of EV charging with V2X technology viewed at: 11:52, 14.02.2020 https://newmotion.com/en/the-future-of-ev-charging-with-v2x-technology/
[31]Tapscott, D. Tapscott (2016) A Blockchain Revolution. New York, New York, Penguin Random House LLC.
[32]Five reasons for broadband Powerline in the intelligent measuring system. Viewed at 15:22 16.06.2020 https://www.devolo.com/fileadmin/Web-Content/DE/Contentseiten/Smart_Grid/PLC-Technologie/EN/White_paper_PLC_for_roll-out_0818_EN_02.pdf

Wifi communication to create the smart grid of the future, which will be one of the important cornerstones of the machine economy.

3. Qualitative Analysis

3.1. Hypotheses

In order to check the current state of the peer-to-peer energy trading system we came up with the following hypothesis:

Our main hypothesis is that *blockchain technology can create trust and connect partners who have been non-trusting and unconnected in the past. Therefore, blockchain technology has the potential to facilitate the trusted ecosystem around the energy sector in the next 3-5 years (H0).* In order to prove this, we will examine the following three hypotheses as well.

H1. Blockchain will empower consumers to control their own electricity supply through smart meters and trade excess energy in a peer-to-peer manner in their close neighborhood, thus helping consumers to become prosumers.

H2. E-vehicles will be able to potentially store excess energy when demand is low and give back some energy when demand is high, trading this excess energy autonomously using a blockchain based smart grid with the help of vehicle-to-grid charging infrastructure.

H3. In the next 3-5 years a machine-to-machine economy will emerge, where, for example, e-vehicles will trade with charging stations in an autonomous fashion using blockchain technology and smart buildings will be able to control their own energy needs and buy/sell energy using microtransactions.

3.2. Methodology

To check the above-mentioned hypothesis, we created two qualitative surveys: one for prosumers, i.e. residential customers, who are already producing renewable energy and using that energy for their own consumption or selling it back to the grid and another survey for the companies. You can find the surveys in the Appendix. The goal was to interview people about their attitudes towards blockchain technology and collect information about the market maturity, the technological readiness and about the respective regulations of the energy sharing ecosystem. Altogether we conducted 14 interviews during this time with 11 companies and 3 residential customers.

Our plan was to talk to six different groups of people: energy operators, smart gateway vendors, electric vehicle charging vendors, blockchain companies, different non-profit organizations and prosumers. Prosumers are residents who are already producing clean energy and selling it or using it to cover their consumption. We managed to talk to one energy operator, one smart gateway vendor, three electric vehicle charging vendors, three blockchain companies, three non-profit organizations and three prosumers. In Appendix A) and B) you can find the used questionnaire for the companies and the prosumers respectively.

4. Results

Out of the 14 interviewed participants, 13 did already get in touch with blockchain technology and 12 had concrete ideas how to use it in different use cases. Almost 30 different use cases were mentioned by the participants altogether. Besides peer-to-peer energy trading, certification (i.e. renewable energy certificates, guarantee of origin) and the usage of microtransactions/micropayments were the two most popular use cases. Many people mentioned also that blockchain would be useful for registration of devices (e.g. smart meters, solar panels or electric vehicles), for traceability (e.g. checking where are the e-vehicles located in real-time or what is the source of the consumed energy), for

demand response management (switching on/off smart devices based on energy demand/supply in the energy grid), for distributed governance of data, for automated charging solutions and for securing the smart meters. You can see the full list of use cases in Appendix C).

In the next pages we will describe, what our interviewees think about peer-to-peer energy trading, what kind of bottlenecks they see, when it comes to the smart meters or the grid itself and where they see the benefit, to use electric vehicles as part of the energy ecosystem. We will also give some insights about how much time is needed for the emergence of real peer-to-peer energy markets as per the viewpoint of the respondents, and how will the democratization of the energy market impact the energy prices.

4.1. Current status of residential solar energy production

We have interviewed three prosumers, who own solar infrastructure and sell their renewable energy back to the grid to understand their production and consumption related behavior. The three interviewed prosumers have started producing solar energy in three different time periods, which highly impacted their consumer behaviour. In the following pages we will describe their profile and their future production plans, while we will discuss their opinion about the P2P energy market, the smart meters and the electric vehicles in the relevant chapters.

The first prosumer operates solar panels for 10 years already, and he will have a contract for the next 10 years. He invested in the infrastructure because he wanted to do something for the environment and earn some money. Both sides of his roof are full of solar panels. He gets paid 43 cents/kwh. This price guarantee lasts for the next 10 years. If he would have started earlier, the guarantee would be even higher (up to 63 cents/kwh). As he recalls, the SPD and Grüne government started the support for solar panels. His contract does not allow him to use the produced energy for himself. He does not mind, as he buys the energy cheaper from the grid than the price, he can sell the energy back to the grid.

After the end of the 20-year feed-in period, he will probably use the energy to cover his household consumption. He uses more energy at the moment than he produces. He had never heard about blockchain technology. If there was a choice of companies or participants to sell the energy to, then maybe he would check the opportunities. He might even change his contracts every month to get the best price, but in this case he would like to use a smart meter, which could be able to decide autonomously and sell the energy to the company that offers the most money for the produced energy without any human interaction. It would not make much difference for him whether he could sell his energy to a company or to his neighbours. Though he can imagine that maybe he could set the device to sell energy to a relative, for example, regardless of the price that companies would give. He thinks that peer-to-peer energy trading has a chance, if there will be enough customers / participants in the market. He adds that one might have to wait for it until the 20-year contracts expire for most people who invested into solar infrastructure.

The second prosumer lives at a farm with her family where they are producing calves. She and her family have a big building. On top of this building they have solar panels. They sell this energy back to the grid. They built their solar panels early and therefore they receive a lot of funding for their energy. They also have a smaller solar panel at home on the top of their barn. That is an older one, so they receive even more money for the produced energy. They are waiting to see what the government will do once their 20-year contract expires, but currently they are planning to use the solar energy to cover their own consumption and maybe also to charge electric vehicles.

She adds that if they would have started investing in the infrastructure now, they would do everything differently because the government now pays much less for renewable energy. They are eco-farmers; therefore, it is important for them to produce and use renewable energy. They ordered renewable energy from the operator, but they cannot check whether it is really renewable. She thinks that peer-to-peer energy trading could be a great way to control where the energy is coming from. She adds that lots of people are asking for their eco meat, so maybe renewable energy could be another thing to offer. She thinks that when it comes to renewable energy, it is a lot about trust. If blockchain

would be available, then it might facilitate people to become prosumers – many people are already thinking about buying rooftop solar panels anyway. However, she would not buy renewable energy from her neighbour if it was much more expensive than buying it from the operator.

Our third prosumer has had a rooftop solar panel for seven years. The infrastructure is able to produce energy up to 8 kwh. In summer he can provide up to 30 kwh a day, while in winter the maximum is 1-2 kwh. He gets 20 cents/kwh. The kwh normally costs around 30 cents from the grid. As he pays more for the energy than the price, he can sell it, he prefers to use it for his household first. He is working on a household battery buffer, which will have a 10-kwh storage capacity. He will connect the battery to his home. The energy will first go to this battery and he will only sell the energy to the grid when the battery is full.

He is not sure if after the 20 years contract it will be worthwhile to initiate a new contract, because those who are starting now only get a few cents for their produced energy. He is thinking about new, sustainable solutions to make use of his produced energy. One of his ideas is to make battery packs for scooters and e-bikes and provide a battery station using his surplus energy. When we asked him about peer-to-peer energy trading, he said that he thinks energy sharing with neighbours will take some time in Germany. He also mentions that currently in Germany there is only one tariff for the whole day, so it does not matter when he uses his devices. He produces 6000 kwh yearly. His goal is to produce more energy than he consumes from the grid to be independent.

4.2. Current status of P2P energy trading/P2P energy markets

When we asked people from the energy industry about their view on peer-to-peer energy markets, we received very mixed reactions. Most people were aware of peer-to-peer pilot projects and some also indicated to start real-life implementations this year. One of the interviewed non-profit organizations in the electric vehicle charging area stated that peer-to-peer cases have a lower priority in the coming two to three years. Others stated that

Germany has a very strong grid system, which does not require a rapid decentralization. Therefore, it does not have such an urgent need for peer-to-peer energy trading markets as other countries, such as Spain or Australia. Those countries have a less stable grid system and a more definite and rapid need for peer-to-peer energy markets. However, Germany has a very supportive government, when it comes to decarbonization and decentralization solutions and whenever there will be a need for multiple energy tariffs, either because of the incorporation of electric vehicle charging stations or because of the climate change friendly regulations, it will also speed up the interest for P2P energy solutions.

One of the mentioned P2P pilot projects is the +CityxChange[33] project, which is a smart city project supported by the European Union's Horizon 2020 program. It has 11 testbeds and two lighthouse cities: Trondheim in Norway and Limerick in Ireland. Trondheim has 3 testbeds. The first one is consisting of company buildings with solar rooftops and there are two campus locations. The buildings involved in the pilot are self-sufficient buildings (or so-called powerhouses). One of these buildings also has a big battery which is filled with thermal energy coming from the fjords. The main goal is to give renewable energy to communities. It is a great playground for experimenting with peer-to-peer energy trading and playing with the flexibility of the grid. There is a lot to learn as the entire energy trading market needs to be shifted from one system to another. More and more communities will look into these renewable solutions and the mechanism of sharing energy will expand into many things. There will be a pool of energy and a pool of vehicles. For example, Norway's Avis budget group is providing electric vehicles for many inhabitants. But there will be even more and more of a sharing economy and mobility sharing solutions in the future.

A lot of pilots exist, which are marketed as peer-to-peer, but currently there is no real P2P energy market existing in the world. The reason for this is the following: it is really complicated to create real P2P markets, not just operationally, but also politically. Payment systems for energy trading need to be built and someone needs to be responsible for the case when energy is not delivered or not paid. Also, there are a lot of

[33]+CityxChange. Viewed at 16:45 21.02.2020 https://cityxchange.eu/about-cityxchange/

questions about equality. If only wealthy people can invest into solar infrastructure, then how does that impact the cost for everyone else? Currently big companies, in addition to being a system operator and delivering the electricity to customers, also play the role of market operators, meaning that they are operating and managing the energy exchange business together with the broker platforms. Bids/offers are coming in for the energy and the operators are responsible to figure out the optimization and distribution of the energy. There has to be a price setting function, a control element in the distribution management system to do the balancing. In the future it might happen that every single node will be able to establish their own price in real-time. Also, the grid safety perspective is important. There might be more participants in the market, because of the democratization of the market. However, that might make it necessary to have a role that ensures that energy stays affordable for all consumers as well as make sure the grid is balanced out.

That's why a layered energy system is much closer in time. One of the interviewed non-profit organizations, who is accelerating decentralized decarbonization solutions, has created a market model design called D3A with a partner company. D3A is a hierarchical set of markets which scales up. One can imagine that D3A is structured like the Russian Matryoshka dolls. The vision is the following: there will be different devices trading with each other (e.g. a refrigerator will buy energy from a solar panel) within a community market and communities will exist on a regional basis. Nodes will trade with each other on the market, but there will be a centralized operation function to do the balancing between the energy demand and supply.

However, it first needs to be sorted out, how grid operators will register, operate and control smart devices such as rooftop solar panels, batteries, smart thermostats, electric vehicles, etc. There is also the question regarding how these assets should participate in existing energy markets. The Transmission System Operators (TSOs) together with the Distribution System Operators (DSOs) have the fundamental challenge that all of their processes are optimized for very large-scale resources (e.g. nuclear power plants, fossil fuel power plants). They don’t have the tools to optimize the market for smaller, renewable energy assets (e.g. windmills, solar panels). They don’t own any metering. At the end of

the day, the transition to smart energy will be all about IT and operation systems. Customers who have a household or electric vehicle battery or a solar system will be able to create a self-sovereign identity and then they can have bilateral transactions using agreed upon processes and documentation which will be verified and have certain attributes. Then the Transmission System Operators/and the Distribution System Operators could allow customers from participating in the wholesale market. Identity also matters a lot when customers are changing operators. For example, a universal, cross-supplier identity anchored to a blockchain can help manage permissions by using cryptocurrency coins and passports to trade electricity. This can be achieved if all System Operators are accepting the customers identities of each other and is one of the important concepts behind self-sovereign identity.

We interviewed one of the first companies doing peer-to-peer pilots worldwide. They created the first community driven project in Brooklyn, New York, where the first paid energy transaction happened via blockchain in 2016. This transaction happened between two neighbours. They paid each other using online money transfer. Their Brooklyn microgrid consists of 50 solid prosumers. These prosumers would normally buy renewable energy from the utility, but now they will work for this start-up in the coming years to test how energy trading works in a fully peer-to-peer system. These people generally want to make a positive impact on climate change. Energy is currently contributing to 2/3rds of the world's carbon footprint. The people in the Brooklyn community are really excited by the opportunity and they are looking forward to getting some money from producing energy, especially those who have already invested in solar panels. They also care a lot about resiliency in addition to climate. There were two blackouts in New York last year because the energy grid there is very old.

The goal of the project is to help the people how to maximize the renewable energy in their community and how to optimize their consumption. The company enables people to set their own energy mix. For example, if somebody wants 80% of his energy to come from a solar panel, then he will receive a notification verifying whether he got the energy or not. If not, then the application will list the different reasons (e.g. not enough sun). Also,

the company's app will help educate the users and to motivate them to live a more sustainable life. There are already a lot of incentives existing in the USA to influence people to become energy independent or to reduce their carbon footprint. For example, in California you can get 30.000 USD, if you switch from a gas to an electric oven.

In the past few years besides developing their application, this company also deployed smart meters and their toolbox in the USA, in Australia, Japan and Germany. However, the two pilots in Germany were not finished because of belated smart meter penetration. Usually retailers pay for the development of the app in each country. Brooklyn is an exception because it is a community driven project without any utility behind it. Some months ago, New York even allowed the company to create a sandbox in Brooklyn to do peer-to-peer energy transactions on the microgrid. This has been a real success. But early stage peer-to-peer markets are starting other places as well: in Vermont[34], for example, Green Mountain Power began to use P2P solutions in production and the same thing is happening in Denmark.

As per one of the interviewed blockchain companies, the core impact of blockchain is the following: "Blockchain is a ledger that can create trust. It is able to do microtransactions. Using the right protocol, it can deal with 8 billion people doing their transactions at the same time. So, communities will be able to do real-time decisions when using blockchain platforms. It will be a lot about grid physics, a lot about how entire communities make decisions based on the available information. Right now all of this is happening with too many Excel sheets"

The interviewed energy operator company gave us details about the obstacles of real-time, peer-to-peer implementations in Germany. The first thing they mentioned was regulations. Regulations are hindering real-time implementations in their view. For example, it is not allowed to sell produced energy to your neighbours because in order to do so, you have to become an energy supplier and you have to fulfil special regulations,

[34]Green Mountain Power, Lo3 utilizes blockchain. Viewed at 19:58 15.06.2020 https://www.publicpower.org/periodical/article/green-mountain-power-lo3-pilot-utilizes-blockchain

and those requirements are practically not possible for a private person. They think that, in the future, farmers will create local energy communities[35] and they will figure out together how to provide local, renewable energy while complying with all the regulations.

Right now, solar panels are heavily supported. The first solar panel owners get 50 eurocents/kwh for producing solar energy and selling this energy back to the grid, while the market price is currently 26-28 euro cents. The first contracts will stop in 2021. Afterwards, the solar panel owners have to manage their systems alone. This means that they will have to route their energy to an energy exchange platform and have to do proper forecasting. In the winter they can get around 5-6 cents/kwh, while summertime provides only 3-4 cents/kwh, so it will be really hard for solar panel owners to participate in the energy ecosystem, to cover the cost of their solar panels and to create revenue. It is possible that some people will eventually shut down their infrastructure. Other possibilities could be for them to increase their consumption, use battery systems or buy electric vehicles and use the energy for the EVs.

The energy operators think that blockchain can facilitate the energy ecosystem in many ways. For example, blockchain can provide real-time incentives to customers to change their energy consumption behaviour. Blockchain can help prosumers manage their forecasting by giving them a traceable overview about their energy production and consumption in real-time, or by doing the matching between the two. Balancing is a very important function, as some people might produce a lot of energy during the day, while they consume energy mainly in the evening. Beside this, blockchain can also optimize data exchange among all involved stakeholders and make it simpler to switch from one energy market to the other while keeping all the user data.

One of the blockchain companies said that in Germany consumers belong to balancing groups, which are virtual "*energy volume accounts*", that allow energy market players to balance the energy capacity based on real-time demand and supply every 15-minutes.

[35]An energy community is a type of consumer (or prosumer) cooperation, with the aim to cover the communities' (e.g. neighbourhood's) energy demand using only local production sources (Distributed Energy Resources, e.g. Local solar panels or windmills).

He added that it is already possible to technically do peer-to-peer energy trading today in Germany within these balancing groups and it is allowed by Bnetz (BNetz is the German Federal Network Agency for Electricity, Gas, Telecommunications, Postal Services and Railways). They also mentioned that Wuppertal Stadtwerke already implemented a blockchain based technology platform called Tal.markt[36].

Altogether, we can state that it is promising for peer-to-peer energy trading that there are many pilots in this area. Moreover, some early stage real-life implementations are starting this year. However, many participants added that there are better markets to do peer-to-peer energy trading than Germany. Most of them mentioned Australia as one of the most advanced markets, as it already has some local markets using peer-to-peer mechanisms. Australia also has a lot of sun and a very weak grid which is quite distributed, consisting of many islands. More than 50% of the country's electricity is already coming from small scale rooftop solar panels. Australia has a real need to better accommodate these renewable energy assets and it has a very competitive market as well. So it is not surprising that Australia is experimenting a lot with peer-to-peer markets. Compared to Australia, the US market is very different because regional markets exist in the US. For example, in Texas nobody is allowed to sell energy except for predefined entities. However, California is similar to Australia because regulators allow energy trading due to the sheer volume of residential solar panels. Some interviewees mentioned Spain as an example to countries which have a less stable energy grid and a bigger need for alternatives. Finally, many people mentioned the Nordic countries, where electric car penetration is very big, multiple tariffs exist (e.g. in Norway the energy prices are four times bigger during the evening than during the day) and there are already many sustainable solutions.

[36]Tal.markt. Viewed at 16:40 21.02.2020 https://talmarkt.wsw-online.de/

4.3 Current status of the metering infrastructure

Most of the participants said that the belated smart meter rollout is the biggest problem hindering the implementation of peer-to-peer energy markets in Germany at the moment. The rollout should have already started back in 2017. However, it took some time to have certified smart meter vendors in the market, so the rollout could only start in 2020. Germany has one of the most rigid regulations because the smart meter and smart meter gateway vendors need to comply both with the BSI (The Federal Office for Information Security) and the PTB (The National Metrology Institute). The current machines are 20 years old and there is almost no electronic measurement system in the field. Reading of the meters happens only one time a year and it is most times analogue. Oftentimes there is a difference between the actual data and the billed data. This problem was also articulated by two of the interviewed prosumers.

Electronic measurements would be better for many reasons, because it could save significant cost for operators by preventing the need to send people to every house. They could see the measurements online. Although the smart meter penetration finally started in January 2020, 80% of the customers won't get smart meters in the near future because they are consuming less than 6000 kWh annually which makes the use of smart meters optional. Few installations will happen in villages as well. Electric vehicle owners will get smart meters, because they consume more than 6000 kWh annually. The full smart meter penetration will only be finished by 2036!

We interviewed a smart gateway company that is currently not a qualified gateway supplier. They are skipping the first generation of smart meters because this generation is only for meter reading. Other features, such as demand response management, are completely missing. The estimated year for second-generation smart meters to include more advanced services is 2025. Therefore, this company decided to focus on pilots with power lines and utilities. Their strategy is to provide high quality data connections to electricity utilities. Utilities need good data communication because gateway products will be attached to every meter in the future and these gateways must fulfil all security

requirements. Utilities don't use the consumer connection because it is not that reliable. Currently, there are four main opportunities for data communication: using sim cards, using wireless technology, building one's own mobile broadband network or transferring internet data using electrical wires. This is where this company is active at the moment.

It is also interesting to note that companies only receive temporary allowances to produce smart meter gateways. Most of the time they install a cage in their factories and all people who work there must have a special allowance to enter. They put the gateways into encapsulated, double secure boxes. No one is allowed to open those boxes, except for the people who are installing the devices. These people are only allowed to take the devices that they install on the very same day. This is because people are afraid of cyberattacks. Even the manufacturing of the devices is only allowed in Germany currently.

Blockchain could definitely further secure these devices. It could also ensure that the data coming from the meters becomes more trusted and safer. Not just blockchain, but also normal cryptography can help to sign the transactions and to sign the data. However, it is not entirely clear whether the current interfaces of the certified smart gateways can be used for interaction with the blockchain. Many blockchain companies are experimenting with certified smart meter gateways to implement a blockchain node on them. Others (e.g. OLI and Energy Web Foundation[37]) are trying to develop their own blockchain gateway. Many experts think that companies need to lobby now that the certified gateways have the ability to use it with blockchain, in order to prevent the need for extra infrastructure for blockchain technology.

Blockchain technology can improve smart gateways in many other ways as well: it could improve the certification scheme, do certification of origin, it could help register devices (e.g. electric vehicles, solar panels, smart devices, batteries). It has the potential to make smart meter gateways autonomous agents that trade energy. It could record the data for

[37] The Energy Web Foundation Partner With OLI By Running A Validator Node So They Can Offer A Trustworthy Blockchain Tailored To The Needs Of The Energy Economy. Viewed at 16:40 21.04.2020 https://medium.com/@HSVGTS/the-energy-web-foundation-partner-with-oli-by-running-a-validator-node-so-they-can-offer-a-a806b1b2133

event logs and do demand response management by switching on/off devices based on supply and demand in the energy grid. Remote management of these devices would also be very valuable. One could reward the smart machines with an incentive: e.g. in case there is an excess of energy in the system, then - if a device is not in a critical state - it might switch itself off in order to receive some rewards. Different meters have different data structures, thus a blockchain layer can create interoperability and empower the smart meter devices to communicate, provide services and trade with each other.

Smart meters that belong to individuals have to comply with the GDPR. One non-profit organization already has a solution how IoT devices could comply with GDPR by using a privacy channel. Currently, a paper is being created about it. They are also involved in securing smart metering. They want to build trust on the edges, so that people will trust not only the data warehouses (i.e. the storage repository for structured, filtered data, which was already processed) but everything along the way to the edges. They are also testing secure elements.

There is no certified gateway at the moment with blockchain capabilities, therefore peer-to-peer pilots require alternative solutions. Some of the blockchain companies, for example, use smart meters that are sitting behind the power company's meters and are within the customer`s control. They are also developing a protocol to control the whole house with all kinds of smart devices, such as window blends and light systems. They also have projects in Denmark where operators store the data in data lakes (i.e. data pools of vast amounts of raw data), while putting great emphasis on privacy as well. If people cannot access the data, then they cannot build any business model on top of it and this is what is missing currently in many countries. Therefore, they are working on data transmission by creating data pools and algorithms. They are using existing blockchains, but they are planning to create a new one as well. They are also creating an app, with which companies will have access to consumer behaviours like when people consume energy and for what purposes (e.g. the company will know, what time consumers turn on/off their coffee machines).

We also asked our prosumers about their satisfaction with their metering infrastructure. Our first prosumer, who installed his solar infrastructure more than 10 years ago, does not have a smart meter. He received a meter from the operator, and it was granted for 10 years. He told us that it approximately tells him how much energy he can sell back to the grid. There is always a difference compared to the inverter. He checks the meter once a month to forecast how much he will produce over the year. He does not use any devices or apps. He says that ten years ago there were no smart devices. His device required smaller repairs, but it is still working, and he is satisfied with it.

Our second prosumer and her family, who live on a farm and produce calves and renewable energy, use a smart meter to measure their energy production. They send the metering data to the operator via the powerline and they are satisfied with it. They could also send the energy data to a mobile phone, but they do not use that because they do not have very good connectivity. She thinks that blockchain could bring more trust in the system. Right now she has to believe in the data that the provider is giving her and then she compares this data to the metering data. There is always a bit of difference. Blockchain could equalize these two data sets and make it more transparent.

Our third consumer has multiple smart meters. He is measuring the output of the solar panels and the throughput from the grid. These are bidirectional meters. There is a wireless model in them, so the prosumer can see the measurements online. The meters also have a SIM card and a GSM module. Our prosumer uses them to control the compensation from the provider. He is satisfied with these devices.

4.4 Smart grid and potential capacity problems

One of the blockchain companies active in the decentralized identity field said that we can only talk about a smart grid once we have smart meters in every household. They also added that the grid needs to be more stable and more flexible for peer-to-peer energy trading. The current instability stems from the fact that it is hard to forecast the production rate of renewable energy and thus it is hard to integrate it into the grid. Currently, the

energy market is a centralized market and it needs very different grid solutions to share the power market with prosumers and local energy markets. This is why blockchain infrastructure companies are already experimenting with distributed energy: They build power plants and renewable energy infrastructure in a distributed way. Currently, when the grid is not able to accommodate the solar plants then the grid operator is able to switch off the infrastructure. This is a workaround and more sophisticated solutions are needed in the future. Accommodating the fast ramp up of the charging stations can also cause capacity problems. If there were more charging points on each street, then operators would have a big problem. Solutions and investments are needed rapidly to solve these bottlenecks.

Unfortunately, operators in general are not motivated to create a smart grid, though renewable energy and electric vehicles are challenging the stability of the grid. Currently, it is still relatively easy to manage the electric vehicles side, but if the number of electric vehicles increases in the future then the grid will not be able to deal with the electricity demand. In order to avoid that, operators can do several things. They can, for example, increase the proportion of copper wires, as it lowers the energy loss during transportation, and thus reduces CO_2 emissions, or do something smarter. The smart grid would be very complex, and it would take a lot of investment to make it really smart. On the other hand, retailers want satisfied customers, so they want to set up energy communities in different neighbourhoods to save costs by using only local energy for satisfying the energy needs of the consumers. Their problem is that the current grid is not ready to provide the data and the needed infrastructure. However, in Germany due to regulations retailers are not allowed to cooperate on any topic with the grid operators. This might be one of the reasons why smart grids are not evolving rapidly because increasing the copper wires is cheaper than implementing a smart infrastructure. In the subsequent chapter we will shed some light on how the e-mobility market could help to mitigate some of the above-mentioned grid capacity problems.

4.5 Current Status of Vehicle-to-Grid Charging

The EV market has grown exponentially in the last years - numbers are doubling every year. However, Germany is still in a learning state. People are just starting to be open to e-mobility. There are around 48 million vehicles in Germany and the proportion of e-vehicles is still under 1%. The original estimation was that 20.000 full battery cars will be sold every month, but this is not happening despite the fact that Tesla Model 3[38] had some impact. However, good quality, middle range electric cars are still missing from the market. The good news is that from 2020 forward there will be different cars in the market in every car segment. People will be able to buy an electric car starting at 4.000-5.000 euros. Punishment systems can also facilitate electric vehicle penetration, such as a ban on diesel cars. Also, electric vehicles will have a snowball effect: the more you see it, the more you want it.

The speed of penetration will also depend on the technology. At the moment, 200 kwh is the biggest battery on the market, but many cars today have an 80-kwh battery that only has a driving range of 200-300 km. Compared to that, you can travel 600-700 km with fuel or diesel. Because of this phenomenon, it is also important to do thorough planning when you own an electric vehicle. The driver always needs to know where the charging points are and how often there will be a charging opportunity. He must calculate how often he needs to refill the vehicle because an electric car's battery can go down rapidly. People will eventually get used to this, but currently they are not using the charging process very well. Each charging point is a bit different. People will have to learn how to use them. Electric charging is a completely different customer experience compared to fuel or diesel cars.

Currently, there are 550 different mobility providers in Germany and 500 different charging points. Therefore many e-mobility organizations (e.g. Share&Charge and Energy Web

[38]Demand Appears Strong for Tesla's Vehicles. Viewed at: 17:48, 29.05.2020 https://www.fool.com/investing/2020/01/06/demand-appears-strong-for-teslas-vehicles.aspx

Foundation[39], GET CHARGE by Deutsche Telekom[40] or Hubject, founded by Innogy, EnBW, Daimler and many others[41]) are aiming to solve the roaming issue with regard to these charging points because all the charging points need to communicate with each other. In order to do so, more infrastructure is needed. In their view, it is not a hardware issue, but an interoperability issue. Blockchain technology can be used to solve those issues. Also, new solutions are needed to avoid concurrent charging and to prevent overburdening the grid.

The core of an open charging network is the communication between the charge points to the supplier company. Transactions and data need to be signed because companies need trusted data. This can be achieved with blockchain technology. Machine identity and certificates can be supported by blockchain technology too. Other projects additionally support automatic payments such as the blockchain-based payment of trucks[42] or scooters[43].

The usage of charging stations is currently lower compared to the original forecasts. Worst case would be that electric vehicles are only an in-between solution and people will start using hydrogen vehicles much faster than estimated. For hydrogen vehicles you would only need gas stations which would not require such a big customer behavioural change as electric vehicles. Another challenge is that charge points also need to be certified because they need permission for every city. Oftentimes charging vendors have to wait so long for these permissions, that in the end their original business case does not work out as planned for the given city.

[39]The time to decentralize electric vehicle e-roaming is now. Viewed at: 17:48, 15.06.2020 https://www.euractiv.com/section/electric-cars/opinion/the-time-to-decentralise-electric-vehicle-e-roaming-is-now/
[40]GET CHARGE. Viewed at 13:59 16.06.2020 https://get-charge.com/
[41]Electric car charging interoperability is the next big thing in mobility. Viewed at: 17:48, 15.06.2020 https://arstechnica.com/cars/2019/06/more-electric-car-charging-networks-link-up-with-roaming-agreements/
[42]Commerzbank testet Blockchain-basierte M2M-Zahlungen mit Daimler. Viewed at: 17:48, 29.05.2020 https://blockchainwelt.de/cash-on-ledger-commerzbank-testet-m2m-transaktionen/
[43]Xride: Erstes Blockchain-basiertes Elektromobilitätsprojekt seiner Art. Viewed at: 17:48, 29.05.2020 https://www.telekom.com/de/medien/medieninformationen/detail/xride-erstes-blockchain-basiertes-elektromobilitaetsprojekt-seiner-art-580924

At the same time, household chargers are available and currently you can charge your car without any permission. But sometimes it takes up to 30 hours to charge the car depending on the cables you use and that will not help to convince people to buy electric vehicles. They need fast chargers instead, which have more than 22 kw charging capacity. Also, ultra-rapid chargers exist on the market, which provide more than 100 kw power (such as the Comfortcharge points with maximum speed of 150 kw[44]). Some charge points can provide energy even up to 350 kw (such as ABB[45], the first company to launch a 350-kw charger in 2018, or BTCPower[46]). But you cannot connect high speed chargers to the grid at the moment without a special allowance from the grid operator, which takes a lot of time to get and this situation will not really change in the next 3-4 years. In upcoming years, 2-3 households might have quick charging per each street but in most streets there will be only one as the grid is not powerful enough to accommodate more quick chargers without potential capacity problems. In most public places there is a battery next to each charger. These batteries are filled with energy and, when a car comes, the car is charged from the battery and not from the grid. Electricity prices are cheap at the moment, but it will be much more expensive in the future if more people start to use electric vehicles and charge them at the same time. For example, electric vehicle users do not have to pay for charging from charging stations because it is not allowed by the German government to bill for charging in Germany. It is possible to ask for a fee for parking but not for charging. However, it is also a general issue, that when people today charge their cars they are paying for the time. They can plug in their car and charge for an hour. In this time if they have a high-power cable, they can get 40-50 kWh energy, while with a smaller cable only 1-2 kWh. There should be a correct measurement system where you pay for the amount of energy that you consume.

The German government highly supports blockchain initiatives[47]. Blockchain is a great technology to record how much energy you have consumed at home or at a public

[44]Comfortcharge.Die Zukunft fährt elektrisch. Viewed at: 17:48, 16.06.2020 https://www.comfortcharge.de/
[45]ABB powers e-mobility with launch of first 350 kw high power car charger. Viewed at: 17:48, 16.06.2020 https://new.abb.com/news/detail/4439/abb-powers-e-mobility-with-launch-of-first-350-kw-high-power-car-charger
[46]Electrify America selects ABB, BTCpower, Efacec and Signet to supply 150/350 kw EV fast chargers. Viewed at: 17:48, 16.06.2020 https://www.greencarcongress.com/2018/04/20180417-ea.html
[47]Blockchain-Strategie der Bundesregierung. Viewed at: 17:48, 29.05.2020 https://www.bmwi.de/Redaktion/DE/Publikationen/Digitale-Welt/blockchain-strategie.pdf?__blob=publicationFile&v=8

charging station via microtransactions. When you do not need the energy, you could charge it back to the grid or to your home using vehicle-to-grid technology and you could earn or save some money. In the future, consumers will have at least three different contracts. As an electric vehicle owner, you will have separate contracts:

- to charge your car from public charge points,
- to charge the car from someone else's charge point (e.g. using your neighbours charge point) and
- to sell your energy back to the grid by using vehicle-to-grid technology.

The potential of the electric vehicle market is huge: the global electricity demand of electric vehicles is estimated to be equal to the total annual energy consumption of Germany by 2030[48]. It is going to be impossible to ignore it in the next five years. The technology is evolving faster than the regulations, so it can be a driving force. It will be a facilitator for green mobility scenarios as well. For example, one of the interviewed non-profit organizations, active with developing a decentralized electricity system, did a certified green energy pilot in California together with an electricity utility. In California the "low carbon fuel standard" provides a quota for carbon intensity of the fuel. Companies get carbon "credits" and "deficits" based on the fuel's carbon intensity. A carbon credit is such a permit that allows a company to emit a certain amount of carbon dioxide or other greenhouse gases. These carbon credits can be traded in the following way: if you are a company that generates a huge amount of greenhouse emissions, then you can purchase carbon credits from another company, who produces less emissions. The use case is the following: anytime an electric vehicle is charged, the car automatically purchases carbon credits and writes the purchase to the blockchain. More complex charging scenarios will come when electric vehicles will be able to modulate their battery's saturation based on charge and carbon signals.

[48]Energy Web Foundation. Electric vehicles. Viewed at: 17:58 29.05.2020 https://www.energyweb.org/solutions/electric-vehicles/

Germany has a good automotive industry and that is also a trigger for change. The innovation lies in the energy sector and its interface to other industries, like the mobility sector. This is where blockchain can be the most useful. Blockchain associations are active in piloting smart charging use cases. One of the first use cases was implemented together with a Dutch consortium called Elaad NL[49] . They created a prototype charger that uses distributed technology. It is a vehicle plug-in charger model. It enables the flow of cryptocurrency and instant payments. The charger is connected to the internet in the background. Both the charger and the car have a wallet and the payment can happen in cryptocurrency between the two devices. Also, the +CityxChange[50] project set up a PoC testbed in Trondheim checking the traceability of the energy. It is equipping a Jaguar with a car wallet with which the vehicle is able to share security information and make payments. They want to connect it to a smart building, which then could provide the surplus energy to the car. At the end of the day, the car will be able to automatically buy green energy from the building. Others, like Spherity, have blockchain based solutions for providing a guarantee of origin to prove that the sold electricity at the charge point is indeed green energy[51].

All of the interviewees thought that storing energy in the battery of e-vehicles will be definitely a useful feature in the future. For example, in New York there is neither a lot of space nor household batteries because people are not allowed to have one. So, it would be very valuable for the inhabitants to use their e-vehicles to store energy for themselves. In the future, parking lots can serve as a battery site as well by feeding energy to the grid. Parking lots will be very valuable for this reason in the future. Many people mentioned that they are aware of ongoing pilots in the vehicle-to-grid area. They mentioned Mitsubishi and Kia as examples. As the technology is already available, electric vehicles could definitely participate in the local energy trade in theory. For example, solar rooftop EVs could participate in the ecosystem in both directions by being a producer or a consumer.

[49] Elaad NL. Viewed at 16:45 15.06.2020 https://www.elaad.nl/
[50]+CityxChange. Viewed at 16:45 21.02.2020 https://cityxchange.eu/about-cityxchange/
[51]Escaping global warming. Viewed at 16:45 21.02.2020 https://medium.com/spherity/escaping-global-warming-e0c6a560b479

The battery of an e-vehicle is not a “traditional generator” because it is moving around. To use an e-vehicle as a flexible resource, it is required that grid operators are able to trace it and identify where the vehicle is at any actual point in time and how much energy it generates/stores. Blockchain could help here for secure identification and registration. Also, these cars need to communicate with each other. Most of the cars are not able to communicate at the moment because car manufacturers are worried that it could bring additional security threats. However, one of the biggest questions is when will there be a significant number of e-vehicles available, because vehicle-to-grid technology can only work in a meaningful way with a large market penetration.

In addition to technology, policies also need to be considered. There are questions such as how many different devices can be recognized by the electric vehicle that could provide a particular energy service to the car or receive energy services from the car. How could operators measure the energy flow and how could consumers pay for it? Also, vehicle-to-grid (V2G) chargers are expensive. They cost around 6000-7000 euros, while a charging box with face recognition costs around 1000 euros. People do not see a clear return on their investments. It is important to note that there are already existing solutions for making power sharing happen without blockchain and vehicle-to-grid technology. For example, you can plug in your car in Hamburg and pay with a voucher to charge your car with the electricity amount that is equal to your solar panel generated energy. Some companies (e.g. Senec) already support prosumers to use their virtual power and get lower prices that they would normally pay for by charging their car[52].

Another big opportunity is charging automatization. Those solutions will be the most powerful when the driver does not need to get out of the vehicle anymore to plug in a cable or to do anything for charging. There is a Volkswagen[53] charging robot pilot for electric vehicles that was introduced to a bigger audience last February. The robot automatically begins the charging process when the vehicle parks next to the charging

[52]Dein Elektroauto mit deinem Solarsrom überall betanken. viewed at: 22:46, 26.02.2020 https://senec.com/de/cloud-to-go

[53]Volkswagen lets its charging robots loose. Viewed at: 17:30, 17.05.2020 https://www.volkswagen-newsroom.com/en/stories/volkswagen-lets-its-charging-robots-loose-5700

station. There is a similar innogy[54] solution as well, where the robot is able to plug a charging cable into the e-car. There will be more and more Plug&Play solutions where the car will be communicating with the charging station and automatically paying for the services, as people find it more comfortable to have no interaction with the charger.

We were also curious what our prosumers think about electric vehicles and the possibility to use them as energy storage and potentially charge back the stored energy to the grid. All of them were very positive about electric vehicles, they are all planning to have one and to charge their car with solar energy. However, most of them perceive that the currently available models are still very expensive.

Our third prosumer, who is very much into sustainable use cases, plans to buy an electric car and fill it with his solar energy. He also wants to charge back the renewable energy to his home, whenever he needs it. He thinks about it as an extra battery next to his household battery. He already thought about having an electric car, but the batteries of his chosen electric car brand are blocked so he could not charge energy back to the grid and he wants to have a car, which he can use for power sharing. The second prosumer and her eco farmer family also want to buy an electric vehicle someday, but they are waiting for better technology. They need something with which they could drive on a field, a jeep for example. They are planning to use their solar energy to fill their car when their 20-year contract expires. They do not think that blockchain will facilitate people to buy electric cars. They think it is more about the distance people can drive before they need to charge their vehicle. Our first prosumer thinks similarly as the other two prosumers. He wants to buy an electric vehicle, but he does not think that it would be worthwhile currently from an economic point of view because it is very expensive at the moment. Most distances that he drives are less than 30 km, but he would need a trailer-ready vehicle. Once his feed-in period expires, he is planning to use the energy he will generate first for the household (e.g. to do cooking, washing, etc) and only the rest for the electric vehicle.

[54] Innogy presents fast-charging robot. Viewed at: 17:35, 17.05.2020
https://www.electrive.com/2019/02/06/innogy-presents-charging-robot/

4.6 Current Status of Machine economy

Many of the P2P energy use cases and their building blocks are dependent on the machine economy. In the machine economy all kinds of devices are able to communicate with each other, provide services to each other and even pay for these services without any human intervention. For this you need smart meters, which are able to do demand response management and potentially sort out whom to sell to and whom to buy from for the most benefit. You need an intelligent grid that is able to manage distributed energy forecasting, to integrate the distributed renewable energy coming from different sources and to do efficient and safe grid balancing based on the fluctuation of energy demand and supply in real-time. You also need an intelligent charging process to avoid capacity problems when charging your electric vehicle. Finally, if you want your electric vehicle to participate actively in the energy ecosystem, it must also be used intelligently. You must know exactly how much energy your vehicle needs, how fast it can charge itself and how much energy it can give back to the grid. The best case is if it all happens without any human interaction, because people do not want to be bothered with complex charging processes or do difficult calculations about their optimum route based on the availability of charging stations. Even if they could profit from it, most of them would not check whom and when to sell manually. They will only use these options if a machine could do it for them. We asked our interviewees what is needed for a full-fledged machine economy, where different kinds of devices are able to communicate and provide services to each other without human intervention, and how much time is needed for these solutions to be market ready.

One of the interviewed blockchain companies prepares products for the machine economy. They are building secure, distributed identities for machines and algorithms. However, their product still anticipates some human interaction. For autonomous decision-making direct Machine-2-Machine (M2M) communication is needed. M2M communication needs to be standardized because machines, which are not in the same sector, need to talk with each other. To bring products to the market user friendly technology is needed that takes care of data privacy and data security.

One of the non-profit organizations who are active with developing next generation protocols for a more connected world also deals a lot with the machine economy. They have brought a digital twin approach to the marketplace, that leverages the micropayment feature. This allows people to exchange money between multiple partners in the machine economy. However, this functionality will be only possible for devices that have a digital version (a digital twin). With a digital twin, physical devices have a blockchain identity that signs transactions and participates in settlements in a tamper proof way. Most of the times this is achieved by tagging or chipping objects with a small microcontroller, which is optimized for cryptographic algorithms[55]. The above-mentioned non-profit organization thinks that the trust in sensors in the mobility market will penetrate the market very quickly. In the future, there will be many autonomous electric vehicles navigating through cities. They will plug themselves in to chargers and pay autonomously. Prices will vary during the day. In the future, you will let your car charge itself when it is cheapest. People will follow the battery status in their app and when it is full, they can drive around or even sell the energy.

As per the interviewed energy operator, the whole industry needs to understand that open standards are the way to go. Blockchain will be the single source of trust and information. It will be the manager of the IoT world. Transactions will be handled by blockchain or similar solutions. There will also be a marketplace/registry where devices will be able to identify each other. There are already a lot of IoT devices installed at the moment, but they do not have a secure identity or technology onboard to interact with other devices. Charging vendors need to understand that there will be millions of charge points in the future. Blockchain could handle the microtransactions for the charging processes. However, not just blockchain, but also automatization and Artificial Intelligence (AI) is necessary for a real machine economy. The reasoning behind this is that not everyone wants to decide about +/- 30 cents, when it comes to peer-to-peer energy trading. Therefore, AI is needed to automate the trading process as it can compare the competing offers of different renewable energy sources and choose the most favourable option.

[55]Voshmgir, S. (2019) Token economy. How blockchains and Smart Contracts Revolutionize the Economy

Another big area to examine is the scalability of blockchain technology. The biggest non-profit organization in the energy sector created a new blockchain dedicated to smart energy use cases. Another one created energy efficient and scalable tokens. The latter organization thinks that the best way to pay for microtransactions is to use tokens or cryptocurrencies. Digital trust, security and integrity are the future and it is a natural fit for distributed ledger technology.

When it comes to the timeline, most people agreed that full-fledged machine economies will require another 10 years to be market ready, but some use cases are already available today. Advanced e-mobility solutions will come in the next five years, our experts stated. And the development of real peer-to-peer energy markets will be more dependent on the legislation than on technology.

As written above, most people agreed that a fully automated machine economy, where the devices will be able to interact and trade with each other without human interaction, will take up to ten years. Reasons are that on the one hand secure monetary exchange among multiple partners needs to be established and on the other hand, AI technology needs to evolve. Learning about consumer engagement and behaviour patterns could become a reality in the next 2-3 years and that will significantly improve the agent algorithms in this area.

Interviewees are guessing that data energy marketplaces will be present within five years. At that time there will be cars that are able to communicate with each other and cars will have a bidirectional energy flow.

People were more optimistic about pure e-mobility solutions. They estimated that high speed chargers will be an integral part of the grid in the next five years and vehicle-to-grid technology will start within the next 2-3 years. However, the employees of e-mobility companies added that a lot depends on the emergence of the electronic vehicle market. They all agreed that current models of mobility will not be sustainable in the future.

Although it is much more comfortable to own a personal car, sharing models will slowly spread in the next 10-15 years, especially as people are getting more and more aware of the impacts of climate change. Although, we also have to count the risk that electric vehicles might be an in-between solution and people will use hydrogen cars instead.

Market forces and policies matter a lot for peer-to-peer energy trading. Participants had very mixed opinions about the emergence of P2P markets. Some interviewees thought that technologically there are not too many problems and it would be possible within 1-2 years to do real P2P energy trading. Some forms of P2P energy trading are already proven in many countries. We have to add here that there is a huge difference among how different participants define peer-to-peer energy trading. All interviewees were aware of regulatory obstacles and, thus their estimation went up to 5, 10 or 15 years. All interviewees agreed that forming energy communities, which are consumer cooperation aiming to cover the neighbourhoods' energy demand with only local energy sources, is a promising concept. Energy communities will evolve once the feed-in period expires for prosumers starting from 2021. It is a very probable outcome that these prosumers will search for alternative solutions to benefit from their infrastructure. But we might need to wait until 2025, when enough 20-years contracts expire in order to have enough people interested in this market. Peer-to-peer energy markets within balancing groups already exist even in Germany. Consumers of the same supplier in the same energy group can trade energy among each other. This is not the vision, of course, because they are still dependent on one supplier and it would be more optimal to choose from more suppliers. In other countries similar early stage peer-to-peer markets are also operating today. For example in Vermont[56], Green Mountain Power is starting to use it in production. The same use case is implemented in Denmark. The +CityxChange[57]-project in Norway wants to deploy peer-to-peer energy markets within two years.

One thing is sure: all of these trends (P2P energy trading, vehicle-to-grid technology, machine economy) require solutions not just for technological issues. They also need

[56]Green Mountain Power, Lo3 utilizes blockchain. Viewed at 19:58 15.06.2020 https://www.publicpower.org/periodical/article/green-mountain-power-lo3-pilot-utilizes-blockchain
[57] +CityxChange. Viewed at 16:45 21.02.2020 https://cityxchange.eu/about-cityxchange/

mindset and regulatory change. Many participants are making big efforts to educate people about energy efficiency. Some of them are creating an app to educate people, others are organizing workshops and creating tutorials. Everyone is involved in some kind of educational activity because they know that a lot will depend on the people's knowledge and their market force to impact regulations.

4.7 Regulations and policies

All participants agreed that many regulations need to be changed for real peer-to-peer energy trading. Of course, complying with some of them, for example with the security and data protection regulations, is inevitable. The energy grid requires more security and is more sensitive than nuclear power plants. If you bring a gateway to the market, you have to ensure that the product chain is very secure. Blockchain could further secure these devices. But at the moment there is no certified smart meter proven to have blockchain interfaces. Lobbying at the political level is highly needed.

The good news is that there are already some supportive initiatives. For example, the European Clean Energy Package requests that customers need to be able to switch providers in very short notice. There will also be a new regulation that will enforce the need for each electric vehicle owner to have charging boxes at home. However, whatever is installed, for example 21 kWh, doesn't mean that the electric vehicle owner will get the 21kWh energy automatically. The minimum will be 3 kWh. Currently even a heater or a boiler is allowed to take 3.6 kwh from the grid. So, it won't be enough to charge the car. The reasoning behind this regulation is that market principles haven`t led to change as there is no real electric vehicle market yet.

Changing the regulations is possible, but it will take some years. It also depends on the big OMVs. The energy regulators in California and Australia do not have a choice when it comes to energy trading because the private use of solar panels is so cheap. The electric vehicle market can also be a trigger. When electric vehicles will have a share of at least 10% of the vehicle market, then it will be a driving force. As per one of the blockchain

startups, regulation is there to find out how to introduce new ideas without disrupting the current processes. The grid is built to send energy from the house to the grid and not built to have energy coming from all different sources. It could melt the wires. Smart platforms could help on this, telling the need to upgrade right here and have a peer-to-peer community over there.

4.8 The Impact of the Current Trends on the Energy Prices

The last question that we asked the interviewees was their energy price expectations in the coming years. Most of them expect increases in the next few years and a decrease in the long run. Some of them are also expecting the introduction of multiple tariffs that charge different prices depending on the time of the day.

The energy price increase will be the result of investments in the coming years as per the respondents. Outdated assumptions exist currently. These are based on energy generated by thermal power plants which have very complicated marginal cost calculations. These assets will be replaced with renewable assets, which have zero short-term marginal cost and very different capital costs. However, many investments are required to successfully accommodate renewable energy sources. Furthermore, the increasing number of charging stations may cause grid capacity problems without additional investments. It will be a huge transformation to create a distributed and democratized smart grid from the centralized grid. The change will require capacity improvement and millions of new smart devices. Millions of smart meters are needed with evolved features such as demand response management (switching on/off smart devices based on energy demand/supply in the energy grid). Also, data communication, data interoperability and data services have to be improved because, without secure and transparent data, it will be hard to trade among multiple participants.

Once the grid becomes more stable and there are more participants in the market, the prices will eventually decline or there will be capacity markets, where customers need to pay more, if they want bigger electricity throughput (but in a shorter charging period). The

latter means that not just the price of kWh will matter, but also how fast someone can charge his devices. New e-mobility will increase the number of transactions in a very short time frame and that energy will need to be provided somehow. Prices might fluctuate, meaning that there won't be just one price for the whole day. There will be different prices for each minute. Charging your car at 6 pm will be probably not the best idea because you might want to delay your consumption until that part of the day, when the prices are cheaper. This is also a possible mitigation option to avoid the future capacity issues stemming from the energy demand of electric vehicles.

At the end of the day, everything will depend on the policy levels and on the people. In some countries, e.g. in Norway, solar panels are more expensive than hydro power but still people buy it because they want to do something for the environment. Because of climate change, e-mobility and energy sharing, everything is in transition, but big operators still need to receive revenue for their investment in existing plants. The current technological development is incredible. Soon you will be able to follow where your energy is coming from and where your money is going to. What is sure is that the next ten years will be very exciting with varying possible outcomes.

5. Conclusion - Validation of Hypotheses

At the beginning of this paper we suggested a main hypothesis with three sub hypotheses. Based on the interviews, some are confirmed to be valid, while some need to be slightly modified. Let's check them one by one:

H1. Blockchain will empower consumers to control their own electricity supply through smart meters and trade excess energy in a peer-to-peer manner in their close neighbourhood, thus helping consumers become prosumers.

Many respondents agreed that blockchain is a great technology to secure smart meters and make the data coming from the smart meters more transparent, more secure and available for more participants. Even prosumers mentioned that blockchain could help to eliminate the differences among their measured data and the billed amount. As accurate registration of energy consumption is definitely required for peer-to-peer energy trading, therefore we can say that this hypothesis is proven to be true. Blockchain can also support the registration of such devices, like rooftop solar panels, electric vehicles or household batteries in the energy ecosystem and these are all required to be tracked for a peer to peer energy ecosystem.

H2. E-vehicles will be able to potentially store excess energy when demand is low and give back some energy when demand is high, trading this excess energy autonomously using a blockchain based smart grid with the help of vehicle-to-grid charging infrastructure.

The first part of this hypothesis is definitely true: vehicle-to-grid technology is evolving fast and soon it will be available in production. Charging back to the household grid for electric vehicle owners will be possible very soon. But to use it for peer-to-peer energy trading, the traceability of the energy (meaning how much energy is coming from which device) and the traceability of the car (meaning where the car is exactly located) must be solved. Also electric vehicles must be able to modulate their battery saturation based on charge (e.g. energy production, nearby consumption) and carbon signals. Blockchain can definitely be an enabler here for the traceability use cases and for providing green certification for renewable energy. However, AI technology also needs to be added to the grid in order to enable autonomous trading.

H3. In the next three to five years a machine-to-machine economy will emerge, where, for example, e-vehicles will trade with charging stations in an autonomous fashion using blockchain technology or smart buildings will be able to control their own energy needs and buy/sell energy using microtransactions.

As it was written above, machine economy use cases are definitely evolving right now, however for a full-fledged machine economy, where devices are able to communicate and trade with each other without any human interaction, we need to wait approximately ten more years. Good news is that many building blocks will be available much sooner and some of them are already available today. For example, the possibility to allow cars to trade with charging stations exists already, though the automatization and the generalization of these use cases will require some more time. Smart, self-sufficient buildings already exist as well. One example for them is the +CityxChange project in Trondheim, Norway. This project is also piloting the possibility to sell the energy produced by the solar panels of one of the powerhouses to cars, buses, neighbouring houses and even to boats[58]. This is already done. What is still needed is the development of automatization. Automatization will again require the development of AI and additional policies and business models. It needs to be clarified how exactly micropayments among multiple stakeholders can be handled. This will take rather five to ten years than three to five years.

Our main Hypothesis was that *blockchain technology can create trust and connect partners who are non-trusting and unconnected in the past, therefore, blockchain technology will highly facilitate the trusted ecosystem around the energy sector in the next three to five years (H0).*

Blockchain is an immutable ledger, which can create trust by increasing data security, transparency and auditability. A third of the interviewees explicitly mentioned the word trust together with blockchain. They mentioned that renewable energy is a lot about trust and blockchain could help to ensure that customers really get clean energy from the operator. Now customers have to believe what their energy operators tell them. It was also mentioned that digital trust, security and integrity are the future, which can be

[58]Cities of the future: IOTA, Jaguar Land Rover, Engie Lab Crigen & Entra showcase energy traceability. Viewed at 11:48, 24. 02. 2020 https://www.youtube.com/watch?time_continue=2&v=erKiOoSiUBM&feature=emb_logo

enhanced by using blockchain technology. Someone even said that blockchain will be the single source of trust, a layer, which will manage all kinds of IoT devices. All people agreed that blockchain can facilitate digital trust via securing smart meters and other devices on the edges. People generally believe that blockchain can bring trust into the energy ecosystem.

On the other hand, the technology's biggest benefit is the ability to optimize data exchange among multiple stakeholders. Blockchain is an enabler of real-time decision making and real-time monetary exchange. Although microtransactions and micropayments are definitely the future, there is still a lot to figure out on the technological side and also on the business side. New policies need to be implemented and somebody at the end of the day has to be financially responsible if the trading participants are not upholding their promises. This will come, but the change will take time. Blockchain will definitely be an enabler here, so our main hypothesis is true, but there is much more to do and one of the most important tasks is educating people about the opportunities in the energy space.

All in all, we could say, that important early, real-life implementations of peer-to-peer energy trading already show important insights today, though bringing these solutions to every customer in Germany will take some time. Challenges on the technology side, but especially on the regulations side need to be solved. Looking at the current status of the energy market digitization, smart meter penetration has just started, and we still need to enable the currently certified smart meters to be able to securely register values to the blockchain. This needs new development and a new/additional certification process for smart meters. Another important aspect is that certified smart meters in the market today do not do "demand response management", meaning that they are not able to switch on/off devices based on the fluctuation of energy supply and demand. This feature is definitely required to create a smart grid. Besides that also grid flexibility and capacity need to be improved. Capacity improvement is especially important to incorporate the electricity demand of electric vehicles and new, distributed energy sources. The good news is that electric vehicles could soon be attached to the grid as an alternative form of energy storage, which will increase grid flexibility.

However, in order to use vehicle to grid (V2G) technology efficiently, you need a certain number of electric cars and the electric vehicle market is not developing as strongly as hoped. The target was to have one million electric cars by 2020 in Germany and now we are at 200.000, so probably this target cannot be reached by the end of the year. Another challenge is that it will take 20 years to equip all households in Germany with smart meters, meaning that it will take a while until it is possible to create a smart grid. There are promising signs as well: many households already own a solar panel and, as we mentioned, there are a lot of pilots ongoing in the moment in the P2P topic. The end of the feed-in period of early adopter prosumers in 2021 can trigger new market opportunities, as prosumers will look for possibilities to further benefit from their solar infrastructure, thus they will be more open to participate in peer-to-peer trading platforms.

A substantial amount of time and effort needs to be spent in the area of regulations. Germany has a complex regulatory system that needs to be highly adjusted to allow peer to peer energy trading. Luckily, there is a lot of support for decarbonization solutions and the market can be also a driving force, once there will be a significant number of consumers both on domestic renewable and on the electric vehicle side. It is also a promising sign that regulations and policies *are* changing rapidly in recent years. Whereas it was not allowed for a prosumer to consume his /her homemade energy ten years ago, today it is possible. We expect that in the coming years the regulation side will be significantly impacted by the growing demand for distributed, renewable energy solutions.

At the same time, we will see more and more proof of concepts, pilots and real-life implementations in the upcoming years. Early stage peer to peer markets are already present or starting this year in the US, in Australia, in Denmark and in Germany. Advanced pilots, like the +CityxChange[59] project in Norway, are experimenting with self-sufficient buildings and vehicle-to-grid solutions. During these pilots, people learn a lot and these learnings support them in planning future-proof business models for applying microtransactions and micropayments. Experiments about grid flexibility, attempts to

[59] +CityxChange. Viewed at 16:45 21.02.2020 https://cityxchange.eu/about-cityxchange/

increase smart meter resiliency or to create more robust data communication are all milestones towards peer to peer energy trading. Eventually these trials will lead the industry to the cited IOTA vision[60], where will really have electric vehicles participating in the energy ecosystem and have prosumers intelligently controlling their energy mix, while also allowing prosumers to rely on smart devices to trade their energy in the most beneficial way.

Conclusion is that it will take a few years before we will have fully peer-to-peer energy markets in Germany and Europe, however, all participants of the study believe that blockchain technology will be definitely an enabler to reach this goal. Blockchain companies are currently doing plenty of work, partly funded by the government, to influence and further develop the ecosystem. They help to secure the devices, the data exchange and to create transparency. They are working on the registration of smart meters, on certifications, carbon credits and on the traceability of energy production and consumption. They help to enable peer to peer business models and microtransactions with smart contracts. They help to create secure open source software, scalable technology and open standards. They help to increase interoperability. They educate the people to unlock the real potential of blockchain. Finally, they will help to create a more democratized, more energy efficient and sustainable future consistent with the world's needs.

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IV. Appendix

A) Questionnaire for companies (applies for the following groups: energy operators, smart gateway vendors, charging station vendors, blockchain startups, associations):

1. Could you please briefly introduce yourself and your role in your company?
2. Do you think that the existing electricity infrastructure satisfies your customers' needs?
3. How many of your customers use smart meters? What is your experience with your customers' electricity supply control?
4. Have you ever heard about blockchain technology?
5. Do you think blockchain technology will be able to improve the smart meter technology, e.g. by verifying the tracked values and register them to an immutable ledger or ensuring automatic, secure payments, when selling back energy to the grid?
6. What is your experience with prosumers? What is your experience with trading excessive energy in a peer-to-peer manner?
7. Do you think that blockchain technology can connect partners who are non-trusting or unconnected currently, e.g. empower neighbours to sell energy to each other?
8. Do you think that blockchain will further enhance customers to become prosumers?
9. Do you own or plan to own an electric vehicle?
10. Have you heard that the battery of vehicles is a potential tool to store excess energy from solar panels and windmills?
11. Do you think that your customers would use their electric cars to store excess renewable energy and use this energy to power their house or to sell it back to the grid?
12. Do you think that blockchain technology can increase trust in the above-mentioned solutions?
13. Can you imagine that this whole process will one day happen autonomously using blockchain technology?
14. Can you imagine that all sorts of machines (e.g. smart meters, cars, charging stations) will be able to trade with each other autonomously, without any human intervention? If yes, then how much time do we need to develop these solutions, - taking into consideration the time for pilot projects, discussions with regulators, etc? Do you think blockchain technology can further facilitate this exchange?

15. Do you think in general, that blockchain technology will highly facilitate the trusted ecosystem around the energy sector?
16. What do you think, how would it change the energy prices, if we would have more actors, more prosumers in the market who would act independently on the market and sell their surplus energy to each other?

B) Questionnaire for prosumers:

1. Could you please briefly introduce yourself?
2. Do you think that the existing electricity infrastructure satisfies your needs?
3. Do you use smart meters? What is your experience with these devices so far? What is your experience with controlling your own electricity supply?
4. Have you heard about blockchain technology?
5. Do you think blockchain technology will be able to improve the smart meter technology, e.g. by verifying the tracked values and register them to an immutable ledger or ensuring automatic, secure payments, when selling back energy to the grid?
6. What is your experience being a prosumer? What is your experience with trading excessive energy in a peer-to-peer manner?
7. Do you think that blockchain technology can connect partners who are non-trusting or unconnected currently, e.g. empower neighbours to sell energy to each other?
8. Do you think that blockchain will further enhance customers to become prosumers?
9. Do you own or plan to own an electric vehicle?
10. Have you heard that the battery of vehicles is a potential tool to store excess energy from solar panels and windmills?
11. Do you think that you would use your electric car to store excess renewable energy and use this energy to power your house or to sell it back to the grid?
12. Do you think that blockchain technology can increase trust in the above-mentioned solutions?
13. Can you imagine that this whole process will one day happen autonomously using blockchain technology?
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15. Do you think in general, that blockchain technology will highly facilitate the trusted ecosystem around the energy sector?
16. What do you think, how would it change the energy prices, if we would have more actors, more prosumers in the market who would act independently on the market and sell their surplus energy to each other?

C) Blockchain use cases mentioned by interviews in the energy sector

- Automated charging solutions
- Billing
- Crypto/tokenization
- Carbon credit
- Carsharing, scooter sharing
- Certification
- Data transitions
- Demand response management (switch on/off devices based on energy demand/supply)
- Distributed governance of data
- Grid flexibility
- Guarantee of renewable energy credits
- Incentives to change customer behaviour
- Flexibility in aggregation
- Micropayments
- Microtransactions
- Peer-to-peer energy trading
- Real time balancing
- Record data for event logs
- Registration of devices
- Registration of throughput when charging
- Save energy data to the blockchain
- Secure communication among devices
- Secure the devices (e.g. smart meters)
- Self-sovereign identity
- Sign transactions/sign data
- Streamlining the processes
- Switch operators
- Traceability
- Traceability of EVs
- Validation of meter data