A MARKET ANALYSIS OF VIRTUAL POWER PLANTS AND SOME IDEAS FOR POTENTIAL OPPORTUNITIES

by
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Abstract

Virtual Power Plants (VPPs) aggregate a group of small/medium distributed supply-side energy resources (DERs), such as PV, wind, electric generators, and even demand side response, and control this potential net supply, such that they act as a single power plant for grid operations and energy trading. VPPs are enabled by the advancement of technologies like artificial intelligence (AI), the internet of things (IoT), and cloud computing amongst others. The recent growth of VPP ventures particularly in Europe is expected to multiply the market size over the next few years and result in a significant disruption of the existing energy market structure, especially with the continuous growth of DERs. This paper explores the maturity of the different technologies enabling VPPs, and some of the business models currently adopted in different countries. By analyzing some of these successful VPPs, and the different policies that impact their operation in different regions, new business opportunities are then identified and investigated as potentially viable business ventures for future analysis and further development.

Mentor: Dr. Thomas James Jenkin

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Last but not least, I've had so many amazing classmates with such diverse backgrounds that I learned as much from the clever discussions with them as from the program's material.

Table of Contents

List of Figures

1 Introduction

The landscape of energy markets has seen many changes over the past decade. The continuing fall in prices for renewable energy technology has made these resources increasingly accessible and desirable for many different types of consumers. Policies favoring the expansion of distributed energy resources (DERs), stimulated by the Paris Agreement and the commitment of many countries to reducing their carbon emissions has encouraged this shift in energy production even further. However, the current electricity transmission and distribution infrastructures are not built to handle the problems that come with the spread of distributed and renewable generation (Asmus, 2019a). Issues from intermittency, congestion, and grid frequency and voltage instability, as well as disparity between supply and demand times have wreaked havoc on elec grids worldwide. Such issues have led to instances of negative energy pricing at some points in time when demand is low and generation is high, and spikes in prices when the opposite occurs. 2020 has been an exceptional year in this regard due to the extraordinary conditions of COVID-19 and long lockdowns which changed consumer behavior drastically. For example, Germany has witnessed electricity prices falling to an unprecedented value of -€83.94/MWh for eight hours in the April of that year (Jones, 2020).

Multiple solutions have sprung up to attempt to manage these issues. Demand Response (DR) is perhaps the most commonly known of these solutions where the utility attempts to reduce the consumption of some of its customers at peak times to stabilize the grid and electricity prices in return for financial incentives; either by setting specific time windows where consumption is reduced, or by using smart grid solutions to control the loads of some of the consumer devices remotely (DOE, n.d, Demand Response Section).

Virtual Power Plants (VPPs) are another groundbreaking solution that relies on intelligent software and decentralized sensors and controllers to manage a large network of distributed resources as a single "virtual" power plant. Not only can VPPs solve many of the issues grid operators have been seeing of late, they provide an opportunity for flexible generation and grid balancing with speed and accuracy that traditional fossil-fuel or nuclear power plants cannot supply (Deign, 2020). The fact that they utilize existing DERs is also a significant advantage as governments do not need to build and deploy new mega-generation projects to deal with these issues, as well as govern the supply of these DERs to the grid. On the prosumer side – the owners and operators of DERs, VPPs provide a chance for higher financial returns on their renewable energy asset investments that they could not have as standalone generators due to their small capacity. As more DERs are deployed to the grid, more resources can be aggregated in VPPs at a low cost, with promise of increasing revenues in the electricity markets (Asmus, 2019a).

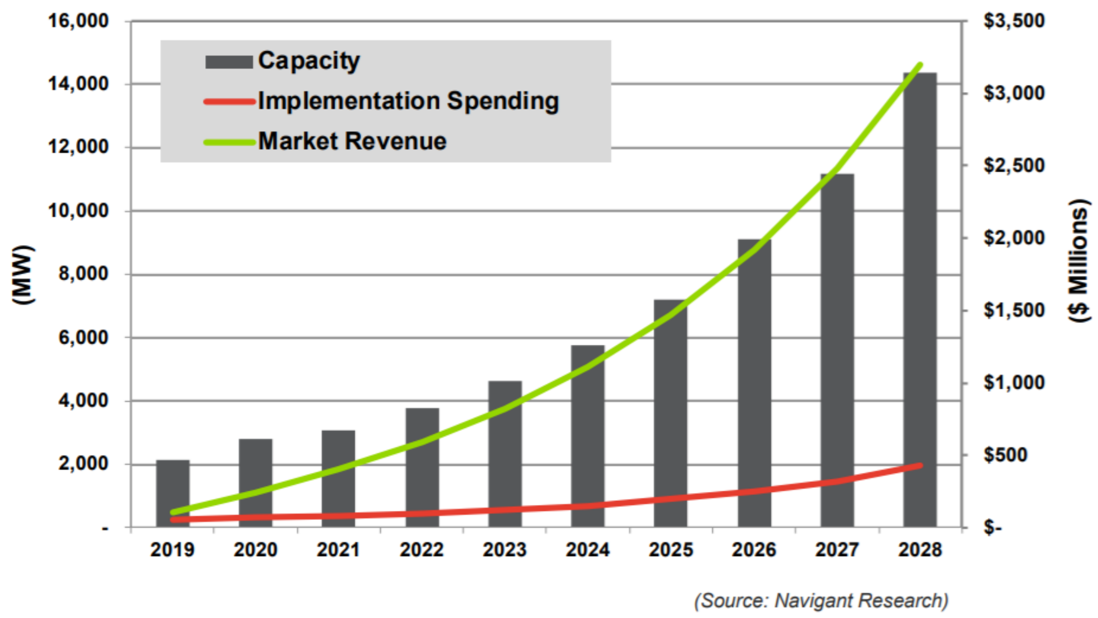

Figure 1: Annual Total VPP Capacity Implementation Spending and Market Revenues, Europe. Source: (Asmus, 2019b)

So far, there are relatively few VPP companies in operation in the world, primarily in Europe like Next Kraftwerke, e2m, and sonnen. Some countries have been engaging in pilot projects to see if VPPs really provide value to their citizens. In Victoria, Australia, the government launched the Battery Aggregation Pilot to see if residential solar and storage solutions to drive the future battery aggregation strategy of the state (Matich, 2021), and Canada's Alectra, a municipally owned utility, have partnered with Enbala, a smart grid solutions provider, to use their platform as a pilot for integrating DERs in Ontario (Juhl, 2018).

Given the increasing interest in VPPs worldwide and their promise of grid solutions on one hand, and profitable energy trading on the other, this paper evaluates whether *the emergence of virtual power plants creates new business opportunities which provide value to their target customers*. The paper explores how a virtual power plant functions both from the point of view of the technologies that enable it, and from the perspective of the business models through which it can operate. It also attempts to identify the market conditions required for the success of a VPP venture by profiling some of the existing VPP companies with regards to their value propositions, differentiators, weaknesses, and possible future opportunities, as well as analyzing the political and socioeconomic environments of some regions and how they impact the business opportunities of VPPs. Based on this information, the paper aims to identify unexplored VPP business opportunities, and explore some of them in more detail using Osterwalder's Business Model Canvas (2010) which can provide the basis for a business plan to develop a virtual power plant.

2 Literature Review

2.1 What is a Virtual Power Plant?

While there is no universal definition for a VPP, most literature are based on few key linked concepts: interconnecting decentralized generation units, creating a single operating utility consisting of aggregated distributed energy resources (DERs), optimizing operations of multiple diverse types of assets, and selling electricity from different small resources connected to the grid. (Wang, et. al, 2019). Wang, et. al (2019), for example, chose to define a VPP as "a group of distributed generations, energy storage systems, and controllable loads, which are aggregated, optimized, coordinated and controlled so that it can function as one dispatchable unit in power system operations as well as one tradable unit in electricity wholesale markets."

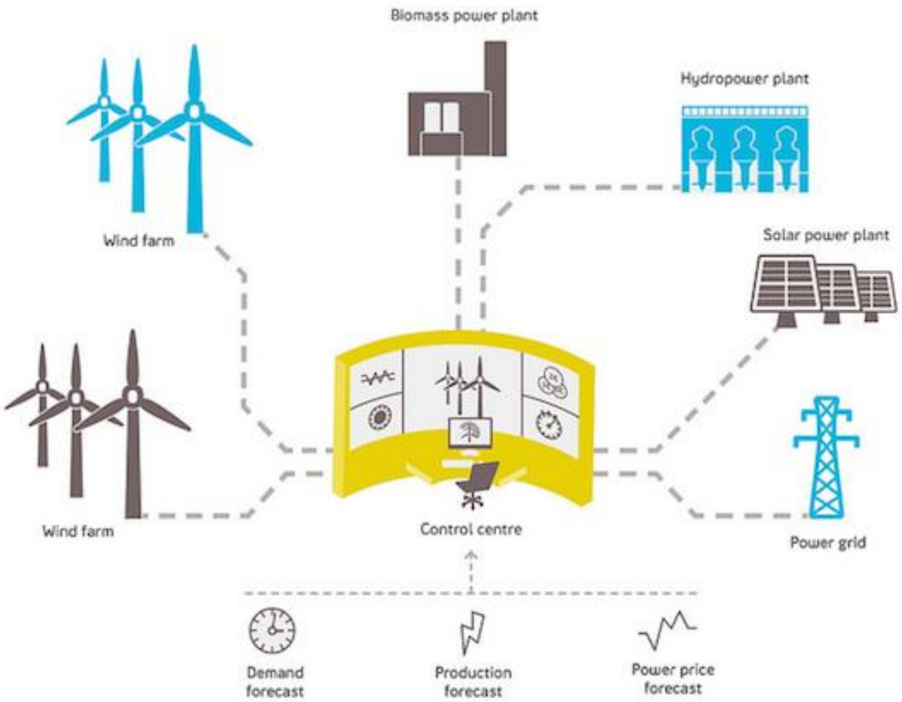

Figure 2: A conceptual diagram of a VPP (BMWi, 2015)

Based on this definition, a VPP does not only need to communicate, connect, and control various types of DERs and loads like PV, wind, storage, and even thermal assets, but it also needs to communicate with the grid to provide the power required to fulfill a specific grid service. This connection is facilitated through the advancement of the Internet of Things (IoT) which allows the assets to communicate with the central controller and with each other. The IoT communication includes collecting different types of data from various sensors in real-time which feed into a centralized controller which combines the data from the different sources and generate real-time control commands like power profiles to optimize the amount of power generated, or operational commands like shutting down or curtailing resources. This centralization is feasible at scale due to the availability of cloud computing, which has become affordable over the past decade (Shahzad et al., 2020). It’s worth noting that the differences between a VPP, a microgrid and microgrid control systems are not very obvious but are explained in more details in Appendix A.

For optimal and profitable operation, different layers of intelligence need to be taken into consideration. Advanced intelligence software like price, supply, and demand forecast algorithms are also required to provide a technical edge to the VPP to make it more robust in the face of uncertainty like changing weather conditions that affect renewable energy generation, or spikes and crashes in power prices. These algorithms need significant computing power to run in real time, and often require and make sure of cloud computing resources.

Hence, the architecture of a VPP is based on IoT-enabled DERs, a centralized cloud-based control system, and a data analysis and forecasting engine.

2.1.1 The Internet of Things (IoT)

At first glance, IoT sounds a lot like regular remote control/telecontrol/machine-to-machine (M2M) systems that transmit data via sensors to a controller, and the controller then relays inputs based on the sensor data. Such systems have been available since the 1970s to enable industrial automation via programmable logic controllers (PLC). Modbus is an example of a widely used communication protocol that's considered industry standard and was first introduced in 1979 (Acromag Inc, 2005). While M2M continued to advance and improve over the years, the "Internet of Things"; a term coined by the technology pioneer Kevin Ashton in 1999, became the next breakthrough in connecting "things" to the internet so that they can be controlled remotely and intelligently by computers (Wood, 2015). Today, M2M and IoT are considered somewhat different for various reasons. M2M systems rely on point-to-point communication via wired or cellular networks that depend on specific embedded hardware and certain protocols with no access to anything other than the system it is designed for (Polsonetti, 2018). IoT expands the scope of the connected devices to be accessed by a myriad of advanced applications, especially over the cloud, and not just for a bespoke control application (Johlie & McDonough, 2019) . In addition, IoT's openness to different types of interfaces makes scaling up easier, and simplifies conforming to standards for data security and privacy (Began, 2020). Additionally, IP-based communication provides additional metadata to the communication like identification, security, location services, and quality of service (QoS) (Davoody-Beni et al., 2019).

Edge Computing is an evolving technology that mixes between distributed computing which has been available since the 1990s, and IoT where computation comes closer to the source, reducing latency and improving performance. We expand on Edge Computing in Appendix A.

2.1.2 Central controller

The central controller is the brain behind the operation of the VPP. It compiles and analyzes all the data it receives from the DERs, the DSO/TSOs, and the energy markets, combines them with the constraints of the system; either set by the customer, or operational constraints, to make decisions on how to use each asset, and dispatch power set point schedules accordingly. In addition, the central controller uses security protocols to authenticate that the information has not been tampered with. Some of the factors determining which asset does what are reaction time, ramping speed, health of the asset, and its capacity. We expand on the exact operation of the central controller in Appendix A.

There is no single architecture for a central controller of a VPP. The most typical setup is where all the data is transmitted to one central unit that stores and processes the data from all the DERs connected to the VPP, integrates this data with data from the energy market, and transmits control parameters to the assets so they fulfill the market requirements. A decentralized VPP architecture makes use of edge computing to reduce some of the load so that any information required in real-time and does not directly affect the VPP operations can be preprocessed on “the edge” at the asset level. This approach has several advantages as mentioned above and frees up memory and computational power for the controller to perform more sophisticated analyses and run more accurate forecasting algorithms (Tasnim, et. al, 2020).

In addition, the data management techniques and communication protocols used can vary widely. We expand on these two topics in Appendix A.

2.1.3 Algorithms and Artificial Intelligence

“Smart” algorithms are responsible for data analysis, optimization, and forecasting. These types of algorithms are not new in the context of energy as they are the reason the term “smart grid” exists. Three areas of particular interest are algorithmic trading, forecasting and optimization. Algorithmic trading is when an intelligent algorithm receives market data, analyzes it, finds opportunities and assesses risks, and places bids without human intervention at speed and accuracy higher than human traders. Machine learning algorithms are used so that the trading application “learns” from the market feedback to continuously improve its accuracy (Pararasasingam, 2020). Algorithmic trading frameworks are explained in more details by Baltaoglu, Tong, & Zhao (2018), and Wang & Yu (2019).

Forecasting is an application of different types of artificial intelligence algorithms and is a very large topic, and lies outside of the intended scope of this paper. Essakiapan et. al (2017) provide a useful article that covers a number of elements of this field in the context of virtual power plants.

Finally, different control mechanisms in VPPs like power flow, dispatch, and cost management rely on optimization processes. The table in figure 7 lists a variety of these techniques which are explored further in (Tasnim, et. al, 2020).

2.1.4 Hardware Requirements

The hardware required to operate the VPP is split into two parts; the peripheral embedded systems on the asset/edge side, and the central core where all the heavy-duty computation and data storage happens. Generation and consumption assets are connected to the electric grid via the normal transmission and distribution networks, and data is exchanged between the assets and the controller via internet connection: LANs, WANs, or mobile data networks.

Implementing IoT in a VPP means that a DER, which could be a single asset or a group of assets that communicate internally, is equipped with sensors and measurement devices that accurately capture different types of data from the asset and the surrounding environment. The DER must also be capable of receiving various types of commands like power set points, on/off commands, or power profiles and fulfill them, which means that a bidirectional inverter. The asset must have a way to communicate with the VPP in the form of a modem or a SIM card to connect to the telecommunications network. The asset is also expected to have a programmable embedded device that can perform data collection and preprocessing on a certain level, encryption and decryption for security purposes, network management, and memory and CPU handling (Mehmood et al., 2021).

On the central controller side, the system is expected to be deployed on a cloud platform that is typically provided by an existing cloud provider which owns, manages, and orchestrates the data center where the data is stored and processed. While it unlikely that the data center is privately owned by the VPP provider, virtual cloud solutions are available on the market for use cases such as this (Mehmood et al., 2021).

2.1.5 Technical Challenges

The VPP's technical challenges are the same as any IoT system. First, the IoT devices need to be resilient to withstand different operational conditions depending on the types of site and assets connected to the VPP. Furthermore, the quality of the IoT devices themselves regardless of operational conditions could also pose a challenge; the batteries shouldn't run out, the device shouldn't require too much maintenance, and the availability of the device need to be high to avoid any gaps in the data (Davoody-Beni et al., 2019).

Second, the most advanced IoT devices would be useless if they cannot transmit and receive the data reliably. While this risk may not be as high in VPPs as in other smart grid applications, nor is the risk very high in countries with good telecommunications infrastructure, it may still be a problem for sites in remote locations where communication is not very reliable (Davoody-Beni et al., 2019).

Third, the 3Vs of Big Data: volume, velocity, and variety, also apply to the data in the VPP system. The volume of the data increases as additional assets are connected to the system, along with additional data communicated from a single asset as the system becomes more advanced. The velocity of the data includes both the velocity of the data transmission, and the velocity of processing such data in a timely manner. Variety refers to the increasing range of information in the system. The data may not only be measurements, but may also include fault information, or information that requires complex data structures to be processed.

Fourth, the system receiving and storing the data needs to be able to handle the above data challenges with regards to both data storage and computing, not to mention the redundancy and backup systems that ensure the data is retained properly as per data retention requirements and that the systems are always available with sufficient computing power and storage (Davoody-Beni et al., 2019).

Fifth, while the data communication protocols used in IoT are used extensively in computing applications, and how to interface with them is standard, there are a lot of protocols being used simultaneously depending on the provider of the asset itself. For example, the communication protocol of a battery storage unit from provider A can be completely different from the protocols used by a similar battery storage unit from provider B. A VPP has to implement interfaces to all the different assets and their protocols, or risk limiting the types of assets or customers connecting to the system (Davoody-Beni et al., 2019).

Finally, cybersecurity will always remain a challenge for any computing system. Sensitive data can be exposed to unauthorized entities if not encrypted or if the encryption algorithm is too weak. Data privacy is also a considerable issue since the metadata of the pieces of information in transit may expose sensitive information about customers that may put them at various risks of cyberattacks, or fraud. Proper firewalls need to be in place to avoid access of manipulation of information which could lead to disruptive results, and proper authentication methods need to be placed at any terminal point to ensure the data is being received from the correct source (Otuoze et al., 2018) . This is assuming that the policies of the country/region where the VPP operates allows for such data to be collected in the first place.

2.1.6 Blockchain[DE1]

The purpose of blockchain is to make transactions transparent and decentralized. Without going into too much detail as this is a big topic, the way it is built is that the data is distributed all over the blockchain network, and using complex encryption techniques, makes it very hard to forge the chain of information due to the huge amount of computational power to do so (Wilshire et. al, 2017). We explain the concepts behind blockchain in more detail in Appendix A.

Blockchain can be used in VPPs both in energy trading and in energy balancing. In the figure below (right), blockchain improves the trading operation by simplifying the transactions between the Renewable Energy Credit (REC) producer and its consumer since the REC is already digitally signed and does not need third-party authentication or orchestration (left). The consumer will “buy” the REC through the blockchain market knowing that it was produced by that specific user, and the money would go directly to that user via the marketplace without the utility having anything to do with it other than provide the transmission and distribution networks. Since the information is publicly available, it can be audited any time through the blockchain network (Wilshire et. al, 2017). In this context, the VPP would be the blockchain marketplace provider.

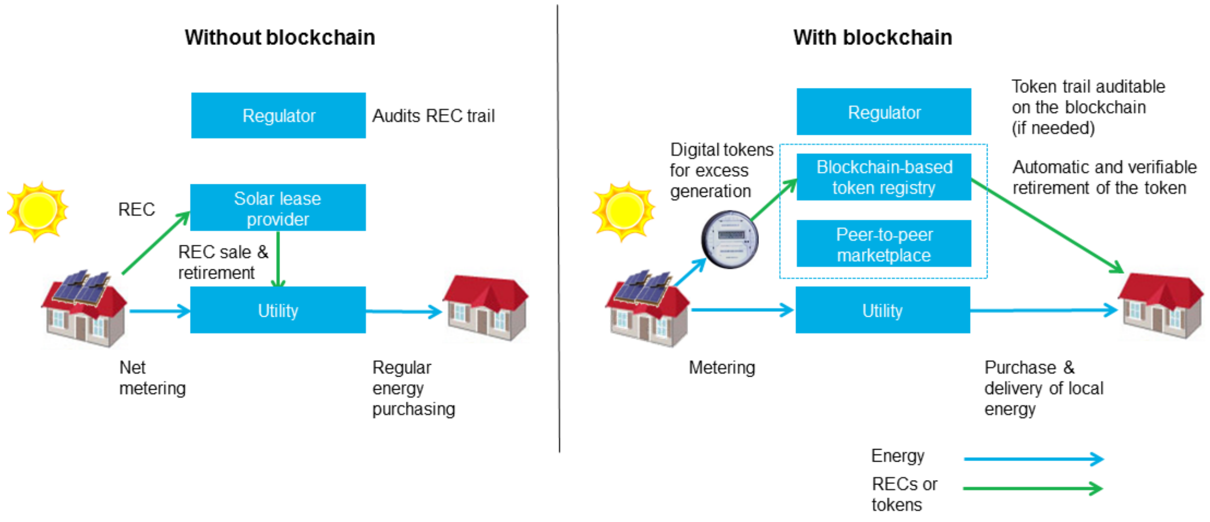

Figure 3:Blockchain in Energy Trading. Source (Wilshire et. al, 2017)

Similarly, in the figure below with blockchain (right), the VPP becomes replaced with a platform that balances itself similar to a free market, while knowing where the energy came from, and where it was consumed via the chain/ledger which would make it significantly faster and more secure (Wilshire et. al, 2017).

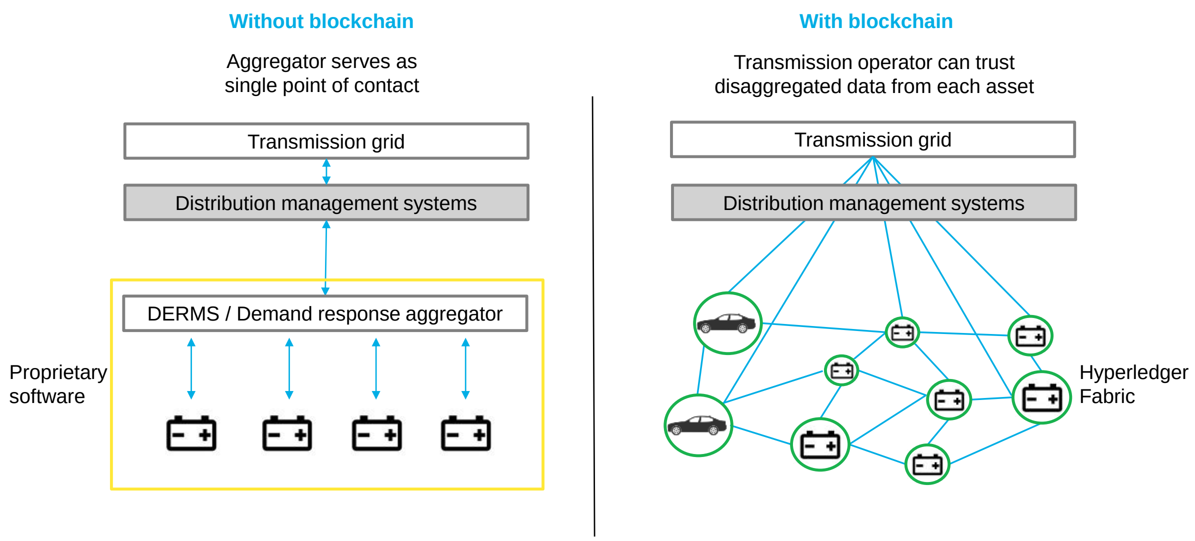

Figure 4: Blockchain in Energy Balancing. Source: (Wilshire et. al, 2017)

2.2 *VPP as a business*

The idea of VPPs has social depth; the democratization of energy where the responsibility of powering the grid is in the hands of the producers and consumers of electricity instead of private or public utilities (Stephens, 2019). A community-VPP is when a group of people in a local area manage their DERs themselves for their maximum benefits; a set of criteria defined by the community's "executive board" (van Summeren et al., 2020) . Community VPPs rarely have profitability as a goal, and are focused on optimization and cost savings instead. It has the same features as a commercial VPP but different priorities, and so would be out of the scope of this paper.

A VPP makes money by aggregating multiple DERs and acts as the middleman between them and the grid. Depending on the type of service, the VPP can either be technical (TVPP), commercial (CVPP), or both. A TVPP interacts with DSO/TSOs and acts as an energy management system for the DERs in their network. In this capacity, the DSO/TSO has more control over the DERs which can become disruptive to the grid in some cases and is provided with flexibility and stability through ancillary services like frequency and voltage control, congestion relief, load management, along with emergency reserves in case a plant goes offline. The profits of a TVPP comes from participating in the ancillary services market regardless of market price points. A CVPP, on the other hand, deals directly with energy markets. It acts on market data and price points to trade energy for maximum profitability regardless of the grid state. This can be done by trading directly on the electricity markets or providing availability information for trading in the day-ahead or intraday markets to other energy brokers who do the trading on the DERs' behalf. The profits of a CVPP are based on energy trading on the energy exchanges and are sensitive to price fluctuations, supply, and demand (Zajc et al., 2019) .

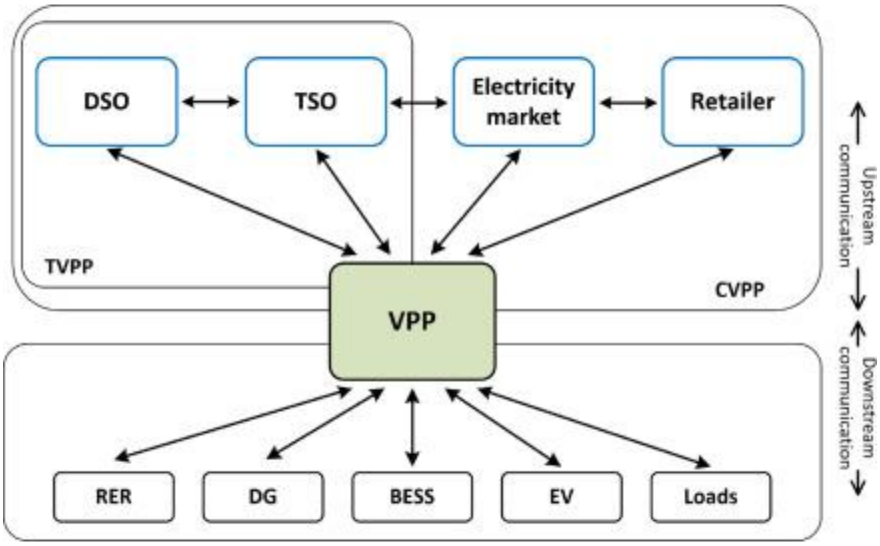

Figure 5:The difference between TVPP and CVPP. Source: (Zajc et al., 2019)

A combined TVPP/CVPP setup can be more complicated as either part may constrain the other. In such cases, optimization algorithms are key to focus on the highest priority service while maintaining reasonable profit margins (Park & Son, 2020). Interestingly, geographical locations of DERs are not a constraint to the VPP provided that they are connected to the same TSO/DSO and different DERs in different locations can act interchangeably, giving the VPP the chance to recover in case of a DER faulting or going offline mid-operation (Park & Son, 2020).

As the middleman, the VPP operator's revenues come in the form of a percentage of the profits the asset owners make, as market premiums or fees for using their trading services similar to any trader in the energy exchange (Alouini, 2019). Another revenue stream would be via a contractual agreement between the asset owners and the VPP operators in the form of a Power Purchase Agreement (PPA) as a Merchant PPA where the VPP utilizes the electricity from the assets in either ancillary services or energy trading, depending on the maximum value (Next Kraftwerke, n.d, PPA).

Figures 6 and 7 below summarize the process in which a VPP operates from a practical perspective. In the first figure, the VPP aggregates and controls the DERs that are the customers of a specific utility or retailer and passes the collective information as a single energy source. The utility/retailer either trades the energy or provides services to the grid while the VPP operator receives a management fee. The actual DER owners' contracts are with the utility/retail and not with the VPP. In the second figure, the VPP acts as a power marketer. It goes into contractual agreements with the DER owners, controls their assets, and trades the power in energy exchanges or as ancillary services. The revenues go to the DER owners while the VPP receives a percentage of the proceeds for its services as a trader (Sprinz, 2018).

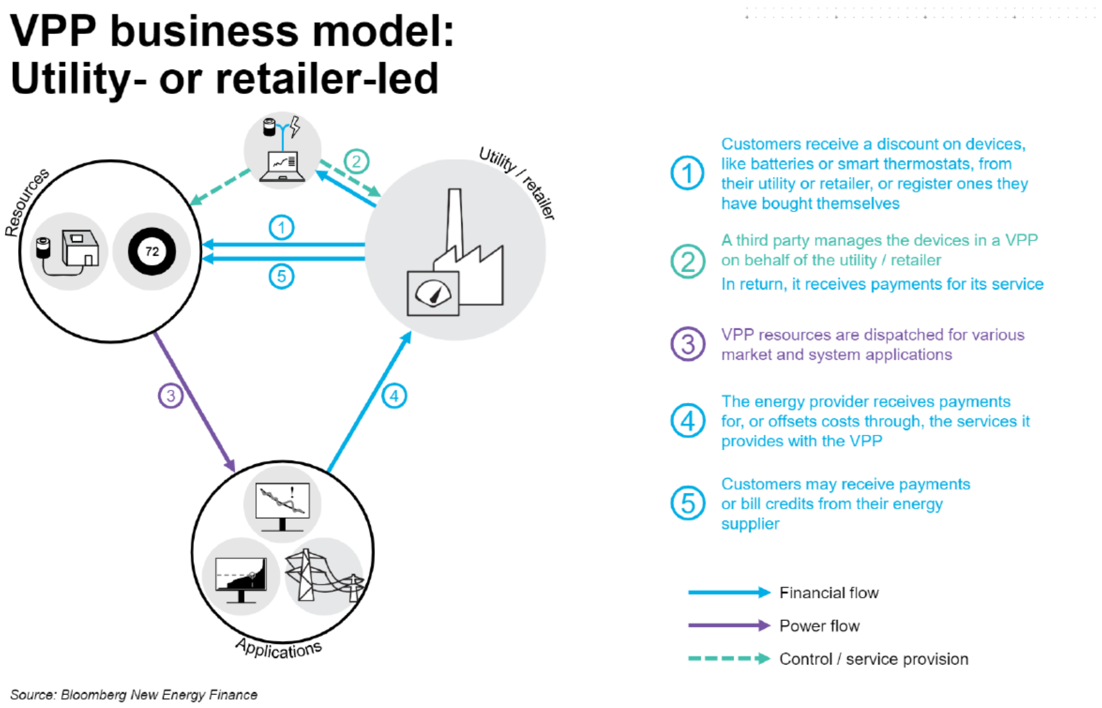

Figure 6:VPP on behalf of Utility/retailer. Source: (Sprinz, 2018)

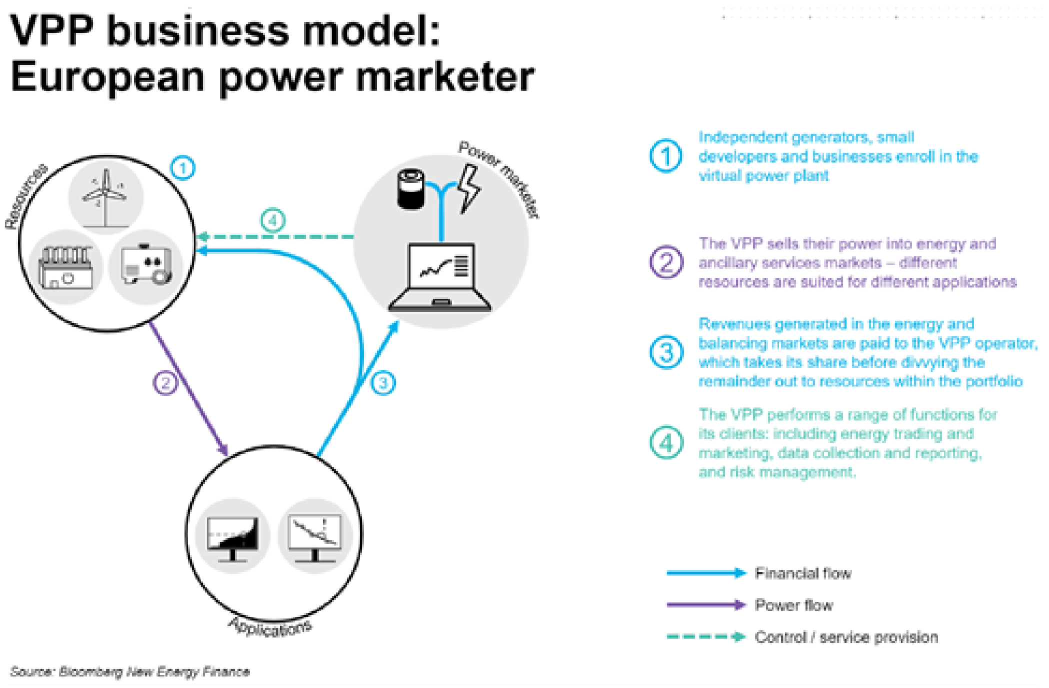

Figure 7:VPP as a power trader. Source:(Sprinz, 2018)

3 Methodology

This paper proposes the following hypothesis:

"The emergence of virtual power plants creates new business opportunities which provide value to their target customers"

To explore whether this hypothesis was valid, this capstone is organized in the following way. First, section two is an extensive literature review of the VPP technology and business models, with some of the technical details included in an appendix. This included sections on how a VPP is defined in the literature and the key enabling technologies from literature in academic and business resources, and a similar review of business models and service offering. The analysis and results in section four then discuss business case examples from a number of leading companies in this field operating across a number of countries. Next, it reviews how different policies in different countries are impacting developments in this growing market. Finally, in section five, we build on the insights gained from the literature review and this analysis, and explore a number of potential business opportunities for VPPs. In many ways, this last part of the discussion section is only intended to be exploratory at this stage and is structured based on the business model canvas template which explores the key components of a new business venture because the purpose of this capstone in part is to provide input information in the right form for potential development of a business plan at some future time.

4 Results/Analysis

This section analyzes some of the existing successful VPP companies and their business models in terms of: their value proposition, their customer base, and their main differentiators. Each example includes a SWOT analysis, which stands for Strengths, Weaknesses, Opportunities, and Threats to give a summarized understanding of their current state and possibilities for the future[TJ2]. It also considers different policies impacting VPPs in different parts of the world.

4.1 Next Kraftwerke (NK)

Literally translating to “Next power plant”, Next Kraftwerke has been at the forefront of virtual power plants in Europe and is one of its largest. It started in 2009 in Germany and was able to spread its operation to Belgium, Austria, France, and the Netherlands among other European countries. As of 2021, Next Kraftwerke manages over 9 GW of capacity with more than 12,000 aggregated units across Europe. NK’s revenues have been steadily increasing; in 2020, the company reported €595 million in revenues. The average asset in its portfolio has a capacity of 800kW (Next Kraftwerke, n.d, The Power of Many Section) and so its focus is small/medium grid-connected generation plants rather than distribution-level asset. In 2017, Next Kraftwerke was valuated at $64.1 million (Kenefick et. al, 2021).

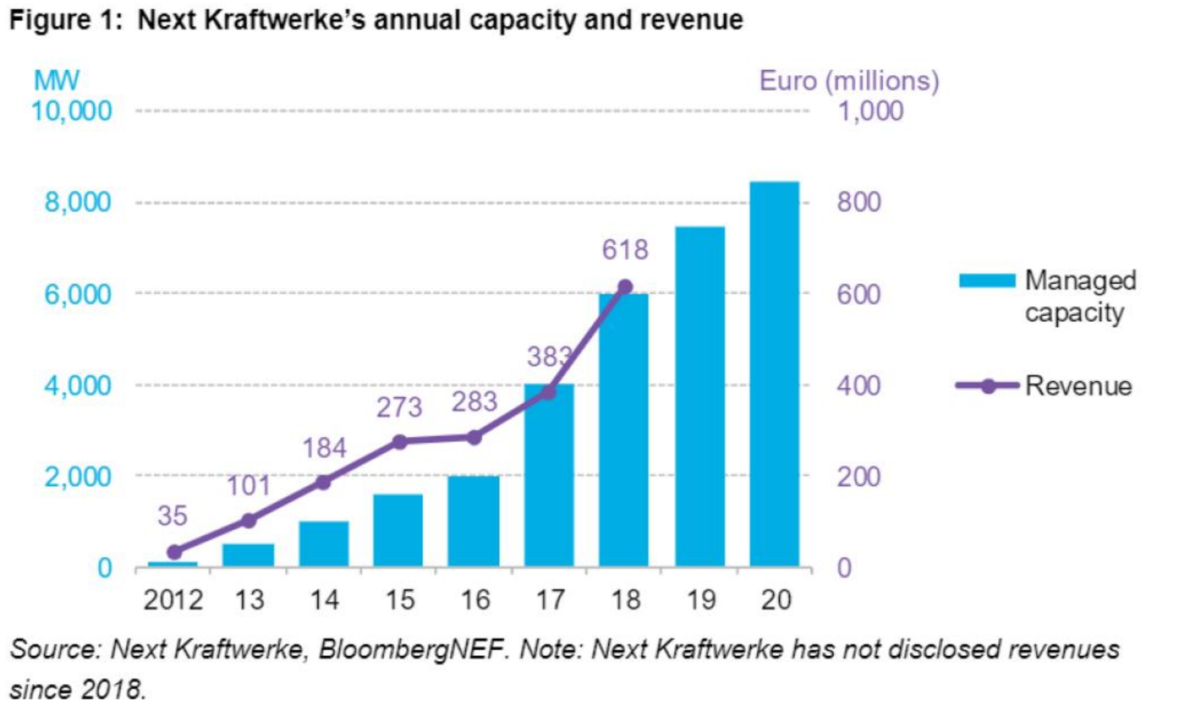

Figure 8: Next Kraftwerke Annual Capacity & Revenue. Source: (Kenefick et. al, 2021)

4.1.1 Products and services

NK integrates various assets, including wind, solar PV, hydro, and CHM, and provides access to European energy exchanges like EPEX SPOT and EXAA to its customers, where it trades on the day-ahead and the intraday markets. Their system uses historical and live data from the connected assets, meteorological weather data for wind and PV assets, and energy markets to adjust their forecasts and optimize energy dispatch for best prices (Next Kraftwerke, n.d, Power Trading). Next Kraftwerke targets small/medium commercial and industrial generators with either single asset types or mixed-asset plants for maximum flexibility (Jedamzik & Radwanska, 2020). NK's VPP offers three types of services: power trading, power scheduling, and energy balancing (Next Kraftwerke, n.d, Virtual Power Plant).

Figure 9: Next Kraftwerke Assets. Source: (Jedamzik & Radwanska, 2020)

Power Trading

In addition to the VPP’s normal trading services[DE3], NK provides multiple forms of portfolio management for a group of assets controlled by the same account. A customer managing multiple small generation and consumption assets can manage their portfolio through NK’s platform for either trading or power balancing between its assets, or they can delegate NK to manage their portfolio for them. Nk also uses its optimization algorithms for over the counter trading (OTC)) – bilateral agreements outside of energy exchanges – to resolve energy imbalances with other energy trading entities to resolve imbalances within a TSO (Next Kraftwerke, n.d, BRP).

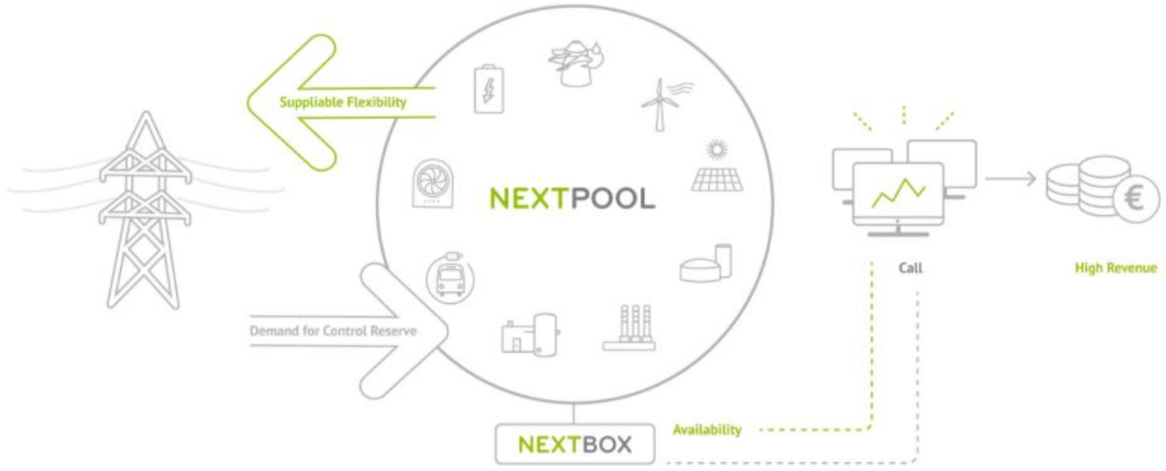

Figure 10: Next Pool Source: (Next Kraftwerke, n.d, Balancing Energy)

Power Scheduling

Scheduling services provide revenues or savings based on the types of assets and their trading in various European energy exchanges' intraday and Day-ahead markets. The assets are controlled in accordance with the restrictions provided by the customer including specific trading slots, power limits, or number of starts and stops.

Energy Balancing

The VPP provides energy balancing services to the grid in the form of ancillary services, depending on the TSO's requirements. The service is provided in both directions through controlling asset production or consumption via demand response, provided that the assets are continuously producing/consuming power. If a customer opts for this service, their assets are connected to NEXTPOOL; the VPP's network of assets, and qualified and registered with the TSO under which they fall (Next Kraftwerke, n.d, Balancing Energy).

4.1.2 Differentiator: VPP-as-a-Service (NEMOCS)

Despite pioneering the VPP market, NK is continuously providing new innovative offerings that distinguish them from competition and cater to different types of customers with different requirements.

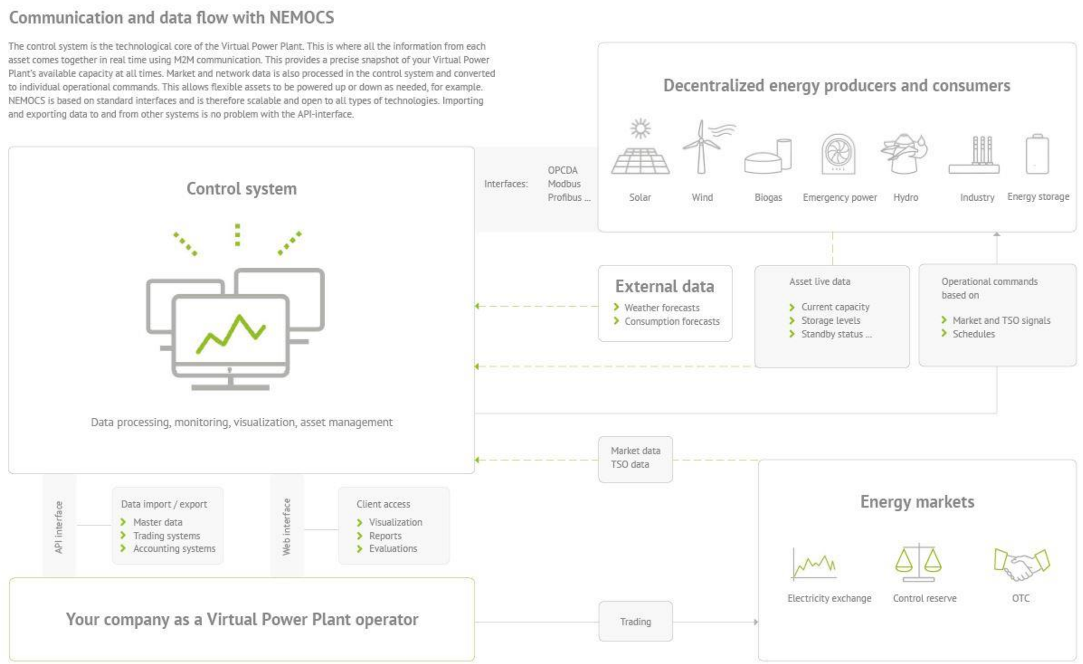

Figure 11: NEMOCS Solution. Source (Next Kraftwerke, n.d, VPP Software as a Service)

Software-as-a-Service (SaaS) is a subscription-based model of selling software where the SaaS provider hosts and manages the system and the customer has a tailored account where they can use some or all the features of the system; a model common for enterprise resource planning (ERP) and customer relationship management (CRM) software (Turner, 2020). NK has modularized its features and services and is now offering NEMOCS as their "VPP-as-a-Service" solution.

NEMOCS allows a customer to manage their assets using the same NK VPP features and services while being completely separated from NEXTPOOL. A customer can opt for certain services like trading, curtailment, or load management depending on the use case that best suits their needs. The system allows a customer to aggregate their assets, monitor, and optimize their operation; the typical features of an aggregated energy management system, but with the added advantage of using the same algorithms of NK's VPP for optimization, scheduling, and trading (Next Kraftwerke, n.d, VPP Software as a Service).

NEMOCS not only targets companies with multiple assets, it is also an attractive solution to s utilities and power companies that need to maximize their return on their pool of customers without running the risk of diving into the digital industry with no previous experience. NEMOCS provides VPP features and services with NK's proven successful track record while maintaining complete autonomy over their assets and their trading strategies (Kenefick et. al, 2021). NEMOCS currently has customers in Japan, UK, South Korea, and Slovakia (Jedamzik & Radwanska, 2020).

4.1.3 SWOT Analysis

Strengths:

- Next Kraftwerke offers a strong set of features that fit the appetite of different types of customers, and participate in both ancillary services and energy trading.
- As a pioneer, NK went through a steep learning curve and were able to successfully tailor their work business model to the ever-changing market terrain, grow, and expand.
- Their VPP-as-a-Service offering is based on a modularized framework that benefits from a standardized development and does not require too much customization.
- NK is ISO 27001 and ISO 27019 certified, and meets German IT security criteria.
- NK's interface to assets, a device called Next Box, is compatible with a large number of controllers from a wide variety of providers, giving them flexibility with new projects.

Weaknesses:

- So far, NK has only been operating in the EU market, and has only recently been experimenting with projects in South Korea or Japan. Expanding outside of the EU may prove more troublesome than expected.
- NK's customer base is focused on small/medium generators or C&I businesses, completely ignoring residential customers, leaving that segment open to competition.

Opportunities:

- The VPP market is still young, and there are still many European countries that NK can expand to.
- Shell's acquisition of NK gives them access to powerful resources, connections, history, and experience.

Threats:

- The European market is relatively mature, but policies are still continuously changing and some future changes may impact NK's profit margins.
- The VPP market has only a few major players at the moment, but the competition is growing as this business domain is showing a lot of promise.
- Shell's acquisition is a double-edged sword. As an established business that has limited experience with digitalization, the new management and operating procedures could negatively impact NK's performance.

4.2 e2m

Energy-to-Market (e2m) was founded in Leipzig, Germany in 2009, and expanded over the years to several other countries in Europe including Poland, Austria, Finland, and most recently, UK. e2m began its VPP operations for decentralized generators by trading in the energy market for different frequency response services: FCR, aFRR, and mFRR, and developed a strong focus on biogas plant management. e2m's expansion to other countries came through partnerships with energy companies as well as providers of renewable resources like small solar and storage, giving them a local advantage in every country they expand in. In 2019, 100% of e2m shares were acquired by EDF, the French utility company (e2m, n.d, Milestones of e2m). As of 2021, e2m's VPP pool consists of 5,500 generating units adding up to a total of 3,260 MW, being used for trading 24/7 (e2m, n.d, About e2m).

4.2.1 Products and Services

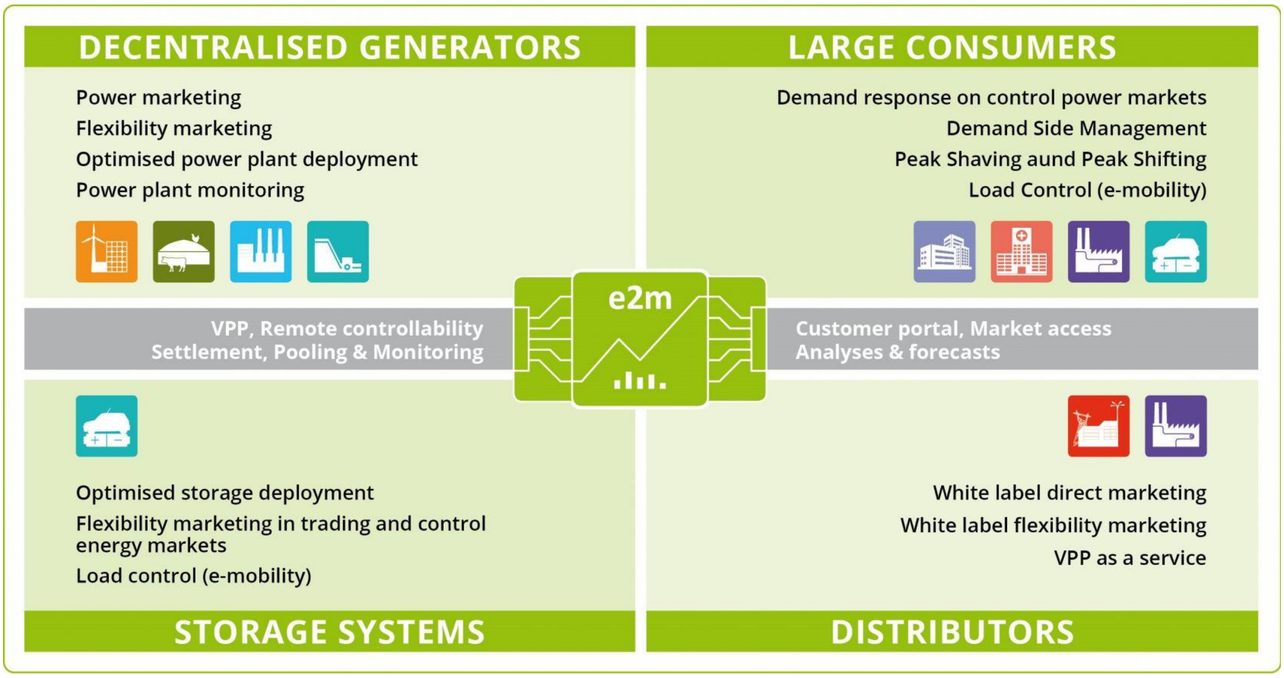

Figure 12:e2m's business model. Source: (e2m, n.d, Business model)

E2m offers the same set of products and services of a VPP to medium/large generators and consumers, with some tweaking depending on the type of assets. Asset monitoring, remote control, and portfolio management offers optimization services to plants such that they trade in the energy markets at the highest profit margins. Storage systems are utilized for ancillary services as well as energy balancing in the VPP pool. Consumers can have demand response and load management services at a schedule that fits their operations. And finally, energy distributors can utilize e2m's system to manage their customers and trade efficiently in the day-ahead and intraday markets (e2m, n.d, Business Model).

While e2m offers "white label marketing" which is very similar to Next Kraftwerke's VPP-as-a-Service model, the difference lies in how this model is implemented. e2m offers their service as a customized service specifically designed for its customer; an old-school approach to software development (e2m, n.d, White Label), while Next Kraftwerke simply provides the interface, the business packages and the technical support without turning it into a bespoke project, capitalizing on the efficiencies of cloud offerings.

4.2.2 Differentiator: Growth Through Partnership

e2m has been one of the earliest players in the VPP market, and so has evolved more or less in the same way as Next Kraftwerke. While they integrate different types of assets, they do so via partnerships with specific DER technology providers and energy companies. On one hand, they are offsetting the technology risk since their technology partner has part of the weight of making sure their assets integrate with e2m's systems (e2m, n.d.). On the other, they are offsetting entry barriers into new countries by partnering with companies that are already in the market. In contrast, Next Kraftwerke's approach tries to attract different types of customers through different types of offerings. They go through an assessment phase on which they base their client relationship. Both approaches to the market are interesting because each company appeals to a certain type of medium/large customer wanting to profit off of the VPP model: one that prefers strict contractual agreements with no shared risks (NK), and the other that is transparent and hands-on so that the customer/partner feels as much part of the operation as the VPP provider (e2m).

4.2.3 SWOT Analysis

Strengths:

- e2m is a pioneer in VPPs with long standing history of success.
- e2m operates in multiple EU countries.
- Their partnership-based business model reduces technical and regulatory risks whenever they expand into a new market.
- e2m has a clearly defined offering for each type of asset, simplifying the contracts and billing for their customers and reducing overhead.

Weaknesses:

- e2m's offering differentiates between the different types of assets and doesn't target mixed-asset plants.
- Their white label offering is not standardized. Bespoke software development and customization can incur high operational costs without much return.

Opportunities:

- EDF backing provides entry into the French market and reduces the risks of setting up bad partnerships.
- EDF's acquisition also provides additional resources for faster and more sustainable growth.
- E2m has been experimenting with new technologies like blockchain which can drive the development of new more advanced products and services.

Threats:

- e2m’s offering doesn’t seem to evolve over the years, making it easier to lose market share to new entrants.

4.3 Sonnen

Sonnen provides small scale battery solutions for homes and small businesses. Founded in 2010 in Germany, Sonnen now has a big global presence with offices in Italy, UK, USA, and Australia with partners in various other countries in Europe like Switzerland, Norway, and Ireland to name a few. Sonnen’s battery offerings have a very distinct objective and that is to integrate their batteries with rooftop solar for homes and small businesses to store excess solar energy instead of curtailing or selling to the grid for cheap prices. Their battery offerings range from 10 to 30 kWh and have recently launched their own virtual power plant. In 2019, Shell acquired Sonnen, adding it to its digital portfolio (Sonnen, n.d, Vision).

4.3.1 Sonnen’s Business Model

Sonnen’s model relies on both direct sales, and a strong partner network. Sonnen’s partners can be property developers or solar installers. Partners are required to become “certified” to prove that they are capable of efficient installment of their systems. Sonnen’s team focuses on developing the technology, manufacturing, and technical and sales support, but they outsource installation to their vast network of certified installers. A Sonnen partner is meant to stand out from regular solar installers and property developers by adding Sonnen’s products and services to their offering. A customer can go to Sonnen directly and get routed to a partner, or the partner can market and sell Sonnen products on their own; either way, both Sonnen and the partner benefit from the relationship (Sonnen, n.d, Become Partner). This business model is not new since companies like Cisco in the telecommunications industry and Microsoft in the software solutions industry take the same approach to sales and marketing in which the partner is deemed “System integrator” (Visnji, 2019). It is hard to go wrong with a tried and true business model that depends on strategic partnerships since this model has been active since the 1990s.

4.3.2 Sonnen Community: A Community VPP for Profit

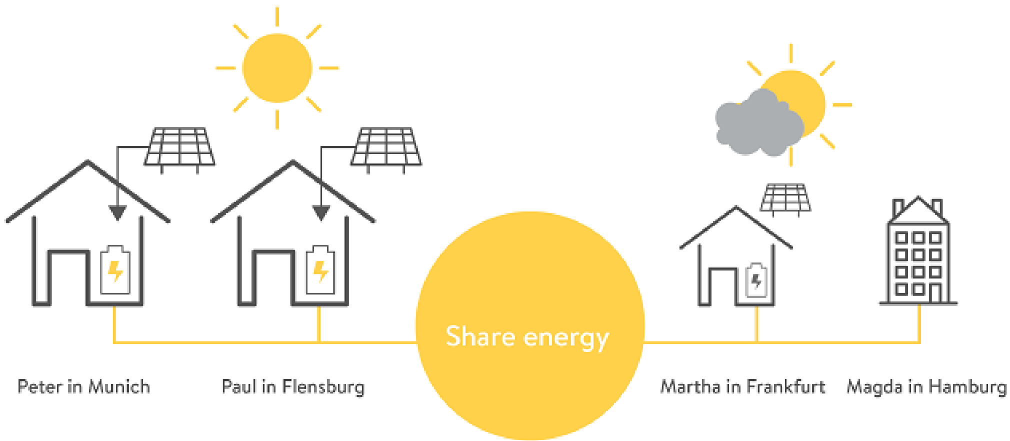

Figure 13: Sonnen Community Model. Source: (Sonnen Group, n.d, Sonnen Community)

Sonnen’s VPP is clever in that it creates a network of their batteries only, which are already optimized for solar + storage solutions. Sonnen’s VPP connects all members of the “Sonnen Community” and balances the energy between all the Sonnen battery systems in the community such that they collectively consume what they produce in an energy balancing scheme. In addition, the Sonnen community VPP replaces the need for an electricity provider since all the energy is supplied by the community and optimized by the VPP. While this is an example of a successful community VPP, Sonnen’s profit comes from the membership contract, called SonnenFlat which provides free electricity up to 4,250 ~ 6,750 kWh depending on the contract tier (Sonnen Group, n.d, Sonnen Community).

4.3.3 SonnenVPP

In addition to Sonnen Community, Sonnen is also registered as a VPP in Germany, providing FCR services by combining multiple battery systems into 2MW bundles that the TSO can tap into whenever needed (Sonnen Group, 2020a). An additional Sonnen VPP came into operation in 2020 specifically for storing excess wind energy in Northeast Germany. When the grid operator signals the need for storage to capture the excess power on the Energy Web Exchange – also called EW Origin, the VPP makes a bid based on the available capacity, the batteries' state of charge, and the usage patterns. EW Origin is a platform based on blockchain which is a decentralized technology used for peer-to-peer secure transactions (Sonnen Group, 2020b).

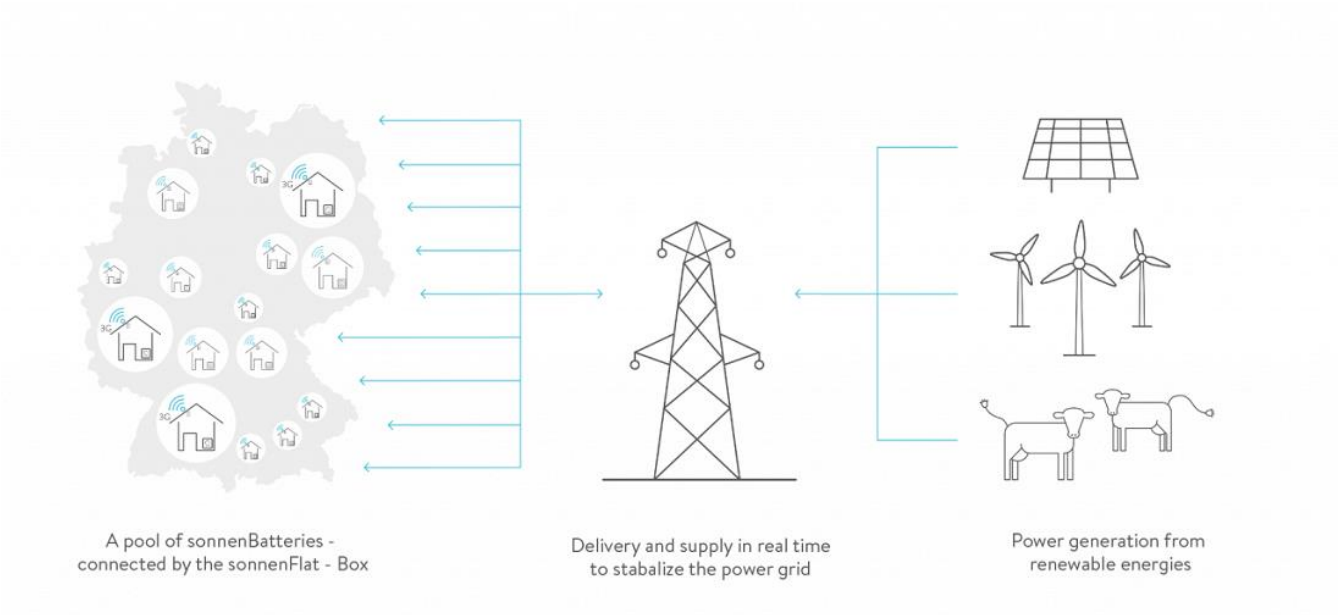

Figure 14: Sonnen Community VPP. Source: (Sonnen Group, n.d, Sonnen Community)

Sonnen has also integrated their partnership model into the SonnenVPP by licensing it to third parties; allowing any utility to tap into Sonnen's algorithms' technical advantages (Sonnen Group, 2020a).

4.3.4 SWOT Analysis

Strengths:

- Sonnen has a large geographic footprint spanning three continents.

- Sonnen’s strong partnership model multiplies their sales and marketing teams and increases their access to larger customer groups.
- Sonnen taps into “micro-installations” – up to 25 kW; most commonly found in residential solutions and difficult to integrate in VPPs, making them an almost unique player in this market segment.
- Sonnen Community provides an attractive free electricity offering to its customers, eliminating the need for traditional energy providers.
- Sonnen VPP uses state of the art technology like blockchain which provides secure decentralized transactions.
- Operating a VPP in USA for Soleil Lofts (see Appendix B) gives Sonnen a "first-mover” advantage; building their brand name and giving them a chance to set the rules for future competitors.
- Sonnen’s focus on integrating a small unique set of assets reduces custom development and increases the benefits of standardized products.
- As sister companies under Shell, Sonnen and Next Kraftwerke are in a unique position to collaborate, complimenting each other’s markets and VPP services; an initiative that has already been announced in September 2020 (Aengenvoort).

Weaknesses:

- Sonnen’s approach to utilize their equipment only limits their growth to only residential and small business installments.

- Sonnen's VPP is localized geographically in the way it provides services to the grid like Northeast Germany. This weakness does not apply to the Sonnen Community setup which is localized by the entire country of the community.
- Sonnen provides limited grid services that may not scale well in the future.

Opportunities:

- Sonnen's partnership program makes it easy for them to break into new markets in Asia or Africa, based on their partners' existing customer bases.
- If Sonnen decides to develop larger scale storage systems, they can significantly increase their VPP profits.

Threats:

- If Sonnen loses its lead in the residential battery market, they also lose potential VPP business.
- Shell's strategy to acquire multiple VPP and storage providers in the past few years can lead to cannibalization where one company would take over the market share of the other.

4.4 VPPs in the Greater Energy Market

In the past few years, big local and global players in the energy industry have shown interest in investing in or acquiring aggregators and virtual power plants. EDF, France's biggest utility, acquired e2m in 2019 for an undisclosed amount. EDF's motivation is to spread its reach outside of France, and to tap into the decentralized energy market and increase its reserve of flexible assets. On e2m's side, it plans to utilize the new resources and reach to expand to Belgium and France (Hanley & Kenefik, 2019).

2021 saw Shell's acquisition of Next Kraftwerke. A major oil company, Shell plans to go carbon neutral by 2050 by taking an approach that's different from its competitors. Instead of building a fleet of renewables, Shell plans to focus on building its Renewables and Energy Solutions vertical by increasing investments in hydrogen and integrated energy in the near future, in line with its strategy of "managing clean electrons". Shell has also acquired Sonnen and Limejump, a UK VPP, in 2019 (Kenefick et. al, 2021).

Enel, another oil giant, acquired EnerNoc in 2017 and rebranded it as Enel X. EnerNoc is one of the leading demand response providers in the US, and Enel sees the investment as a step on their path to digital transformation and building energy solutions (Enel X, 2017).

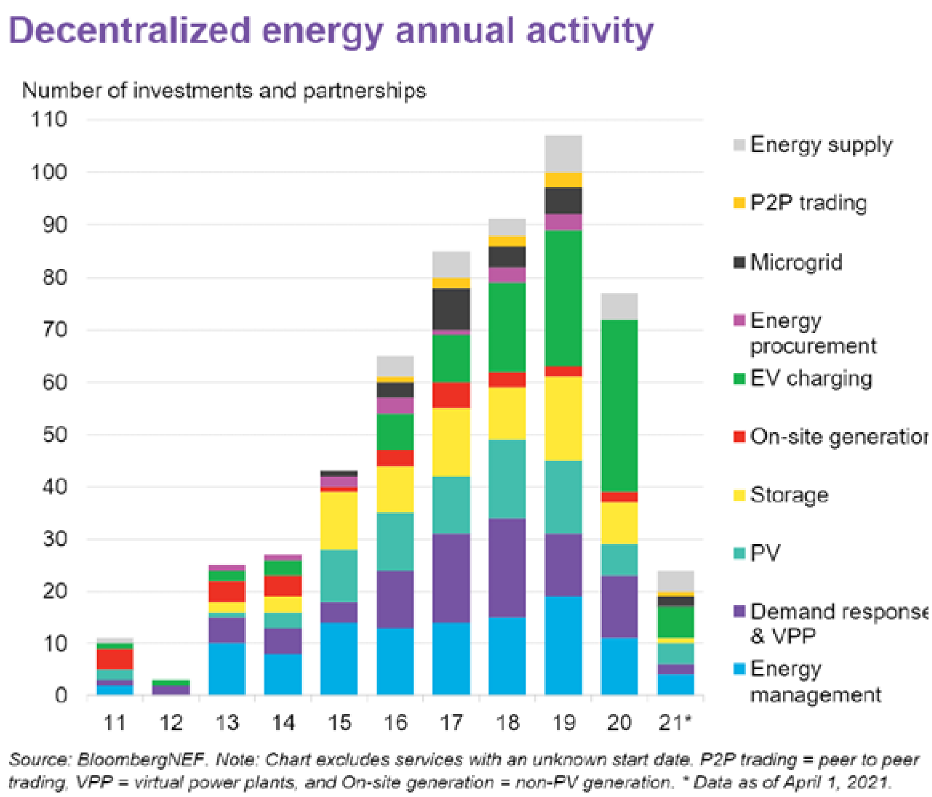

Figure 15:Decentralized Energy Annual Activity in Number of Investments and Partnerships. Source: (Kenefick, 2021)

It's no surprise that the leading VPPs are being picked up by the larger energy companies, especially the ones originating in Germany like Next Kraftwerke and e2m since Germany has one of the most mature VPP markets with the longest operational track record (Asmus, 2019a). German VPPs have been able to expand their operations effectively outside of

Germany to cover multiple European countries, breaking the normal boundaries utilities are used to in their operations. They've also fulfilled any regulation requirements for the countries in which they operate. It makes sense to build on their success instead of reinventing the wheel, and their proven track record of successfully integrating assets, using them for grid services, and scaling up with an increasingly growing customer base shows that a bigger company's backing and resources would only increase their combined reach and reduce their barrier to entry into the new VPP and DER management market (Asmus, 2019b).

Managing energy storage is also attractive due to the large potential expected of Electric Vehicles (EVs) as a source for flexible energy storage. Companies like Sonnen or Fluence, a battery storage system provider, prove that they can manage decentralized storage systems and effectively use them to provide grid services (Asmus, 2019b).

On the other hand, it is becoming clear that simple aggregators are not attractive. Investments in companies that focus solely on the software side of the VPP like UK-based Origami energy have not been a target for acquisitions despite attracting investments, implying that they would rather have complete trading solutions rather than a softare licensing business (Kefenick, et. al, 2021). Origami, like other aggregators, provides a platform that does just that: aggregate DERs with no direct relation to the markets. They do not do energy balancing or trading, and there is no guarantee for the owners/operators of the DERs that they would profit, especially that the contractual agreement and financial compensation calculations can become complicated: which resource was active in selling which service at what time, and to which trading or balancing entity (Verhaegen & Dierckxsens, 2016).

4.5 Impact of Policy on VPPs in Different Regions

Virtual Power Plants have been operating in various countries under various regulatory conditions. Below, the socioeconomic and political situation in certain countries and regions are explored in the context of VPP operation and development. The image below provides a sense of the large amount of activity in this sector in different regions by a diverse set of players.

Figure 16:Selected VPPs by Country. Source: (Arthur D. Little, 2018)

4.5.1 Germany: A Mature VPP Market

Germany's energy transition "Energiewende" had roots in the 1970s when Germany shifted to nuclear power as an alternative to oil in light of the energy crises. The book by renewable energy activists: "Energie-Wende: Growth and Prosperity Without Oil and Uranium" was published in 1980 and marked the beginning of Germany's energy transition into renewables (Hockenos, 2015). With both coal and nuclear falling out of favor with the German population, the government has agreed to phase out nuclear energy by 2022 and launched the coal-exit commission in 2018 to close down the last coal plant by 2038 at the latest (Russell & Wettengel, 2019). In parallel, Germany passed the feed-in-tariff policy in 1991; the first ever in the world and amended it into the Renewable Energy Sources act (EEG) multiple times over the years to "guarantee producer compensations at fixed rates" among other things to further support the spread of renewable energy sources use, and opened the energy market for trading profitably (Russell & Wettengel, 2019).

In 2014's amendment of the EEG, any renewable energy source connected to the grid with capacity larger than 100 kW is obliged to participate in "direct marketing" in a demand-driven manner at the energy exchanges at a market premium (Loßner et al., 2017). This legislation has led to loss of profits for traditional utilities since, in addition to having to close down their nuclear and coal plants, they are not competitive against renewables, and they are becoming even more reliant on flexible generation to balance the grid (Sämisch, 2016). VPPs come under the direct marketing framework of EEG since they manage renewable resources, giving them a unique opportunity to trade make a considerable profit (Loßner et al., 2017).

Germany is currently in the process of drafting The Act of the Digitization of the Energy Transition; promoting mandatory smart meters to enable German smart homes and benefit residential consumers. The act also specifies the technical requirements for data privacy, security, and interoperability (BMWi, 2021). The act would reduce the barriers to entry for VPPs with the residential markets and other prosumers. It's likely that the Internet of Energy (IoE) would become a major player in Germany's VPP scene in the near future. The smart meter regulation is also expected to stabilize the load from small DERs on the grid.

In addition, residential solar and storage systems are on the rise, and are expected to increase with the spread of e-mobility in the future. Germany's residential storage capacity is expected to increase from 2.3 GWh in 2020 to 12.8 GWh by 2025. However, the regulations governing storage systems in general are not very clear cut and represent a barrier to entry for larger scale commercial and industrial storage systems, causing a sluggish adoption of larger energy storage systems (Colthorpe, 2021).

4.5.2 USA: A Budding VPP Market

ISO/RTOs and wholesale electricity markets came live in the US with FERC Order 2000 which allowed independent power producers (IIPs) to trade electricity instead of the vertically integrated model for electricity generation and distribution. RTO/ISOs cover around two-thirds of electricity consumers in the United States. On the side of DER regulation, net-metering has been the main method of compensation for DERs selling power to the grid. Multiple valuation schemes are under constant review in many states to improve the way DER energy is utilized effectively. In 2018, FERC Order 841 set concrete requirements for storage systems to participate in wholesale energy markets, and brought out additional discussions for how to tackle aggregation of DERs like state vs. federal regulation, dual participation in both wholesale and retail markets, and impact on transformers and other distribution equipment (Lowder & Xu, 2020).

In September 2020, FERC Order 2222 was issued to "remove barriers to the participation of distributed energy resource aggregations in the capacity, energy, and ancillary services markets operated by RTOs and ISOs" (FERC Order No. 2222, 2020). The Order is very tolerant; there is no minimum capacity for individual DERs and aggregator capacity is required to be at least 100 kW. Geographical restrictions are "as geographically broad as technically feasible"; to be decided by the RTOs (Labastida, 2020). RTOs need to set up specific tariffs for aggregators to allow them to register their resources under different models based on the participating DERs in their portfolio. With respect to DERs under a specific utility, they are not allowed to participate in the energy markets unless they are approved by the utility itself. Moreover, demand response customers are prohibited from bidding in the regional markets (FERC, 2020). While it would take a couple of years for the RTOs/ISOs to finalize their tariffs and regulations, the Order provides a new frontier for VPPs to operate more openly in the US markets (Labastida, 2020).

Before Order 2222 was issued, the extent of VPP operations in the US was based on demand response almost exclusively. Other VPP options include some sort of partnership between the VPP provider and the utility like Kiwi Power, a UK based VPP, and Engie North America, a utility operating in ERCOT/Texas (Nash, 2020). It is worth noting that Kiwi Power has been a subsidiary of Engie group since 2018; yet another VPP purchase by a major energy company (Hanley & Kenefik, 2019).

On a socioeconomic level, customer appetite for renewable installments in residential and commercial sites and the continuing drop in prices of new renewable technologies and storage systems are creating an ideal ecosystem for VPPs to operate in the US (Guidehouse Insights, 2020).

4.5.3 Middle East and Africa

VPPs are popping up in South Korea, Japan, and China either locally or with partnerships with existing VPP providers like Next Kraftwerke (Next Kraftwerke, n.d.). Australia is also showing a lot of potential with Tesla's announcement of a VPP based on their battery deployments there (Tesla, n.d.). This comes as no surprise since these countries are reasonably developed and are never lagging behind in new technology adoption. It becomes interesting when a VPP is announced to be established [DE4]in Dubai, UAE. In 2019, Dubai Electricity and Water Authority announced its partnership with Enbala, the Canadian smart grids solution provider, to setup an intelligent VPP in Dubai to maximize the benefits of DERs in the city, in line with Dubai's Muhammed Bin Rashid Al Maktoum Solar Park (MBR Solar Park), and in support of Dubai's Clean Energy Strategy 2050 that aims to generate 75% of Dubai's energy through clean energy sources. The VPP would be owned/operated by DEWA, not as a player in a deregulated market. So, it is more like a giant DER Management

System than an actual VPP, and a preemptive step to avoid grid instability issues with the increase of renewables share in Dubai's grid (Gordon, 2019).

In Sub-Saharan Africa, the idea of a VPP is an overlap between a community VPP and an islanded microgrid. Africa's weak grid and lack of resources to develop infrastructure means that a lot of villages rely on micro-installations of solar plus storage systems. Adding a next level of intelligence to this structure would give a village's inhabitants more stable power to overcome the electricity generation barriers (Prasad & Samikannu, 2018).

5 Discussion: Potential Business Opportunities for VPPs

The analysis shows that there is indeed an opportunity for new VPPs to be established in different parts of the world and for the global market to greatly expand. The US market holds perhaps the highest potential in the short term. In addition, utilities now have an appetite for this market since it has proven its potential with several successful ventures, promising new revenue streams, especially when the falling profit margins of existing fossil-fuel based plants. This process is already being fast-forwarded as large energy companies are buying or partnering with VPPs to add quick digital energy transition to their portfolio. The residential market is also ripe for the taking with a continuously increasing capacity as prices keep falling for home solar and storage systems. Moreover, market reports from leaders like Guidehouse Insights and BloombergNEF are showing promising forecasts for the development of VPPs over the next decade.

5.1 Potential business Ideas

We've seen many successful business models like sonnen's partnerships, NK's SaaS offering, and e2m's standardized offering, but other business opportunities can be developed for a new VPP venture.

1. **Apply one of the existing models in Europe to the US market.**
   Now that the policy allows, a VPP that has the same business model as Next Kraftwerke or e2m can be implemented in the US. As RTO/ISOs roll out their guidelines and tariffs for VPPs, a business can start there and expand to other RTO/ISOs as they develop their guidelines. States such as California, New York, and Hawaii would probably be the best markets to begin with given their high share of DERs (St. John, 2019). Load management, aggregation, energy trading, and energy balancing would all be possible in the new ecosystem and could easily be copied.

2. **Tackle the untapped residential market in Europe.**

   As this business model is already proven and the policy and market structure are mature, marketing to home-owners can attract many small prosumers. Clever compensation schemes similar to what is already being developed by Sonnen like Sonnen Community could be a good approach.

3. **Deploy distributed solar/storage systems on available rooftops and use these resources exclusively for grid services and energy trading.**

   This model requires collaboration between a software/VPP venture, a solar/storage provider, and possibly, a real-estate company. If unused roof space is leased (by a partner real-estate company), solar/storage systems can be deployed (by a partner solar/storage solution provider), and the distributed generated energy can be traded on the energy exchange or for ancillary services (by the VPP platform).

4. **Develop a VPP which builds on existing feed-in-tariff schemes in countries with regulated energy markets.**

   Many countries in the Middle East, Africa, and Asia provide feed-in tariffs for distributed energy systems. While there is no specific regulation for VPPs, there is no ban either. Given the abundance of wind and solar renewable resources in the Middle East, a system that slowly scales up by combining and managing multiple DERs connected via feed-in tariffs and smart meters to the grid can prove profitable, especially that this is a blue ocean: an unknown market space with considerable growth opportunities. Algeria, Egypt, Israel, and Turkey have policies governing feed-in-tariffs and premiums going up to 200% in some cases (pv magazine, n.d). The exact profit & loss model would have to be drawn up, and potential partners would need to be identified before such an endeavor becomes viable.

5. **Build a VPP value proposition around providing corporate PPAs to corporations that require green energy to source their energy via small/medium DERs instead of large projects.**

   Corporate PPAs are long-term contracts between large corporates requiring large amounts of power and require 100% green electricity, and renewable energy plants. Amazon alone has a portfolio of 6.5 GW all over the world, overtaking tech giants like Google and Microsoft which are making similar corporate PPA agreements to achieve net-zero carbon between 2030 and 2040 (Parnell, 2020). The VPP can replace the renewable energy plants in the PPA by providing a large pool of distributed resources instead of major renewable developments and complicated deals. On one hand, this scenario relieves corporates from having to manage multiple PPA agreements and can maintain a single flexible contract with the VPP, and on the other, it would encourage prosumers to install DERs and connect to the VPP knowing that they have a chance to profit with continuous demand. The difficulty in implementing this scheme would be that the tech giants have global PPAs in multiple regions of the world, and it would be difficult to spring up a new endeavor of this size on multiple continents at once.

6. **Implement a decentralized energy market based on blockchain technology.**

   As discussed earlier, blockchain is a technology that provides a lot of potential to energy trading and balancing markets. Building a platform based on blockchain for energy trading would be one of the earliest on the international market. However, this model poses multiple risks. First, the technology is still fairly new and untested in energy applications. Second, this venture would only attract tech-savvy customers who understand the value of blockchain and the opportunities it may bring. A marketplace with no traders would be difficult to implement. Third, some of the

7. existing VPPs with a strong customer base that can easily depose this venture as a blockchain leader. An approach to make this venture successful is to target existing VPP companies and enhance their existing business with better technology. However, further analysis needs to go into that idea before it can be considered to make business sense.

The study expands on two of these ideas by presenting the business model for each one using the business model canvas[TJ5] (Appendix B).

5.2 Tackling the untapped residential market in Europe

With the success of VPP enterprises in Europe and their acquisition by energy giants, it is only a matter of time before the residential DER market becomes the next frontier. Any of the countries that have already shown promise when it comes to VPPs such as Germany, Belgium, Italy, UK, or the Netherlands could be a good place to start. This business model would be similar to Sonnen but without limiting technology providers. The business model canvas for this venture would be as follows:

<table>
<tr><th colspan="2">Value Proposition</th></tr>
<tr><td colspan="2">• VPP energy trading services to sell unused power generation at better prices. Customer receives profits while a percentage goes to the company as a fee.
• Subscription to the energy balancing scheme.</td></tr>
<tr><td>Key Partners</td><td>Key Activities</td></tr>
<tr><td>• Residential energy retailers can provide access to their customer base (cooperation)
• Home DER installers can promote (cooperation)
• Embedded device and modem providers (suppliers)</td><td>• Software development (core controller)
• Embedded development (edge side device)
• Developing interfaces for multiple different protocols
• Business-to-consumer (B2C) marketing
• Energy exchange trading
• Ancillary service trading</td></tr>
</table>

	• Energy balancing • Optimizing existing algorithms • Technical training to partner installers • Embedded hardware installation at customer sites • Certification, licensing of the VPP, registering new assets/customers with TSOs
	Key Resources
	Physical/intellectual: • Embedded devices (outsourced) • Software development tools • Cloud infrastructure Human: • Software/embedded developers • Customer support personnel • Electrical engineers and technicians • Account management and customer satisfaction teams • Energy traders
Customer Segments	***Customer Relationships***
• Residential customers with DER resources deployed incl. Solar, storage, or generators.	• Customer communities provide good peer pressure and confidence. • Account management per energy retailer/installer • Technical support • Remote device maintenance
	Channels
	• Partner channels (energy retailers and installers) • Automated CRM system for the large number of customers • Graphical user interface with customer usage and trading information and device status (web or mobile app)

Cost Structure
• Salaries for developers – support teams – marketing and account management • Hardware costs (computers, IT infrastructure and embedded devices) • Cloud costs • Customer support costs • Tool licenses (development tools, CRM) • Training and installation costs
Revenue Streams
• Brokerage fees for energy exchange sales • Commissions based on successful ancillary service bids • Subscription fees for energy trading

5.3 Deploying distributed solar/storage systems on leased rooftops exclusively for grid services and energy trading

If we consider empty rooftops of residential, commercial, industrial, and municipal buildings, schools, universities, hospitals, along with garages, parking lots, and any other roof that gets some solar resources or can carry storage systems, we are looking at a huge area of unused potential DERs. This venture proposed to find a way to utilize this real-estate to deploy DERs depending on the potential of the energy resource at that site. On one hand, this is purely real-estate; leasing of property that otherwise adds no value to its owners. On the other, a joint venture between a DER solution provider and a VPP provider can prove profitable to both of these entities; the first will get to deploy more of its systems, and the second will get to aggregate, manage, and trade the output energy for profit. The profits of this venture are split between the DER provider and the VPP.

<table>
<tr><td colspan="2">Value Proposition</td></tr>
<tr><td colspan="2">Property owners with viable unused space like rooftops that have energy resource potential can lease this space to this venture which would deploy DERs for its own benefit. The DER output will be managed by the VPP and the energy traded for profit.
The property owners can choose to receive a percentage of the profit instead of the lease, however in such case, they would share the risk.</td></tr>
<tr><td>Key Partners</td><td>Key Activities</td></tr>
<tr><td rowspan="3">DER installers that provide the generation and storage equipment (joint venture).
Real-estate companies can either be cooperative partners or suppliers.</td><td>Real-estate activities including finding the property and negotiating lease contracts on behalf of the venture
DER potential assessment
Installing energy and storage hardware.
Software/embedded development (core controller)
Energy exchange trading
Ancillary service trading
Energy balancing
Optimizing existing algorithms
Certification, licensing of the VPP, registering new assets/customers with TSOs</td></tr>
<tr><td>Key Resources</td></tr>
<tr><td>Physical/intellectual:
Solar panels and storage battery packs
Embedded devices
Software development tools
Cloud infrastructure
Human:
Software developers
Real-estate management team
Embedded systems developers
Technicians and solar/storage installers
Energy traders</td></tr>
</table>

Customer Segments	*Customer Relationships*
• Residential, commercial, industrial, and municipal customers with viable real-estate for solar/storage deployments.	• Support and maintenance of equipment ***Channels*** • Real-estate agents and property management entities.

Cost Structure
• Salaries for developers – technical support and maintenance teams – energy traders • Real-estate team commissions • Solar/storage system costs • Hardware costs (computers, IT infrastructure and embedded devices) • Cloud costs • Tool licenses (development tools) • Installation costs

Revenue Streams
• Energy trading revenues • Ancillary services revenues • Energy balancing revenues

Any new business venture has significant business risk and uncertainty, both in terms of technology development, customer acquisition costs, and the business landscape. For VPPs, these business models may be particularly sensitive to existing and future policy changes.

6 Conclusion

The landscape of the energy market is changing. DERs are changing how grids are designed and[TJ6] modernized to cope with faster response times and less predictability in supply. Governments need to act to accommodate these changes in infrastructure development and policy. The increase in the number of electric vehicles (EVs) sales and adoption is bringing a lot of these questions to the forefront of electricity market issues. The potential of Vehicle-to-Grid (V2G) integration could provide a solution of massive decentralized storage in the form of parked EVs. As charging stations increase and spread geographically, the transmission and distribution grids will not only have to support bidirectional inverters to allow for both charging and discharging, they also have to provide communication methods to optimize these operations. These features are inherent in the technical design of virtual power plants (Atmus, 2019a).

Australia is a great example of the booming growth of DER. One in four homes currently have solar solutions in place and are feeding energy back to the grid. Australia is expected to be the leader in decentralized capacity by 2050 with 39 GWh of behind-the-meter storage. This explosion of growth can cause significant congestion problems if not addressed (Edmonds, 2019). The potential value of a VPP is already being tested as the Southern Australia government contracted Tesla to pilot a VPP trial with 1,100 household, aiming to ultimately integrate 250 MW of generation capacity (Wu, et. al, 2018). Tesla provides integration into the VPP when a home-owner purchases a "Powerwall", their home storage energy solution. So while they currently focus on their own technology, they will eventually gain sufficient VPP operating knowledge, and have the first-mover advantage in Australia (Tesla, 2021). Tesla's interest in VPPs, even if it is for home storage solutions, ultimately benefits their EV business since the method to utilize EVs charging at home would be no different. As a trend setter Tesla's interest in VPPs can be considered a strong indicator that VPPs may indeed be the key to solving future energy problems.

As we've seen in this report, the technology supporting the operation of VPPs is not only available, but it is becoming cheaper and more advanced.

This report has established that the technology supporting the operation of VPPs is not only available, but it is becoming cheaper and more advanced. The potential of utilizing small DERs in a profitable VPP model also seems possible, whether they operate in energy trading, energy balancing, or ancillary services, as was shown in the different business and policy examples in the analysis, and with many other trials and ventures continuously emerging to establish a foothold in this developing market. We presented several ideas demonstrate the potential of VPPs in the energy market. While two of these ideas were presented in some detail, they could form a basis for an actual business venture with more analysis, prototyping, and customer testing.

To conclude, we believe the emergence of virtual power plants creates valuable business opportunities. Not only do they provide value to their target customers, they also form a key step in solving existing and future issues with the global electricity markets.

Appendix A

Microgrid vs. VPP

While VPPs are similar to microgrid controllers in terms of features, there are a few differences that make VPPs stand out as a unique system. A VPP has no value if it is not connected to the grid, which is the opposite of the main value of a microgrid which is to operate as an island independent of the grid. Along those same lines, a VPP, in theory, can be connected to any assets connected to the grid while a microgrid only controls the assets connected to the particular microgrid. This means that a VPP can expand to cover larger geographical areas as well as different types of controllers, whereas microgrid controllers may be tailored for the specific assets connected to it (Cohn, 2018). From a technical perspective, the control system of a VPP does not require any controls for the islanding operations which are critical to the control of a microgrid. The VPP, however, needs to reliably provide grid services like frequency response and peak shaving (Wang, et. al, 2019). A VPP targets the wholesale energy market and are required to conform to the regulations that apply to any powerplant connected to the grid. On the other hand, a microgrid does not need to behave like a utility-scale power plant and should only conform to the regulations required by the customer/industry that the microgrid operates (Deign, 2020).

Edge Computing

Edge computing (EC); one of Gartner's top 10 technology trends of 2018 (Panetta, 2017) brings computation and storage closer to the source of the distributed device as opposed to have all the data transmitted and processed at the side of the central controller. Like IoT, EC is not a new concept; it has its roots in decentralized computing which is something available since the 1990s, but it has come to the forefront with new technological trends like IoT and cloud computing to improve the general performance of these systems and give them more flexibility to operate complex systems (Aktaş, 2020). EC makes use of the evolution of embedded systems to perform complex computations and store larger amounts of data at the asset level, and thus reduces the amount of data transmitted over the network, and some of the basic computationally intensive processes done on the server side. EC becomes especially important in reducing latency to some of the time intensive data. For example, if a device detects a fault, it could process and attempt to resolve the fault without needing to wait for instructions from the central controller. In case the fault is too severe, the device can shut down or go into maintenance mode immediately to avoid any safety concerns, or damage to the device (Mehmood et al., 2021).

Communication protocols and interfaces

There are different levels of communication in a smart grid/VPP setup, but this section will focus on the application layer only. The objective of the application layer communication is to convert the analog and digital signals received from the various sensors in the system into information that can be understood by the software that manages the smart grid system. (Sikic et al., 2020) (2020) explain three main protocols commonly used in smart grid applications: HTTP, MQTT, and AMQP.

Hypertext Transfer Protocol (HTTP) is the protocol used to transfer data on the World Wide Web. A request/response pair is used to communicate between client applications (like an internet browser) and a server. Both request and response are structured in Hypertext, that can be parsed by web applications. HTTP is not well-suited for IoT applications because it’s designed to transfer and break down large chunks of data. IoT devices on the other hand provide small chunks of data at high speed, so using HTTP would end up creating network overhead instead of optimizing communication (Sikic et al., 2020).

Message Queue Telemetry Transport (MQTT) works in a publish/subscribe framework. A client (like an IoT sensor) publishes a message to a messaging broker; a sort of gateway that receives all the messages from all the clients. Each message has a specific "address" called a topic that other clients can subscribe to in order to receive this data. This structure allows for messages to be received and processed by different clients at the same time, making it very suitable for distributed IoT systems that have limited processing and network bandwidth and need to process very specific data. While MQTT is widely used in IoT applications, it has some restrictions like lacking message priorities which could impact the performance of smart grid applications (Sikic et al., 2020).

Advanced Messaging Queuing Protocol (AMQP), is the last protocol discussed by (Sikic et al., 2020). AMQP is an upgraded version of MQTT that is also based on publish/subscribe messaging, but it has additional features like reliable message queuing so no data is lost, and flexible routing. Instead of the message broker in MQTT, the messages are stored in queues at different nodes in the system, so the decentralization makes the system resilient in case of disruption. However, it does not support automatic discovery, i.e. the protocol cannot identify if a new device is added to the network or removed from it, leaving the task of providing identification information and other metadata to the different clients which can lead to processing and network overheads.

In an experiment to compare between the three different protocols, under various message size conditions. The figure below shows the size of the actual data (payload) compared to the size of the message per each protocol, which represents the additional overhead in a message. MQTT and AMQP require initial connection handshaking (first column), and the connection maintenance message or keep-alive is shown in the second column. The keep-alive message provides important information to indicate if a device is offline or has lost connection.

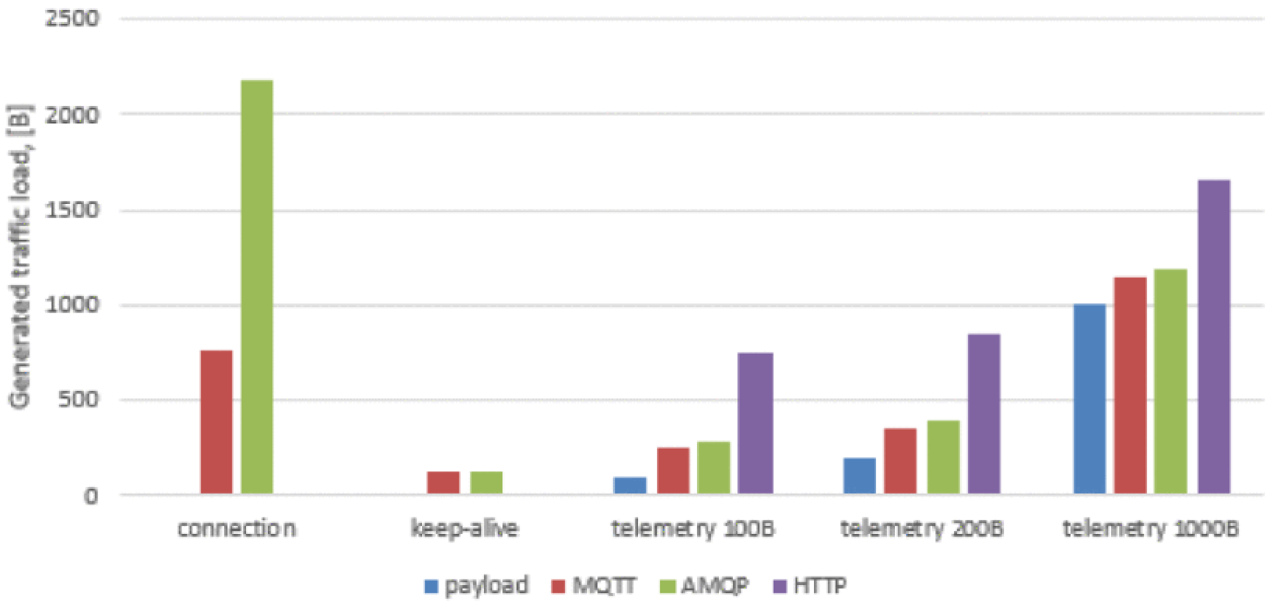

Figure 17:Comparison between size of messages with different communication protocols. Source: (Sikic et al., 2020)

Based on the figure, it is clear that MQT and AMQP provide the least overhead, and so are the most optimal in this comparison. The technical design of the application can help define which protocol would be most suited for a VPP.

It's important to note that these three protocols are just examples. Other protocols exist and are discussed and reviewed in higher detail in Tightiz & Yang, (2021).

Data Management

Data management is a discipline on its own in computer science and has been research extensively in the context of smart grids. It would be difficult to discuss all the different techniques of data management in this paper, but the common denominator in the literature reviewed is "Big Data". Potdar et. al (2018) show the data lifecycle in smart grids as shown in figure 18.

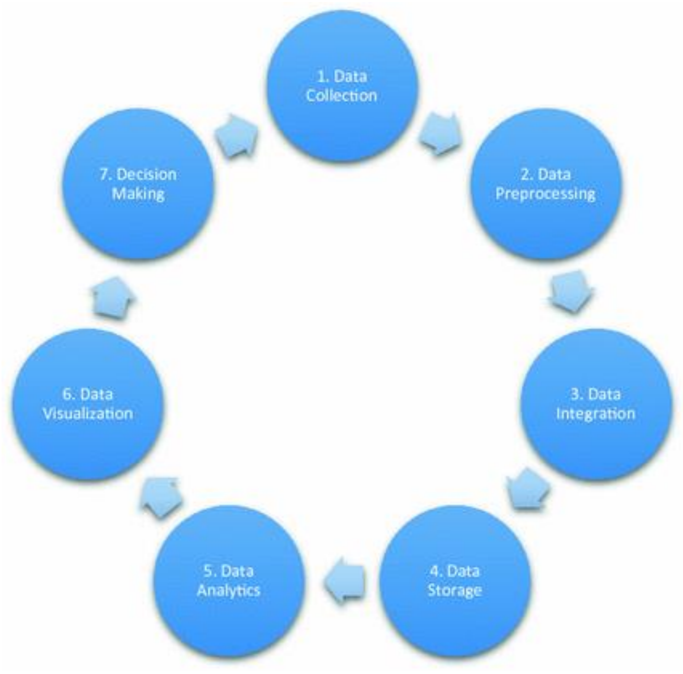

Figure 18:Energy Data Lifecycle in Smart Grids. Source: (Potdar et. al, 2018)

While each stage in the lifecycle can be delved into in more details, the area of most interest in this section is related to data storage. In the past, the data that needed storage from the different sources was required for historical tracking and future forecasting which could be stored on regular databases. However, in the context of smart grids and VPPs, much more data being received from different sensors and related to different types of resources like storage, solar, or wind needs to be stored and analyzed which would require large data storage capacity. In addition, to fulfill the promise of fast and robust response, the system where the data s stored and processed needs to have fast input/output speed, which means that the hardware where the data lives has to also be fast enough to handle the throughput. Different big data system providers (also cloud providers) like Google provide a type of file system called Distributed File System (DFS) which allows sharing of resources among multiple users and so is more efficient that traditional file systems (Potdar et. al, 2018).

Regarding the type of database itself, in order to handle such vast amounts of data, a new type of database called NoSQL databases which are not relational/transactional databases.

Instead, they store the data in more innovative ways that, depending on the use case, make data retrieval and processing more efficient. The data structure could be graph-based, document based, or key-value based. NoSQL databases provide flexibility for constant change and update without breaking the data model. In addition, the database should also handle time-series data well since the processing and visualization will usually happen over time (MongoDB, n.d).

Zainab et. al (2021) and Daki et. al (2017) dive deeper into the different data management techniques in the context of smart grids and IoT.

Core processing

After the central controller receives all the information from the assets in the VPP pool; be it status information, measurement monitoring, available power, or weather information, it needs to analyze this data along with market data, price signals, and DSO/TSO requests for ancillary services, and come up with operational commands to send to each asset. The idea is to identify which assets should be used with which grid service for maximum benefit. Asset selection depends on multiple factors:

- The type of the asset itself affects the two most important factors:
    - Reaction time: reaction time is how fast the asset registers a remote-control command from the VPP and is fastest in Battery storage units, responding within 10 seconds, while thermal units and demand response consumption operations can take longer (Zajc et al., 2019).

Resource type	Ramp-up time	Classification
Consumers		
Steel mills, paper mills, cement mills, refineries	15 min	Slow
HVAC, chillers	5–15 min	Medium
Chillers	1 min	Fast
Producers		
Steam or gas turbine	10–15 min (cold start) 5 min (hot start)	Slow
Small-scale hydropower, wind mills, photo-voltaics (PVs), pump-storage, combined heat and power (CHP), diesel and gasoline generators	2–5 min	Medium
Batteries, battery energy storage systems (BESS)	1–10 s	Fast

Figure 19:Response time of different types of assets. Source: (Zajc et al., 2019)

- Ramping speed: ramping speed is how fast the asset goes from its current state to the new power set point. Similar to reaction times, Battery storage systems are the fastest responders, in part because the inverters attached to them are quite fast, while hydropower would take the longest time to ramp up (Zajc et al., 2019).

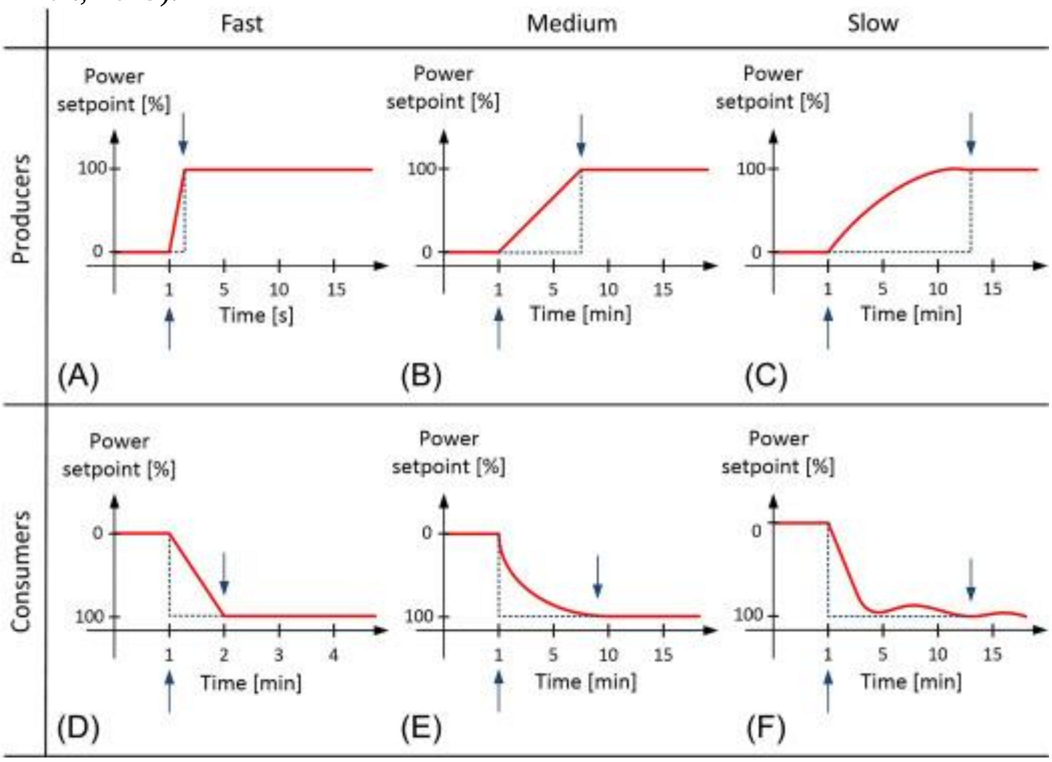

Figure 20: Ramping speed of different assets. (A) Batteries, (B) industrial steam or gas turbines with a hot start, (C) hydropower run-off river plant, (D) CHP, (E) industrial loads, and (F) steel mills.Source: (Zajc et al., 2019)

- The health of the asset: if the asset has some sort of fault or in maintenance, or simply not available due to other operational conditions.
- Capacity of the asset: the capacity of the plant as a whole along with the current state of the asset determine how long it could be used for. This also covers the size of the fuel tank, which type of fuel is being used, and the state of energy of the system.
- Geographical location: the geographical location of the asset determines which DSO/TSO it is part of or if it is required for energy balancing which would come as a higher priority.
- The constraints of the units defined by the owner/operator of the unit like operating schedules or power limits.
- Operating costs vs. expected revenues: the pool must contain

These criteria divide the available assets into pools; each pool would be available for a certain type of service. For example, energy balancing comes at the highest priority. If the energy balancing assets' available power exceed the amount required, the surplus is moved to a different pool for a different service like frequency response. If the assets are only subscribed to energy trading, then they fall in a separate pool, if an asset subscribes to both ancillary services and energy trading, but is not needed as part of the ancillary service bid, then it participates in energy trading (Quak, 2020).

The table in figure 6 represents different frequency response ancillary services; their required activation times (how fast an asset responds to a frequency event), and cycle time (how quickly the asset transmits information to allow for adjustment if needed) as per ENTSO-E's requirements, the European Network of Transmission System Operators. The table shows three types of frequency response services: Frequency Containment Reserve (FCR), automatic Frequency Restoration Reserve (aFRR), and manual Frequency Restoration Reserve (mFRR) (Zajc et al., 2019).

Table 11.1. Load-frequency control technical requirements (ENTSO-E, 2009)

Load-frequency control action	Activation time T_A	Cycle time T_C
FCR	15 s–30 s	1–2 s
aFRR	5 min–15 min	1–5 s
mFRR	15 min	1 min

Figure 21: Frequency control timing requirements. Source: (Zajc et al., 2019)

It is also important distribute the required amount of power between different assets. On the one hand, it ensures that a failure in one of the participating assets has minimal impact on the service rendered, and on the other, it ensures equitable utilization of the different assets in a particular pool. It is also sometimes better to keep as many assets as possible “switched on” to avoid any latency or hardware failure that may happen as a result of the switching on and off. This way, the assets have less risk of causing problems (Quak, 2020).

Blockchain[DE7]

Blockchain technology first became known in the context of cryptocurrency and Bitcoin, but it’s so much more than just that. Bitcoin is rather an application of blockchain; something that would not be available if it weren’t for it. Blockchain is a way of securing transactions in a decentralized manner based on encryption and hashing algorithms. Simply put, a transaction contains certain information that is publicly available within the blockchain network. I.e., the same data exists on a lot of different databases but without any identification information. This data is bundled as a block that contains the hashed (one way encryption) information of the transaction itself that uses a specific function that only the sender and receiver have (a hash is like a code that is unique per information and the hash function), the sender’s encrypted “signature”, and a timestamp depicting when this transaction took place. To verify that the data really came from that sender, the receiver first decrypts the block using the sender’s public key which should make the hashed information available. The receiver then uses the same hash function which they and sender agreed on, to hash the publicly available transaction data. Finally, if the hash in the block matches the result of the hash done independently by the sender, then this data really came from that sender and the information is correct. Hackers attempt to install malware on people’s computers unbeknownst to them to “steal” their processing power and try to decrypt the information in the block. In the context of cryptocurrency, that would allow them to steal the money (or any other sensitive transactional information) if they are successful (Wilshire et. al, 2017).

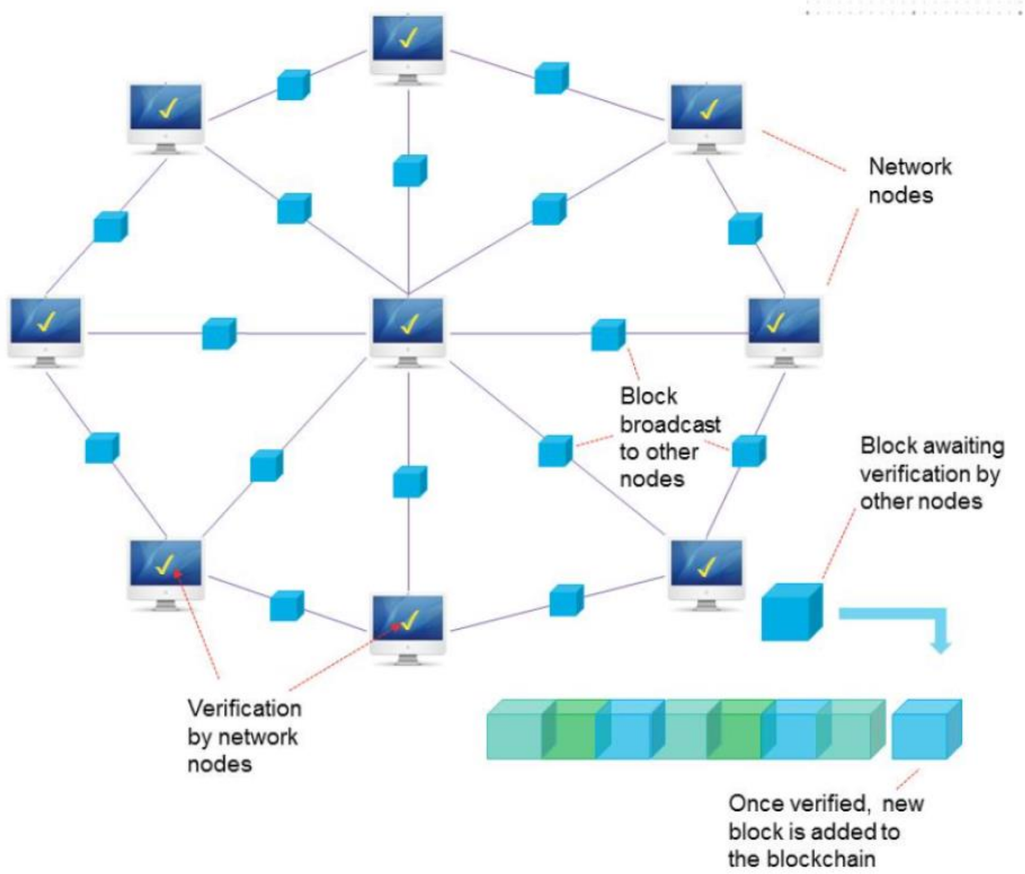

Figure 22: The Blockchain Verification Process. Source: (Wilshire et. al, 2017)

Appendix B

Soleil Lofts: A sonnen Case Study

A case study for Sonnen' partnership with the Wasach Group, a real estate developer, and the utility Rocky Mountain Power showcases Soleil Lofts, a luxury apartment complex outside of Sale Lake City. Soleil Lofts has 5.2 MW rooftop solar arrays installed coupled with 12.6 MWh of Sonnen's battery storage. The utility is able to use some of the battery storage capacity to balance the grid or to prioritize clean energy (since the stored energy in the batteries comes from the excess solar power) instead of fossil-fuel based generation, as well as making use of the fast response time of the batteries. Rocky Mountain Power integrated the system at Soleil Lofts in their energy management system and controls it accordingly by sending and receiving signals to solar/battery system (Woody, 2021).

The Business Model Canvas Explained

The business model canvas is a tool for assessing business ideas. It consists of 9 sections, summarized on one page. Each section answers the following key questions about the business (Osterwalder & Pigneur, 2010):

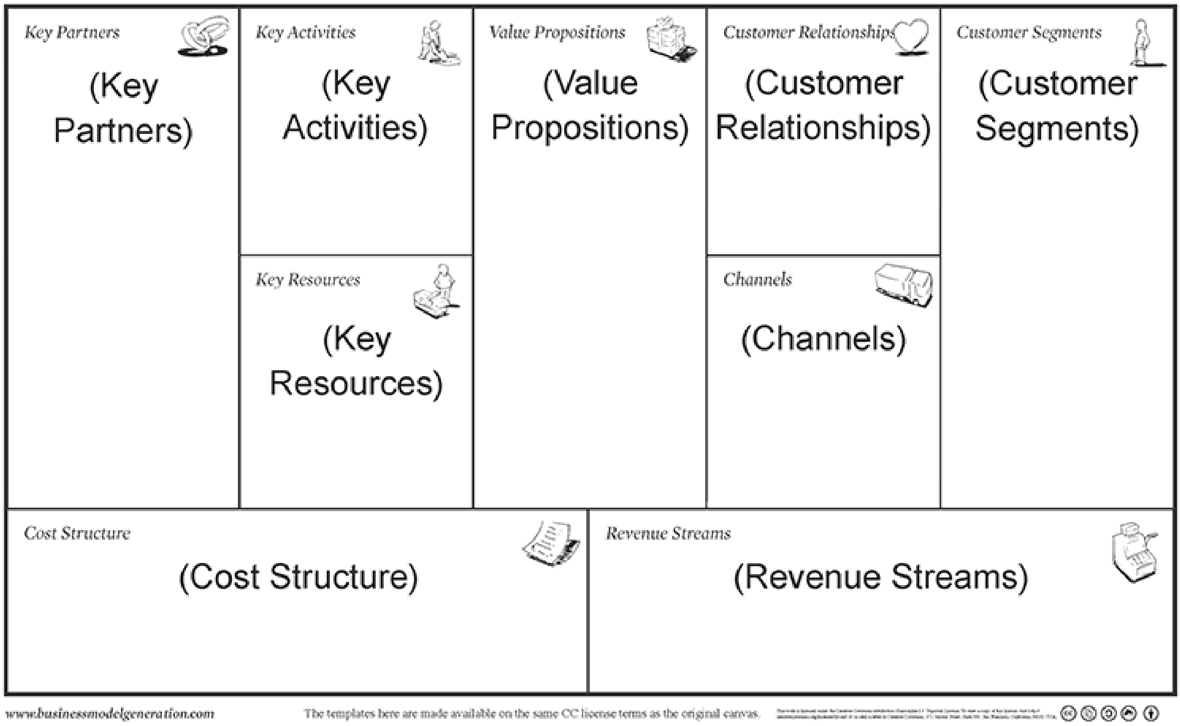

Figure 23: Business Model Canvas Template. Source: (Osterwalder & Pigneur, 2010)

1. **Partners**: Who are the partners? Who are the suppliers? What type of partnership is it? (e.g. joint venture, strategic alliance, cooperation, etc.)

2. **Activities**: What are the key activities required to deliver the value proposition? (e.g. software development, manufacturing, etc.) What are the activities required to set up customer relationships and distribution channels? (e.g. direct marketing, advertising, etc.) What are the key activities to set up the revenue streams? (e.g. billing and invoicing, contractual agreements, legal requirements, etc.)

3. **Resources**: What are the key resources? Human resources: how many and what skills should they have?

   Physical resources can be computers, embedded devices, manufacturing machinery, etc. Intellectual resources can be intellectual property rights, patents, commercial software, etc.

   Financial resources: capital, debt, etc.

4. **Value Proposition:** What value do we deliver to our customers? Which customer problem are we solving? Which customer need are we satisfying? What products or services deliver this value?

5. **Customer Relationships:** What kind of relationship do we want to have with our customers? (e.g. account management, technical support, maintenance, communities, etc.)

6. **Distribution Channels:** How do we reach our customers? Do we provide our own channels or do we use channels provided by a partner?

7. **Customer Segments:** For whom are we creating value? What kind of customer segment are we targeting?

8. **Cost Structure:** What are the costs of each key activity? What are the costs of each key resource and channels? Are there any other costs?

9. **Revenue Streams:** What are the customers willing to pay for? (e.g. brokerage fees, management fees, commission, etc.) How are they willing to pay? (e.g. subscription model, long term contract, etc.

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