VIRTUAL POWER PLANTS (VPP) AGGREGATING DISTRIBUTED ENERGY RESOURCES (DER): A TOOL FOR INTEGRATING LARGE SHARES OF VRE RESOURCES IN A FLEXIBLE POWER SYSTEM
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We find ourselves in a bewildering world. (...) Up to now, most scientists have been too occupied with the development of new theories that describe what the universe is to ask the question why.

Stephen Hawking
Acknowledgments

Firstly, I would like to express my sincere gratitude to my colleague, friend and thesis advisor Roger Pasola, for his availability, guidance, constructive feedback, knowledge and kindness. His continuous help and encouragement throughout the elaboration of this thesis motivated me and helped me to grow as a professional.

I would also like to thank my thesis advisor Carlos Vazquez for his assistance and amiability throughout the elaboration of this thesis.

Besides my thesis advisors, I would like to thank all the teaching staff at the UPM involved in the MSc in Energy Engineering for the teachings during the master’s degree.

I am also grateful for the assistance received from all my colleagues in i-deals, who trusted me from the start and have helped me keep growing professionally.

Last but not least, I would like to thank my family and friends for their support and encouragement throughout my studies.
Abstract

The energy sector is witnessing an unprecedented transformation. The liberalization of the energy markets set the scene for a competitive scenario in which different alternatives for meeting our energy needs with reduced carbon footprint are being explored. For the ongoing energy transition to materialize and keep the planet within the 2ºC scenario that was agreed in the Paris Agreement, a full set of innovative technologies, market designs and regulatory changes are needed. The increasing cost-competitiveness of variable renewable energy sources, mainly wind and solar, dominate the new capacity additions in the power systems of the developed countries. These technologies, which today represent the cheapest source of new energy additions in many regions in the world on a $/MWh basis and which costs are expected to keep following a downward trend in the coming decades, are inherently variable and uncertain. These undesirable characteristics hinder the task of keeping the balance between generation and load and therefore threat to endanger grid’s reliability. In order for us to be able to successfully transition to an inertia-less grid in which large shares of variable renewable energy are seamlessly integrated several challenges are to be addressed.

In order for the system to be able to effectively follow load with a variable and uncertain source of energy, a flexible power system is needed. In traditional centralized power system flexibility was present only in the supply side; changes in demanded load where immediately followed by a change in the output of coal- or gas-powered plants. In the future power system the flexibility is founded at all stages across the power sector, as the increasingly relevant penetration of distributed energy resources forces the power system to transition to a decentralized system and the electrification and digitalization trends reshape the existing paradigm. Energy storage systems, flexible generation assets, large interconnection capacity between balancing regions offer potential flexibility sources to meet these needs. However, the low-Capex-intensive and disruptive demand-side flexibility is the trend that is currently experiencing the most dramatic growth.

The broadening pool of behind-the-meter available energy resources can benefit from market participation when aggregated into Virtual Power Plants. At the same time, the coordinated dispatch of heterogeneous pools of generation, storage and load resources into wholesale or ancillary services markets stands out as a feasible solution for the latent threat that distributed energy resources represent to the power grid. However, optimal orchestration of diverse portfolios of energy assets face challenges from both a technical and regulatory point of view. Developed countries are making efforts towards the creation of aggregation-friendly regulatory frameworks and promising start-ups and technology giants are working on developing the appropriate tools for making Virtual Power Plants a reality. Several business models are emerging around the concept of the Virtual Power Plant, as a result of different actors trying to capitalize the value of flexibility in diverse markets. The market size for Virtual Power Plants globally is experiencing impressive expansion and the forecasted growth is not less remarkable. For this reason, Virtual Power Plants have drawn the attention of most players in the energy sector, from utilities trying to expand their service offering to Oil & Gas giants trying to diversify their business into electricity and out of price-plummeting oil markets.

The purpose of this work is to illustrate the concept of the Virtual Power Plant and to propose a business model to effectively exploit power system flexibility through VPPs. To serve this purpose, first the context in which Virtual Power Plants emerge is explained. A review of relevant literature about distributed energy resources, aggregation and virtual power plants is then summarized. For assessing the creation of a venture to develop a VPP in a specific market, the
market is evaluated, the different business models are analyzed and a business model is
designed to the specific target market; then a model for illustrating the market participation
process of a VPP is shown. Lastly, an economic and planning estimation is provided.

Keywords
Virtual Power Plant, Aggregation, Distributed Energy Resources, DERs, Power System
Agreement, Clean Energy Package, Demand Response, Demand Side Flexibility, Demand Side
Management
Resumen

El sector energético está siendo objeto de una transformación sin precedentes. Desde hace más de 20 años, la liberalización del sector permitió la entrada libre de participantes en la generación, donde, en la actualidad, diferentes alternativas que permiten cubrir las necesidades energéticas sin comprometer el medio ambiente se están convirtiendo en protagonistas. Tecnologías innovadoras, nuevos diseños de mercado y cambios regulatorios serán necesarios para que la transición energética que está teniendo lugar sea fructífera y sea posible alcanzar el escenario objetivo de 2ºC de incremento de la temperatura global previsto por el IPCC. La energía solar y eólica, que son cada vez más competitivas en coste, son las principales adiciones de nueva capacidad en los países desarrollados. Estas fuentes de energía, que son en muchos casos la fuente más barata disponible, presumiblemente seguirán viendo sus costes reducidos en las próximas décadas. Sin embargo, se trata de fuentes de energía que presentan desafíos para el sistema debido a la variabilidad e incertidumbre inherentes al recurso subyacente. Mantener el equilibrio entre generación y demanda en un sistema con grandes cantidades de este tipo de recurso se antoja complicado, y la transición de un sistema basado en generadores térmicos sincrónicos a un sistema dominado por energía renovable variable que interactúa con la red a través de inversores presenta numerosos desafíos.

Para que sea posible mantener el equilibrio entre generación y demanda en este contexto, el sistema debe ser flexible. Flexibilidad, en el contexto del sector eléctrico, es la cualidad del sistema de mantener el equilibrio entre generación y demanda en cualquier momento en el tiempo. Tradicionalmente, la flexibilidad en el sistema eléctrico solo existía en el lado de la generación; los cambios en la demanda se acomodaban con cambios en la generación, normalmente con plantas de generación flexibles de gas, carbón o fuelóleo. En el sistema eléctrico del futuro la flexibilidad se encuentra en todas las etapas de la cadena de valor, desde la generación hasta el consumo final. Activos de generación flexibles, sistemas de almacenamiento de energía a diferentes escalas, elevadas capacidades de interconexión entre sistemas vecinos, o la gestión activa de la demanda son algunas de las palancas que permitirán al sistema dotarse de la flexibilidad cada vez más necesaria. De entre todas ellas, la gestión de la demanda es el recurso que ofrece mayor flexibilidad a menor CAPEX; es por eso que soluciones de este tipo están experimentando un crecimiento dramático en los últimos años.

Los diferentes recursos energéticos que se encuentran detrás del medidor pueden obtener beneficios al participar de manera agregada en el mercado eléctrico. Al mismo tiempo, la gestión coordinada de portafolios heterogéneos de activos de generación, almacenamiento y demanda se presenta como una necesidad para responder a la amenaza para el equilibrio del sistema que presenta una red con números recursos distribuidos conectados a ella. No obstante, existen desafíos tanto desde el punto de vista técnico como regulatorio para habilitar la orquestación efectiva de recursos distribuidos.

Las Virtual Power Plants o Plantas de Generación Virtuales, surgen como una solución que permite gestionar numerosos recursos distribuidos de diferentes tipos, a través de una plataforma de software y apoyándose en una infraestructura que permita el control de los mismos, para llevar la capacidad agregada a diferentes mercados eléctricos y obtener retornos sobre activos que por sí solos no tendrían acceso al mercado. Aunque la provisión de servicios de flexibilidad a través de la agregación de recursos distribuidos no es económicamente viable por sí misma, ya que los retornos que se obtienen no justifican la inversión en nuevos recursos energéticos, con soluciones de este tipo se optimiza el uso de la energía, se mejora el retorno en la inversión de estos recursos distribuidos y se dota de flexibilidad al sistema de una manera...
sostenible. Los países desarrollados están avanzando hacia marcos regulatorios que permitan la agregación y tanto empresas emergentes como gigantes del sector están llevando a cabo desarrollos para materializar estas soluciones. En este sentido, el mercado para estas soluciones está experimentado un impresionante crecimiento y las predicciones de crecimiento para los próximos años son aún más dramáticas. Por este motivo, algunos de los players más relevantes del sector, tanto eléctricas que quieren reforzar su posición en el mercado eléctrico como petroleras que buscan diversificar su negocio fuera del propio petróleo, ya se están posicionando en este negocio, bien a través de estrategias de innovación abierta o bien a través de desarrollos propios.

En este contexto surge este trabajo, con el objetivo de ilustrar el concepto de la Virtual Power Plant. En ese sentido, se muestra el contexto y el estado del arte de esta solución en una revisión bibliográfica extensa. A continuación, se propone un modelo de negocio que permita capitalizar la flexibilidad de los recursos distribuidos a través de una VPP, para el mercado español, que habilitará la participación de la agregación en los mercados eléctricos en la segunda mitad del presente año 2020.
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Part 1: LITERATURE REVIEW
1. Introduction and context

1.1 Historical perspective

Energy is a fundamental variable for modern societies; it provides comfort, boosts economic activity and contributes to health and well-being. Replacing manual labor with energy resources was the platform for a period of unprecedented economic and social development: the industrial revolution (OECD, 2012). Since then, energy demand has grown along with world population and economic output, reaching a society that cannot be conceived without a massive power system that supports its high living standards.

Since the industrial revolution, the energy industry succeeded to keep up with the continued growth of the industry. This was done while maintaining a consistent drop in energy costs, encouraging consumers to keep increasing their demand, which led to higher living standards and prosperity.

At this time, the electricity supply industry grew and evolved around two basic principles: (i) the output of large generation plants was delivered to consumers using massive transmission and distribution network, while maintaining balance between generation and demand and (ii) consumers paid a flat tariff applied to volumetric consumption (Sioshansi, 2014).

Electricity supply industry was back then made up of vertically integrated utilities and consumers, with minor exceptions concerning large industrial consumers that had more market power due to their scale and could buy their electricity from the grid; the business case for bypassing the intermediary utility or self-generating their own electricity did not exist.

In the following years, the development of modern modular and flexible gas turbines, market reforms that led to liberalization of generation and retail; environmental concerns and subsequent restrictions, fossil fuel increasing costs and uncertainty due to unstable producing countries and other events contributed to transform the old-fashioned monopolistic energy supply industry (Sioshansi, 2014).

Nowadays, the increasing prosperity in the developing world (mainly China and India) maintains a steady and continued growth in the world’s economy. This growth carries higher living standards, which are associated with higher energy demand. Even though energy intensity (energy used per unit of GDP) increases with world development and technical innovations, primary energy demand grows at a steady rate and is expected to keep doing so in a global basis (IEA, 2019).

Although centralized, non-renewable generation is still present today in most power systems, the paradigm is rapidly changing specially in developed countries. Flat electricity demand (in developed countries) and consolidation of renewable energies are driving utilities to reformulate their approach to electricity supply. Renewable energies’ weight in the energy mix is growing by the day; conventional flat tariffs are being substituted by time-of-use tariff and distributed generation is gaining traction. Important changes are taking place in a giant industry that is by nature reluctant to change.

During the first years of the energy supply industry the term “energy efficiency” was not just unknown, but even ran against the business model of the companies. Huge investments in infrastructure brought a significant rate of return, which boosted more investments and more consumption (Sioshansi, 2014).
Environmental concern started gaining weight during the last decades of the XX century, growing up to become a massive concern in modern day society. The environmental movement has penetrated at all levels, local, national and international and sustainable development plans are a hot topic in almost any countries’ political agenda. Actions are being taken towards a less polluting society and companies are looking for emergent new business models that this new landscape offers. Technological solutions to support the so needed energy transition require innovation efforts to be made and challenges to be addressed.

In the last years, most countries political leaders have agreed to take actions and coordinate to pollute less, reduce the carbon footprint and diminish the environmental impact. Proof of this are the Kyoto Protocol or the Paris Agreement that show the willingness of taking action, with questionable success (UNFCC, 2005) (IPCC, 2015).

However, as global economy and living standards grow, world energy demand is not expected to go down. Whereas energy demand grows, pollution restrictions become more severe and renewable energies have been called to come to the frontline to solve this problem. Despite most renewable energies are mature technologies, costs still need to decrease and there are some intrinsic issues that need to be addressed. In brief: there is a need for more energy and less carbon.

Regarding renewable power, falling costs both in total installed costs and in LCOE (Levelised Cost of Electricity) along with increasing capacity factor for most technologies are making them already a real solution for today rather than a future option. However, there are still big challenges to be addressed in order to allow renewable power integration in the grid (IRENA, 2019).

Most renewable energy sources are intermittent by nature. The generation technologies that are most on the rise, solar PV and wind, rely their final output on weather. In the case of solar PV, they do not generate at night, which in most countries is the moment of greater demand. Due to these intermittencies, coupling generation and demand cannot be done without introducing in the power system a concept that was overseen in the precedent paradigm: flexibility.

Power system flexibility is the ability of a system to accommodate to dynamic and variable conditions, modifying electricity generation or consumption (or both). Therefore, flexibility can refer to the capability to change power supply/demand of the system as a whole or a particular unit.

Innovations that can be used to integrate high shares of variable renewable energy are emerging worldwide. New technologies, business models, market designs and system operation models are being created and the synergies among them are offering solutions to address this problem in a successful way.

The rise on distributed energy resources, such as rooftop solar PV, behind-the-meter batteries, electric vehicles, residential heat pumps, demand response and others, along with innovation in digitalization (IoT, IA, Big Data, Blockchain) have made possible the arise of a new business model based on aggregating decentralized energy resources in a Virtual Power Plant (VPP) that can provide grid services.

VPPs offer flexibility to the grid operators in order to support them in running the power system. These technologies, their current state of development and the market that could be addressed...
by companies based on them are the main focus of this work. First, however, the context in which the energy transition is taking place needs to be described in order not to misunderstand why these solutions emerged and why the problem they try to solve is so relevant for modern society (MITei, 2016).

1.2 Liberalization of Energy Markets

The liberalization of the Energy Markets is the opening of electricity and gas markets to free competition, breaking existing monopolies and enabling the entrance of new market participants. Generally, liberalization included unbundling, transitioning from vertically integrated utilities to differentiated generation, transmission, distribution and retail sectors. The goal of the liberalization was combining competition and regulation for a more efficient power system. In Europe, liberalization began in 1996.

In the past, vertically integrated companies were responsible for generation, transmission and supply of electricity. These companies could determine prices for electricity due to the lack of competition. As incumbent players held the grid infrastructure, access to the energy markets for new player was impossible.

The European Union started the liberalization of the energy sector in 1996 with the Treaty of the Functioning of the European Union, in which the basis for liberalization and harmonization of European energy markets were set. The ultimate goal is to create a unified single integral internal European electricity market in order to reduce grid costs and enhance security of supply.

The process of unbundling the different energy sectors is a key aspect of the process of liberalization. As a result of this measure, the same company cannot combine generation, transmission, distribution and retail activities. Even though the basis of unbundling were set in 1996, it was not until 2003 when legal unbundling was required. However, as companies could still be part of the same holding they had quite market power. In 2009, the European Union took a further step towards unbundling by requiring ownership unbundling (Next Kraftwerke, 2020).

With generation and supply being fully competitive advantages, none of the companies could use their market power to influence market prices, resulting in lower energy prices and benefiting the consumer. End users are now free to choose the energy retailer of their choice. However, perfect competition seldom exists in reality, as most of the commercial activity is in the hands of a few large incumbent players. In the Spanish market, for example, there are more than 300 electricity retailers but only five players account for 95% of the market share (CNMC, 2018).

![Figure 1 Market share in Spanish electricity retail market in 2019, own elaboration based on data from CNMC](image)

Despite the liberalization efforts in the energy sector, the transmission and operation of the power system is a natural monopoly due to the infrastructure of the electricity grid. Free competition in this sector cannot exist, as building a new grid for competitive reasons does not make sense due to its cost. To ensure grid reliability and avoid market power abuse the natural
monopoly is regulated by an independent agent. Whereas this is the common scheme for European countries, there are other market architectures in other countries. In the US for example, unbundled markets coexist with vertically integrated utilities, as the power system is divided into several balancing areas (ERCOT, CAISO, PJM, etc.) with their own rules.

![Figure 2 Liberalization of the energy markets (Next Kraftwerke, 2020)](image)

The liberalization and unbundling of the energy markets is key for the emergence of innovations and disruptive solutions within the energy transition. As it will be explained later in detail, energy market unbundling is a basic requirement for enabling demand-side participation in the energy markets.

1.2 Climate change

Climate change includes a variety of changes on global climate that, until recently, scientists argued that could only be caused by natural events such as volcanic eruptions, changes in ocean currents or movements in tectonic plates. In the common language, usually the term *Climate change* is used as a synonym of *Global Warming*, even though the two terms represent different concepts. This changes manifest by modifications on global average, minimum and maximum temperatures; volume and location of rainfall, direction and strength of winds. Empiric and periodic monitored global average temperature has shown an accelerated rise, which can be specially observed since the 1960s (Gonzalez, 2018).

![Figure 3 Global Temperature Variation (PNAS, 2006)](image)
It shall be noted the difference between anthropogenic climate change, which is the transformations on global climate caused by the impact that human activities have in the biosphere and natural climate change, that are the changes in global climate that have occur throughout Earth’s geological history. The United Nations Framework Convention on Climate Change defines Climate Change as a “change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods” (UN, 1992).

The IPCC considers that is very likely that anthropogenic greenhouse gas emissions are the main cause of occurring climate change (IPCC, 2014). This can be explained by the heat balance of the earth surface-atmosphere system. Energy inputs to this system is entirely solar radiation; this can be absorbed or reflected by the clouds in the atmosphere; it can also reach the Earth’s surface and then be absorbed or reflected. When radiation reaches the Earth’s surface, it causes either water evaporation (when it is absorbed by water) or it can cause an increase in land surface. The increase in land surface temperature causes short wave radiation that is reflected by the atmosphere and goes back to the surface. This is known as natural greenhouse effect.

The natural greenhouse effect shows that the surface-atmosphere system is in thermal balance. This is why Earth’s surface remains constant. However, the increase in global average temperature shows that this balance is no longer in place. This can be caused by a higher energy input (stronger solar radiation) or by a higher concentration of Green House Gases in the atmosphere.

Greenhouse gases are those gases that can absorb and emit infrared radiation, causing Earth’s emitted radiation to remain within the atmosphere. Some of the existing GHG are considered natural (CO$_2$, CH$_4$, H$_2$O, N$_2$O, etc.), as they are naturally present in the atmosphere. Others are exclusively produced by human action (HFCs, PFCs, SF$_6$, etc.).

The main GHG and the one used to benchmark the GHG effect (GWP, Global Warming Potential) of other gases is Carbon Dioxide. The anthropogenic sources of this pollutant are mainly fuel combustion for electricity, heat, and work production; industrial use in electro intensive and heat intensive industries such as oil refineries, steel production, aluminum, concrete, chemical industry, etc.

GHG have long lasting permanence periods in the atmosphere, ranging from 12 years (Methane) to up to 50,000 years (CF$_4$). In recent years, countries covered by Kyoto Protocol’s Annex A decreased slightly their emissions, whereas others countries increased theirs (Gonzalez, 2018).

1.3 Kyoto Protocol, 1997

In 1992, the United Nations created the United Nations Framework Convention on Climate Change (UNFCCC), which was the first international climate treaty, signed until the date. It was established as a general framework to establish GHG emissions limits and international cooperation. It was the starting point from which every further international climate negotiation would take place. At this moment, there was not enough evidence so as to establish which levels of GHG would mean a dangerous anthropogenic interference for the biosphere.

In 1997, the Kyoto Protocol was adopted in Kyoto, Japan. This document recognized that developed countries were the mainly responsible for the levels of GHG emissions in the
atmosphere as a result all the years of industrial activity. It is considered as the next big milestone since the UNFCCC in 1992. This document had two acting directions:

On the one hand, it established binding commitments for GHG emissions reduction, aiming for a 5% reduction on global GHG emissions in the period 1990-2005. Despite being a global objective, the document clearly stated the distribution of emissions commitments was not equal for all countries. Individual emission reductions were established to each country, even though in some cases established reductions where only a reduction compared to the projected emissions in the target year, meaning a need for controlling the GHG emissions increase in those countries.

On the other hand, the document also addressed the fact that the binding commitments would have undesirable collateral effects by enabling some flexibility. This was done by allowing countries to develop projects to reduce GHG concentration in the atmosphere regardless if these projects where located in countries with binding commitments. There were also established Carbon emissions markets between sovereign states or private entities. Although this was raised on the UNFCCC, the architecture and operation of such markets was not designed until the Kyoto Protocol.

The Carbon Dioxide Emissions Allowances are granted to each country and allow agents to emit CO$_2$ without any penalization. Each country is granted CO$_2$ Emissions Allowances equal to GHG emissions in 1990, discounting the committed reduction rate. This allowances are distributed among each country's industries and can be traded in an internationally exchange system. Therefore agents that are polluting more, need to buy allowances from agents that are polluting less, paying the price established by the market in a supply-demand system. Polluting agents can also implement projects that result in GHG emissions reduction and will receive in exchange CO$_2$ allowances equivalent to the reduced emissions.

The Kyoto Protocol did not enter into force until 2005. Under this agreement, industrialized countries (Annex I countries) committed to reduce their collective GHG emissions. It’s first commitment period started in 2008 and ended in 2012; later in 2012, the Doha Amendment to the Kyoto Protocol was adopted which include, among other, new commitments for Annex I countries from 2013 to 2020.

The Kyoto Protocol was not ratified by the US; Australia did not comply either until 2010. The case of the US is significantly relevant as its emissions added 25% of the total. In 2011 Canada left the Protocol; Russia and Japan followed later. The only big industrialized countries that remained for the 2013-2020 period where the EU.

Whether the implementation of the protocol was a success and to which degree each of the participants fulfilled their goals is beyond the scope of this work. The first period of the Kyoto Protocol resulted in only nine countries exceeding the committed emissions. This deviation was compensated by the reduction in other countries. However, countries without binding commitments increased their emissions, some in a very substantial way. In any case, it is important to highlight how this agreement set the starting point of a needed international and coordinated action towards a more sustainable society model (UNFCC, 2005) (Gonzalez, 2018).
1.4 Paris Agreement 2017
In 2015, the Paris Agreement was adopted in the COP 21. The goal of this agreement was to strengthen the international action against climate change, setting a global framework to keep the global warming well below 2°C and pursue efforts to limit it to 1.5°C.

Related to the 2°C limitation, the agreement states that total GHG emissions need to stop increasing, in order to be able to walk towards a carbon neutral scenario in the second half of the XX century.

The 2°C threshold is not considered as a safe global temperature variation. It shall be understood as a risk that the international community accepts, as the impact of the climate change are already taking place with a recorded 0.8°C increase between 1880-2015 (NASA, 2015). It is assumed that an increase of 2°C will have undesirable consequences but there is also a hope for this consequences to be limited. This is why the document estates that efforts shall be made to keep the increase at 1.5°C if possible; if the increase is smaller, the consequences faced will be less damaging.

It also must be understood that the 2°C limit is established as a commitment to find a balance between the warnings raised by scientific communities, the need to act to avoid them and the economic interest that would be damaged by a radical actuation.

Unlike the Kyoto Protocol, in which only the countries included in the Annex I were committed to reduce their GHG emissions, in the Paris Agreement all signing countries must submit their GHG emissions reduction plan, being the reduction objective set by each country.

The Paris Agreement will enter into force in 2020, and it won’t be until 2023 (and every 5 years thereafter) when the first global stocktake will take place. The goal of the stocktake of the implementation of the agreement is to assess the collective progress towards achieving the purposes of the agreement and its long-term goals.

Although it is hard to predict if the agreement will be enough to fulfill the ambitious goals therein set, it consolidates the global concern on climate change and the disposal of act to mitigate the actions that are causing it. In this scenario, the transition towards a decarbonized global energy system is consolidated.

The Paris Agreement, in its article 2, stated that its objectives are:

“(a) Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change;

(b) Increasing the ability to adapt to the adverse impacts of climate change and foster climate resilience and low greenhouse gas emissions development, in a manner that does not threaten food production; and

(c) Making finance flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development.” (IPCC, 2015)

1st Goal
This objective estate that global emissions need to hit roof as soon as possible, even though it is conceded that developing countries might take longer to reach such scenario. However,
Stabilizing global emissions is not enough; by the time this happens, there is the need for emissions to start decreasing in a mid and long term. By doing this, a carbon neutral scenario can be reached in the second half of the XXI century. A carbon neutral scenario is one in which the GHG emissions and absorption are balanced.

The document highlights the importance of GHG sinks for being able to reach this objective. The most important GHG sinks are forests, oceans and the land. Engineered artificial sinks might also be relevant in the near future.

Each country needs to establish national commitments for GHG emissions reductions and needs to design a mitigation plan to fulfill such commitments. This is a substantial difference from the Kyoto Protocol, in which only Annex I countries where committed to reduce or limit their emissions. In the Paris Agreement, all signing countries must submit its emissions targets and mitigation plans, even if it is each country’s concern to state its degree of commitment.

It shall be noted that even though the Paris Agreement is legally binding, as any other agreement reached under the United Nations framework, the individual national commitments of each country are not. It is also an Agreement; that has a lower degree of legal binding for the signers than a Protocol. Countries not fulfilling its own established emissions targets will not be punished. This is a noticeable change from the Kyoto Protocol and the reason why many relevant actors decided to not comply with the Protocol. The legally binding of the emissions reduction that was established in the Kyoto Protocol is now substituted by a voluntary commitment and a non-punitive supervision.

The Paris Agreement is technologically neutral; it does not state anything about how each country shall reduce its carbon emissions. However, it does advocate for the use of the international carbon exchange markets and the substitution of preceding mechanisms for newer ones more aligned with the present reality and goals.

In the same manner that the Kyoto Protocol states that distribution of the needed GHG reductions shall not be equal between developed and developing countries, the Paris Agreement states that it corresponds to developed countries to lead the emission reduction process (IPCC, 2015) (Gonzalez, 2018).

2nd and 3rd goals
In the framework of the energy transition, both 2nd and 3rd goals are secondary.

The 2nd objective is addressed as the need to adapt to the effects of the climate change, as it is now an undeniable reality. The 2nd objective is related to the 1st as the more efforts made on mitigating climate change, less efforts will be needed in adapting to the changing reality. Less adaption efforts mean a reduced economic impact.

In the same way the GHG emissions mitigation targets and policies are up to each countries’ criteria, the same happens with the adaptation strategy. The agreement focuses also in the need for international cooperation to both mitigate damage and losses caused by the effects of climate change and also help developing countries with technologies developed in more advanced countries.

The 3rd objective addresses the need to provide financing to developing countries in order for them to be able to reach the climate goals of the agreement (IPCC, 2015) (Gonzalez, 2018).
In sum, apart from the objectives, the Paris Agreement exalts the paper of the so-called Non-signing Interested Parties. By this term cities and other sub-national entities as well as private agents and the society are addressed. The agreement recognizes its importance in order to reach the needed emission reduction and adaptation strategy via regional and international cooperation.

1.5 The Energy Transition
The need for an Energy Transition in the context of Climate Change is crucial. This can be seen when the GHG emissions by sector are observed. The energy-related emissions in the Annex I countries account for 80% of the total emissions. This is not a new phenomenon as the data from 1990 show roughly the same picture. When the energy-related emissions are broken down by activity, the energy industry is the main pollutant agent. The energy industry and transportation account for more than 50% of global emissions. In any case, energy-related emissions are diversified among different sources: energy industry, mobility, heat-intensive industries, construction, etc. (UNFCCC, 2017).

From the data shown above it can be drawn that in order for us to be able to reach the climate goals of the Paris Agreement, most of the effort shall be focused on energy-related activities and its emissions. These emissions can be reduced either by a more efficient energy use or by substituting today’s energy sources with less carbon-intensive alternatives.

In this context, even if it is hard to predict the future of energy, the main principles in which the new system will be based can be clearly seen. To cope with global development while fighting against climate change, an energy system that is sustainable, reliable, safe and affordable is crucial. In other words, the system needs to find the balance between environmental sustainability, energy security and energy equity. Renewable sources will remain in the core of any viable solution, penetrating into heat, industry, mobility, light and others.

The change, which is already taking place, has no precedent in reach or speed. It will impact societies and economies and it will transform the roles of producers, consumers and all actors involved in the energy sector. New business models will be created and markets will need to be reshaped in order to adapt to these changes.
The main changes that are taking place, are: (i) the efforts of being more energy-efficient and reduce GHG emissions due to decarbonisation aims in order to reach addressed climate targets; (ii) advances in ICTs that allow great amounts of energy-related information to flow through the smart grid’s communication infrastructure, enabling a power system that is more efficient, secure and open to heterogeneous agent’s participation; (iii) the growing maturity and reducing costs of VREs, which allow the integration of high shares in the mix; (iv) the rise of new decentralized agents that can provide electrical services and participate from the energy markets; and (v) the coupling of different sectors (heat, transportation) with the power system either via direct electrification or via Power-to-X solutions. In short, the energy sector is transitioning from a centralized system in which transportation and heat are provided by burning fossil fuels and information flows are scarce to a decentralized, electrified and digitalized system.

The falling costs and technological innovation are strengthening the business case for renewables, offering and economically attractive response to climate concerns. Renewable energy have accounted for more than half of all the capacity additions in the global power sector since 2011, exceeding 2300 GW globally in 2019. Most of these new installations come from wind and solar PV, which are gaining weight in the energy mix of the future scenarios.

Reaching net zero CO2 emissions globally in the second half of the XXI century is a necessity in order to successfully comply with 2ºC of global warming limitations. The key to an energy system capable of doing so is in renewable energy and energy efficiency. For getting there, energy demand will need to be reduced, decarbonisation of electricity will need to be addressed and electrification of energy end use are among the most ambitious and remarkable measures. To stay on a 2ºC pathway the cost reduction in renewable energy and the technological breakthroughs will be crucial.

In a scenario in which renewable generation is cost-competitive, the success of the energy transition will be mainly underpinned by the integration of high shares of Variable Renewable Energy (VRE) into the power system at low cost. Nowadays, the share of VRE in G20 countries’ final energy is about 10%, although this number is higher in some countries (Denmark, South Australia, Spain, Germany, etc.) (IRENA, 2016). Due to the uncertainty and variability of VRE, especially wind and solar, innovative solutions that provide flexibility are needed. In this context, flexibility is the capability of a power system to deal with the uncertainty and variability that VRE generation introduces into the system.

Flexibility can be provided from different sources. Traditionally it was only provided from supply side, adjusting generation to follow demand. The new system will need to be able to provide flexibility from all the actors involved. Some key drivers to unlock flexibility in a power system are the electrification of heat and mobility, the widespread digitalization of the system (through establishment of IoT, IA, Smart meters, etc.) and the decentralization of generation (and storage) agents.

Regarding supply-side flexibility, the renewable generators will be needed to provide flexibility to the extent of their capabilities while conventional plants will need to be refurbished to improve their ramp factor and minimum load.

From the grid side, regional markets will need to be established in order to allow electricity to be transported through a larger balancing area and a greater network capacity will need to be
developed. This way, more resources will be available to balance supply and demand by taking advantage of weather and resource diversity.

On the demand side, decentralized energy resources such as rooftop solar PV, residential battery storage, EV, micro wind turbines can provide flexibility by changing from passive to active participants of the system. The electrification of end use sectors such as mobility or heating will further increase these possibilities. On a first approach, load-shifting solutions that intelligently switch the moment when energy is consumed from peak demand hours to off-peak hours can have a significant impact on grid flexibility. On a more complex approach, solutions that use the decentralized resources to give energy to the grid when needed could provide a huge impact on systems flexibility. To enable these solutions, numerous distributed resources would need to be coupled by aggregators in order to provide a significant capacity that can have a noticeable impact on the grid. It is here where VPP will play a major role in the new power system.

Also, there are solutions that will provide flexibility system-wide and also be crucial in reshaping the power system. The energy storage solutions, such as batteries or Power-to-X solutions can highly increase system flexibility by storing energy at moments of high renewable production and low demand or storing energy to avoid grid congestion (IRENA, 2019).

It is not clear which of the solutions will be the key to unlock power system flexibility, but it is a consensus that there is no one-fit-all solution for the energy transition. In many cases, this will be context-specific or country-specific, depending on interconnections, growth of demand, the spread of natural resources and other factors. All in all, innovation is essential to enable the power system modification needed to integrate VRE.

1.6 The 2ºC degree scenario

Energy related emissions have been relatively flat in recent years, remaining stable at around 33 Gt in 2019, even with the global GDP growing at a 2.9% (IEA, 2019). This has been possible primarily due to reducing emissions from electricity generation in advanced economies with the expansion of renewable generation, mainly wind and solar PV. Fuel switching from coal to natural gas and more nuclear energy use also were significant factors. Other factors such as slower economic growth in some developing countries and milder weather also were relevant.

However, as stated before this is not by far enough for climate targets. There is an urgent need for this recent signs of stabilization to become the basis from which emissions begin to decline. It is estimated that in order to reach the 2ºC degree scenario a cumulative reduction of more than 700 Gt of GHG emissions in the 2020-2050 period. In order to be able to make possible such a huge CO₂ abatement various technological solutions are needed. It is widely accepted that there is no single technology that can be drawn as the solution for such reduction. A portfolio of technologies is needed. Some of the needed technologies are mature today and some others are in an early stage of development. However, we today have some estimates of the contribution of each technology to the GHG emissions reduction needed.
All end use and supply sectors contribute to the emissions reduction. Energy efficiency remains as crucial in industrial, buildings and transportation. Carbon Capture and Storage is key in the industry, transformation and power sectors. Renewable energy is aggressively deployed in the power sector, driven by the maturity of the technologies, falling costs and need for rapid decarbonisation. Renewables are also introduced in the transportation (biofuels, electric vehicles), buildings (renewable based heating and cooling) and industry (renewable feedstocks) sectors. Nuclear plays an important role in the power sector; despite many countries, mainly in Europe, are betting on a future without nuclear power, especially after the 2011 Fukushima incident, there are still plans for new and existing nuclear power plants in many developing countries, mainly China.

It shall be noted that the 2ºC scenario represents a very challenging target. Pursuing even a further reduction would be very challenging, probably needing more than just a full decarbonisation of the power sector, but rather it to be carbon negative by 2060 (IEA, 2017).
Estimations show that in the 2ºC degree scenario renewables alone account for 35% of the total needed CO₂ reduction. This renewables are mostly wind and solar; this energy resources are considered Variable Renewable Energy resources. This resources are variable, uncertain and intermittent. They are variable because the output of the resource changes over time, the uncertainty of the resource represents the gap between the forecast and actual output; the intermittency represents the fact that the resource alternates available and unavailable periods of time. Because of these key characteristics, the integration of large shares of VRE resources in an energy mix is somewhat challenging.

1.7 Flexibility
As stated above, decarbonisation of the energy sector, which is the core of the energy transition requires both the integration of high shares of VRE in the energy mix and the electrification of the end-use sectors.

On the one hand, integration of high shares of VRE may happen in high ramp requirements; in systems with high penetration of solar PV, there is a substantial increase in net load (net load = demand minus renewable generation) when the sun sets as solar PV only generates when the sun is shining. This sets a requirement of high ramp capacity in order to compensate all the solar PV generation in just a few hours.

On the other hand, the electrification of the end-use sectors implies two challenges: first, electricity consumption will most likely double from today’s values; secondly, demand profiles could be reshaped, increasing uncertainty that would add to an already variable and to some degree uncertain generation mix.

In this context, flexibility can be provided at all stages of the energy supply chain (generation, transmission, distribution, demand) and at different time scales (seconds, minutes, hours, days, seasons). The most disruptive and innovative solutions come from providing flexibility on the demand side, which traditionally has been the less flexible stage. Demand side flexibility stands out as the most disruptive and growing trend because other sources of flexibility that are on the supply side (flexible generation, power-to-X, etc.) or that are that can be implemented all throughout the energy chain (storage) are by far much more CAPEX intensive than demand side flexibility. For this reason, demand side flexibility is more feasible than other sources of flexibility.

Demand side flexibility is the portion of the demand that could be reduced, shifted or increased in a specific period of time and as a response to a price signal or a previously agreed commitment (USEF, 2018). By doing this, load profiles can be reshaped to match VRE generation; peak load and seasonality can be reduced; electricity cost may decrease by shifting loads from periods with higher costs to periods with lower costs.

The demand-side flexibility can come from different sources: industrial, commercial or residential. Depending on which the source is, different innovative solutions can be developed. Flexibility in the consumer side is already a reality, with some innovative solutions developed around the world. However, the huge flexibility potential that could be addressed in the demand-side needs different innovations for successfully implement the solutions in the different end-use sectors.
Demand-side flexibility is not a new concept. Transpower, New Zealand’s TSO, is allowed to temporarily switch off user’s hot water heaters when demand is high in order to reduce it, and has been doing so since the 1950s. Other examples of such are Spain’s ‘interruptible’ service (servicio de interrumpibilidad) or Germany’s interruptible loads. Nevertheless, there is a skeptical point of view regarding interruptible loads, which are seen by some people as hidden subsidies for heavy industry as they get paid for remaining available but are rarely used. Also, demand response services are not widespread because of barriers like the absence of the right price signals (which is being solved with technological innovation in the field of digitalization) or because of inadequate regulatory frameworks (which is changing recently).

Demand side flexibility can be differentiated in implicit and explicit [82]. Implicit demand side flexibility, sometimes called price-based demand side flexibility, is the consumers’ reaction to price signals. Where consumers have the possibility to choose hourly or shorter-term market pricing, reflecting variability on the market and the network, they can adapt their behavior to save on energy costs, either by personal choices or by automated ones. Explicit demand side flexibility, sometimes called “incentive-driven” demand-side flexibility, is committed and dispatchable flexibility that can be traded on the energy markets just as generated energy does. This trading will likely occur in the balancing and reserve markets or in local flexibility markets in the near future; it can also take place on wholesale markets but it is less likely. This type of flexibility is usually provided to the system operator and managed by an aggregator, which acts as a facilitator and can be an independent service provider or a utility. In this context, the role of an aggregator is key in order to unlock this portion of the so needed system flexibility.

The development of enabling technologies and the adequacy of the regulatory framework are crucial for the escalation of demand-side flexibility. Also, under the term demand-side flexibility is included sector coupling. Sector coupling consist in the interconnection of the different end use sectors with the power system. By doing this, VRE excess production could be used to heat water that would be stored to heat buildings; it could also be used to produce green hydrogen.
that could be later either combusted or used in fuel cells to produce electricity. To which degree will each sector be directly electrified or will underlay in other ways of coupling with the power sector is not yet clear.

In short, demand-side flexibility can be provided from various energy assets: industrial demand response (energy-intensive industries’ load shifting availability), residential energy storage, electric vehicles (electrification of mobility will enable a large number of mobile batteries to participate in demand response and aggregation programs thanks to smart charging and V2G), smart appliances and responsive residential loads, power-to-heat (heating/cooling sector coupling), power-to-hydrogen (energy storage, grid balancing services, renewable source for hydrogen-intensive industries) and others.

Aggregators will play an important role aggregating small decentralized flexibility from heterogeneous energy assets and bidding it into different energy markets, benefiting from economies of scale and scope and unlocking market participation for small asset owners. Leveraging in advanced forecast technology, intelligent predictive models and a robust ICT structure those decentralized assets will be operated as a unique energy resource, being viewed by the energy markets as a conventional fossil fuel fired power plant. The operation of this Virtual Power Plant faces significant challenges from technical, regulatory and economic points of view, but it represent a considerable opportunity to unlock substantial volumes of demand side flexibility and enable integration of large shares of VRE in the energy mix.

![Virtual Power Plant simplified scheme](image)

*Figure 8 Virtual Power Plant simplified scheme, (Navigant Research, 2018)*
The rise of wind and solar generation enables a renewable powered energy sector but raises uncertainty, variability, and intermittency inherent to VRE.

The active system management of TSO-DSO-consumer bi-directional power flows enables a reliable, connected and efficient energy supply.

The harmonization of the market and the participation of Virtual Power Plants fosters energy system flexibility to enhance system operation.

Figure 9 Virtual Power Plant general overview, i-deals analysis.
Variable Renewable Energy (VRE) is defined by the IEA as “those technologies whose maximum output at any time depends on the availability of fluctuating renewable energy resources. VRE includes a broad array of technologies such as wind power, solar PV, run-of-river hydro, concentrating solar power (where no thermal storage is included) and marine (tidal and wave)” (IEA, 2019).

The share of VRE in the global electricity generation mix grew from under 2% in 2010 to 7% in 2018. It is estimated that by 2040 the share reaches between 24-40% (IEA, 2019). The global installed solar capacity increased from 6.5 GW to almost 500 GW in the 2006-2018 period; wind capacity grew from 150 GW to 563 GW in the 2009-2018 period (IRENA, 2019). Market growth could accelerate further from today’s growth, reaching 1500 GW of wind and 1250 GW of solar by 2030, some reports say (IRENA, 2014).

The main reason for this accelerated growth is price fall. Solar PV modules have decreased by more than 80% since 2009 (IRENA, 2019) and wind turbines have fallen by 30-40%. For these reasons, VRE are becoming increasingly cost-competitive, being the most cheap energy resource in many countries, generating power for as low as $28/MWh while solar PV can generate for as little as 32%/MWh (LAZARD, 2019).

However, VRE integration into power systems entail some difficulties due to its inherent characteristics of uncertainty and variability. Uncertainty is mainly caused due to errors in weather forecasting resulting in higher or lower outputs of wind and solar resources; variability is the output change due to the expected variability in the available primary resource. Those are the main issues that VRE impose; however there are others: primary resources are location
constrained, as they are not uniformly distributed across the geography; VRE are non-synchronous technologies and therefore interact with the grid using power electronics.

Operating a system with a 100% VRE mix is not yet possible, even though some countries may have had been able to do so for extended periods of time. Large shares of VRE poses some challenges; VPPs emerge in this context as one potential solution for those challenges.

Following load with VRE generation is complicated, and implementation of VPPs can help solve this problem while creating value at different steps of the energy value chain; however, there are other challenges that need to be considered for systems with large shares of VRE in the generation mix. Some of these challenges are explained herein.

1.8 VRE resources grid integration challenges

VRE present some inherent characteristics that its fossil fuel based counterparts do not. The above mentioned uncertainty and variability stands out as the most concerning, but there are others. The main difference between variability and uncertainty is that the first can be measured, whereas the second is unexpected. It shall be noted that both take place at different time scales, as weather forecast can fail to predict the sun radiation for the next hour or if the wind is going to blow the next week. Regarding solar PV, its output varies during the daytime with no energy produced at night; cloud coverage cause rapid decreases in output and are hard to predict. Wind does not follow the same diurnal pattern, as it can more strongly blow during night time in some locations. Storms cause rapid changes in wind’s output. For these reasons is hard for VRE output to follow demand.

As mentioned above, VRE interact with the grid using power electronics. Fossil fuel fired power plants and nuclear generators use synchronous generators that spin at a specified constant speed to maintain frequency. The rotation speed and frequency of the generated current are directly correlated. Frequency must be maintained in order for the system to operate reliably; balance between mechanical power and electrical load must be kept. The system operator uses different mechanisms when the frequency shifts from its nominal value to alleviate any imbalance in the system (Kroposki, 2017).

VRE need power electronics to interact with the grid. Inverters have different characteristics and they interact differently with the grid than synchronous generators, as they do not exhibit inertia or synchronizing torque. For this reason, control mechanisms and strategies are different when VRE are used, as they use inverters and controllers to regulate the AC output to the grid.

Lastly, VRE are location specific. This means that the generating resources is not equally distributed across one given geography. This does not happen with their pollutant counterparts, as you can build a conventional power plant virtually anywhere. This results in situations where the resource might not be closely positioned to the given load, needing expensive transmissions lines; this happens with wind resources, which are usually located far away from largely populated areas. This is clearly understood when looking at offshore wind installations.

For the above mentioned reasons, integration of VRE in the power grid entail challenges both for long term planning and for real time operation (Zaman, 2018) (Kroposki, 2017).

Frequency regulation

In a conventional power system, when an imbalance occurs, the frequency control mechanism is called. The rate of change of frequency (ROCOF) (Riepnieks & Kirkham, 2016) is related to the
systems inertia; the systems inertia is related to the spinning mass that is in the system at any given moment. Power systems with high shares of VRE are systems with low inertia and inverter-dominated; these systems have unique characteristics that change power system dynamics. When a frequency event takes place in a conventional power system, generators with governor adjust their output to maintain the frequency stable. VRE, unlike synchronous generators, do not contribute to systems inertia. In scenarios with high shares of VRE in the mix, imbalance events with low system inertia can lead to high ROCOF and cascade effects causing outages and blackouts (Zaman, 2018).

Voltage regulation
Synchronous generators regulate voltage in each bus of the grid by adjusting the injected reactive power in the grid. Voltage needs to be kept stable in order for the system to operate reliably. Whereas active power is needed for run the connected loads, reactive power is needed to maintain a steady voltage. Reactive power is also used for high voltage transmission lines and cannot travel long distances, so locational availability is key.

Power electronics used with VRE, mainly inverters, can also inject reactive power into the grid and therefore contribute to voltage regulation. For this matter, inverters need to be built with voltage controllers. For this reason, system operators need to define regulations that ensure that those voltage regulation capabilities are available from VRE resources.

In short, a 100% VRE grid means a no-inertia grid. New control strategies and mechanisms are needed to keep these grids reliable and secure (Zaman, 2018).

Ramping requirements
The primary generating resource behind VRE generators fluctuates during the day. The high amount of uncertainty and variability in grids with large shares of VRE entail substantial challenges. Steeper ramps, deeper turn downs and shorter peaks are expected in this type of grids. This can result in inefficient operation, both from a technological and an economical point of view.

If the system is not flexible enough, curtailment of wind and solar resources might happen. Despite being the most cost-effective solutions for this situations, large curtailment periods can significantly reduce project revenues (Zaman, 2018).

Resource adequacy
Generally higher shares of VRE entail the need for larger volumes of operating reserves to be held. Operating reserves are the energy assets that remain available in case a significant imbalance occurs. It is challenging to elaborate long term power system planning with high shares of VRE as it is not well known the amount and the type of reserves that are going to be needed to keep the system reliable.

Transmission adequacy
A central challenge to scaling up VRE is the development of required transmission infrastructure. Viable wind and solar resources are often not located near load centers or existing transmission systems. Unlike conventional generators, VRE plant siting is less flexible and more location constrained. Thus, new transmission infrastructure is often needed to connect the VRE source to the load.

Large investment in transmission lines and greater needs for coordination between existing regional grids will be needed to develop larger balancing areas (Zaman, 2018).
1.9 VRE resources grid integration solutions
Solutions to address the above mentioned challenges can be of different types. From an innovation point of view, advanced weather forecasting is seen as fundamental to reduce VRE uncertainty. It is one of the most cost effective tools, as it effectively reduces the amount of operating reserves needed. Even slight improvements can suppose large benefits in both day-ahead and hour-ahead predictions. Nevertheless, some degree of uncertainty will always be associated to these resources.

There are also new inverter technologies that are being developed that can emulate the inertial and frequency response of conventional generators. Smart-grids (in which VPPs are integrated), which are grids that incorporate information and communication technologies into every aspect of the electricity value chain to enhance system flexibility and storage technologies for all timespans (hydro-pumped storage, batteries, thermal, etc.) are also fundamental to enhance system flexibility and enable VRE integration.

Lastly, modifying market designs and system operation dynamics can be a relatively cost-effective way of addressing VRE challenges. Some of the potential measures could be bringing dispatch time closer to real time and creating larger balancing areas (or coordinating independent balancing areas, like the ancillary services harmonization projects in the ENTSOE region) (Zaman, 2018) (Kroposki, 2017).

1.10 Security of Supply
Another issue related to the integration of large shares of VRE in the mix is related to market prices. As renewable generators have virtually zero marginal costs, their bid in the electricity market is zero. As the penetration of renewables increases, the merit order lists moves to the right and as the demand curve remains invariant, the market price for electricity is consistently reduced.

![Figure 11 Merit Order fluctuations due to renewables (Clean Energy Wire)](image-url)
As the average pool price for electricity decreases, players on the generation side of the chain see their revenues curtailed. For this reason, investment activity in the generation business is discouraged as power mixes have increasingly more weight of clean energy sources. As the supply side of the system is organized as a liberalized market, security of supply is endangered if the price at which electricity is sold faces sustained falls. System operators can leverage in different mechanisms in order to ensure that the system has always enough generation capacity to meet demand. These mechanisms aim to protect the return on investment in order for them to keep investing in building new generation capacity as old capacity is gradually phased out.

Electricity markets can be organized as energy-only markets. In this markets, generators bid in the market to ensure their return of investment. For this to happen, price caps need to be eliminated and peaking power plants (power plants that run just a few hours, with low capital costs and high operational costs, typically fuel-oil fired or gas fired power plants) bid with prices that are various orders of magnitude higher than average prices. This results in more price volatility and in huge electricity prices a few hours a year, resulting in a price for electricity that is higher than the value customers give to electricity. For these reasons, this types of markets are not usual and mechanisms to ensure generators obtain adequate return on investments are held in place.

Strategic reserves consist on old power plants that are bought by the system operator before they are definitely phased out. The system operator keeps these power plant operative and runs them when demand peaks. For this mechanism is crucial to establish an adequate dispatch price for the reserve. A high dispatch price will result in higher revenues for the rest of generators and therefore investment in new capacity will be incentivized, resulting in the system needing smaller reserves. On the other hand, a low dispatch price results in the need for larger reserves, as new generation capacity is not incentivized that much. The difficulty here is to establish a correct combination of dispatch price and reserve volume. This type of mechanism is sometimes discarded as the system operator, which is said to be a neutral agent, somehow influences prices and participates in the market. Elia, the system operator in Belgium, uses strategic reserves as a mechanism to ensure security of supply (Elia, 2019) (Edx, 2020).

Another mechanism that is commonly used for ensuring security of supply is capacity payments. Capacity payments consist on generators being paid for remaining available and to ensure they return their investment. This is addressed either by the system operator establishing a regulated pay that is passed to consumers in the electricity bill, like on Spain; or by binding consumers to pay for their maximum demand (plus a security margin), like in the PJM area in the US. In the PJM region, retailers and big industrial consumers need to buy capacity tickets from generators, which can also be traded in a secondary market (PJM, 2020).

One disruptive method for capacity payments allocation is known as capacity subscriptions. As defined in (Zwijnenburg, 2019), capacity subscriptions is a novel mechanism for ensuring enough capacity is available in the mix. In this scheme, consumers individually choose their capacity payment based on the essential power they would need in a scenario of generation shortage. Based on this, system operator would curtail the energy consumed up to the capacity payment threshold when there is not enough generation in the system.

These schemes are gradually being adapted to the new power system paradigm and demand response, storage or interconnection capacity are being considered for capacity mechanisms. Also, introducing flexibility requirements for new generation capacity additions will help mitigate the issues related to the integration of VRE resources.
Figure 12 New participants in capacity markets addressing supply shortages (IRENA, 2019)
2 Aggregation of distributed energy resources (DERs)

2.1 Understanding Distributed Energy Resources

On the new power system, one of the main providers of electricity services are DERs. DERs are any resource capable of providing electricity services of any kind that is located in the distribution level of the grid, although in some cases DERs can also be located on the transmission level. They are connected at lower voltages levels than conventional centralized resources and have relatively small capacity (Burger, Jenkins, Batlle, & Pérez-Arriaga, 2018).

DERs can be either specifically designed to provide electricity services (storage, rooftop solar PV, etc.) or can provide electricity services as a side operation complementary to their main function (Plug-in EV, flexible demand, etc.). Nevertheless, despite being capable of providing electricity services it shall not be overlooked that DERs main function is to provide services to the owner itself and only eventually provide services to the grid when the power system needs it (and the adequate price signal is sent) (Burger, Chaves-Ávila, Batlle, & Pérez-Arriaga, 2016).

With the proliferation of DERs, along with other technology enablers especially in the field of ICTs and appropriate regulation, the power system can transition into a new paradigm in which a large number of small agents can make decisions about their consumption and their participation in the provision of electricity services to the system in competition with traditional centralized incumbents.

Under this new paradigm, demand-side agents can both consume or provide electricity services. Nevertheless, these agents can participate in providing flexibility to the system in two ways that shall not be mistaken (USEF, 2018):

- Consumers can act as price responsive agents, arranging their consumption as a function of electricity prices. This can help smoothening the demand profile, by shifting loads from peak hours to non-peak hours whenever time-of-use tariffs are in place. Even though these behavior can help improve system’s efficiency and operation by avoiding VRE curtailment and grid congestion, it cannot be considered as providing an electricity service as it only represents the degree to which the consumer values electrical energy at that given time. This behavior can be referred to as “price-responsive demand” or “implicit demand-side flexibility”.
- On the other hand, consumers can act as flexible agents by making a commitment to curtail (or increase) their consumption when needed by the power system. In this case, the commitment to adjust the consumption itself can be considered as providing an electricity service and it has values thereof, beyond the value of the energy that is not consumed when called to adjust the demand. These case can be referred as “demand response” or “explicit demand-side flexibility”.

DERs can be very varied and thereof its technical and economic characteristics can differ too. There can be differences in performance and cost among the same class of DERs; there are substantial differences between a flow battery, a lead-acid battery and a Lithium-Ion battery and if a comparison is to be made further analysis must be undertaken. There are also cost and performance differences among the same technology (a Lithium-Ion battery with one hour of storage capacity has a significant lower cost than a Lithium-Ion battery with four hours of storage capacity) and there are also important differences between different scales given the same technology (LCOE is lower when a utility-scale 100MW solar PV installation is made compared
2.2 Aggregation of DERs
As stated before, one of the main characteristics of DERs is that their capacity is really small compared to centralized resources. Allowing such small agents to provide electricity services and participate in the electricity markets can be a huge challenge to the operation of both the transmission and distribution system could make demand profiles unpredictable and would probably add great volatility to electricity prices among other considerations. In this context, a new business models emerges that aims to aggregate all the small-capacity DERs and be able to provide electricity services at a utility scale. The aggregated capacity of large numbers of DERs can compete with conventional centralized generators either in the wholesale market or in providing ancillary services if a level playing field is enabled. By leveraging in aggregated DERs (which owners would commit to be controllable to some extent under certain conditions) to provide electricity services the aggregator would run a Virtual Power Plant.

A Virtual Power Plant run by an aggregator would entail engaging agents of the power system in unfamiliar ways. Aggregators (and their clients owning DERs) would benefit from a high level of time and location granularity, although this would comprise important operational challenges.

Even tough aggregation is emerging as promising business model to compliment core business of various energy players and reduce return on investment of energy assets for DER owners, regulation and operation challenges also emerge. Market designs need to be accommodated in order to allow these new agents to participate and existing agents; TSO and DSO will need to develop new procedures in order to coordinate and adapt themselves to this new model (Burger, Chaves-Ávila, Batlle, & Pérez-Arriaga, 2016).

2.3 The value proposition for DERs through aggregators
Aggregation can be defined as the act of grouping different agents in a power system to make them act as a single entity when engaging in power system markets or selling electricity services to system operators. By doing this, aggregators can help unlock DERs full potential by enabling their competition at scale (Burger, Chaves-Ávila, Batlle, & Pérez-Arriaga, 2016).

In liberalized markets, retailers can be considered some sort of “aggregators”. Retailers aggregate disperse and numerous consumers and act as an intermediary between them and the wholesale market, trading the aggregated consumption and holding responsible for the imbalances caused. The emergence of independent aggregators in this scenario creates a debate about whether the participation of this new agents over the well-established traditional retailers is efficient and cost-competitive. The role of the new actors and their added value need to be clearly defined, and to which extent some of this functions could be performed by conventional retail electricity providers has to be clarified. In some power systems, like is the case of Spain, aggregation is only allowed through retailers until the figure of the independent aggregator is developed.

Aggregators can create value in different manners, for different agents and in different time scales. Whereas creating value for a private single actor could be just the result of a rent
transaction between market agents, aggregators are also able to create value to the power system by managing grid congestion or providing some electricity services.

The uncertain pace of technological change and the constantly evolving regulatory framework add difficulty to the task of defining in which way the aggregators can create value, and if this created value will last or it will only be transitory. The changes that affect the cost structure of electricity services may change the business case for aggregators in a way that is hard to predict. Nonetheless, value created by aggregators can be described as transitory or permanent (to some extent) based in regulatory and technology context (MITei, 2016) (Burger, Chaves-Ávila, Batlle, & Pérez-Arriaga, 2016).

Fundamental value

In this framework, value created that is permanent in time is defined as fundamental. This value is not dependent on specific regulation, market context or technology so it can be expected to endure in time. However, although fundamental value is not dependent on these factors, they do substantially impact whether this value is captured or not (Burger, Chaves-Ávila, Batlle, & Pérez-Arriaga, 2016).

3.3.1.1 Economies of scale

Fundamental value created by aggregators is derived from different aspects. First, there are unavoidable costs inherent to participating in electricity markets: the engagement of the owner of the DER, the technically required ICT equipment and the compliance with existing regulatory framework. These costs have both a fixed and a variable cost and as a long as they have a fixed cost aggregators can create value by benefiting from economies of scale.

Economies of scale are defined as the proportionate cost savings gained when production level is increased. Traditionally, generators have benefited from economies of scale by aggregating customers and signing long term contracts with them, what allowed them to build larger generation units. However, aggregators apply economies of scale to create value in different ways.

In many systems, in order to be able to participate in a market there are a few inherent transaction cost. An agent needs to be registered and acquire an insurance against economic losses. There are also other costs like reporting costs or costs associated with complying with existing codes. Also, in most systems market agents need to be responsible or delegate into a third party costs associated with potential imbalances caused. These costs represent a high transaction cost per unit of energy sold for small agents like single DERs. Evaluating if these costs are necessary or efficient falls outside the scope of this work, however it is assumed that these fixed cost exist and are a relevant entry barrier for small agents. For this reason, value can be created by aggregating DERs so that the costs are spread among a larger number of agents.

Also, costs related to ICT can be substantially reduced if economies of scale are applied, especially in a context in which cloud services are becoming more and more relevant. For residential customers to be aggregated a device that acts a gateway is usually needed; ideally, assets will be able to be controlled by the aggregator in a hardware agnostic manner, leveraging in IoT or other form of communication protocol (IRENA, 2019).

The hardware gateway is some sort of energy management system (EMS) that (among other functions) can communicate with the grid and the aggregator, can control in-house assets and can receive and send price and operational signals. As the variables that control gateways can
manage increase, so does the efficiency and the possibilities of increasing users’ comfort and output, but so does the computational capacity needed.

In this context, it may be more economically efficient for an aggregator to use cloud or edge computing to centralize the computing capacity, allowing customers to use inexpensive computing equipment that receive simple control signals. Under this paradigm, cybersecurity concerns and associated costs could not be overlooked (Burger, Chaves-Ávila, Batlle, & Pérez-Arriaga, 2016).

3.3.1.2 Economies of scope
In most cases where aggregators can benefit from economies of scale can also do so from economies of scope. Economies of scope are defined as the cost savings created by efficiency that is formed by product variety. In the case of providing electricity services, most cost related to participation in markets are applicable to the provision of different services, and so are the costs associated with ICTs. Thereby, bundling the provision of different services into one aggregator can create value via economies of scope.

Depending on to which extent the benefits of economies of scope and scale are exhausted, the most efficient solution will be one or another, ranging from one centralized aggregator or multiple of them (Burger, Chaves-Ávila, Batlle, & Pérez-Arriaga, 2016).

3.3.1.3 Uncertainty and price risks
Another way in which an aggregator could create fundamental value is by mitigating uncertainty and price risks. By aggregating a large number of agents, an aggregator can help reduce uncertainty by providing accurate of information and behavioral forecast. Appropriate regulation will need to be set in order to allow the transaction of certain information related to customer use of electricity, but if the framework is adequate, forecast-as-a-service could also be an added value created by aggregators.

In addition, price risks can be mitigated the same way retailers protect customers from price volatility by aggregating a large number of them and offering fixed prices. However, both benefits will probably be more efficiently managed in a scenario in which aggregation is done by a single agent that would be able to access to more information than multiple agents (Burger, Chaves-Ávila, Batlle, & Pérez-Arriaga, 2016) (MITei, 2016).

Whereas economies of scale and scope and risk and uncertainty management presumably will tend to benefit a paradigm in which aggregation is done by a single centralized agent, a scenario in which level playing field is guaranteed for aggregators to compete in the market might benefit from a larger consumer engagement (due to attractive product and tariff offers), enhanced innovation and market power mitigation. Which is the most suitable and efficient solution is not yet clear and will depend on the magnitude of each of the sources of fundamental value herein defined.

Transitory value
Regulation, system operation and technology are changing and will need to adapt to reality at each moment in time. This situation can end up in aggregators creating value under a certain set of regulation, operation and technology circumstances but not under another. The value created by aggregators under current paradigm that might wane under a more advanced paradigm is called transitory value.
There are, under the current scenario, a set of biases that hold back efficiency improvements in the system. Time granularity in electricity retail tariffs, insufficient deployment of ICTs, lack of engagement and other factors are not allowing this value to be created. These factors, that might eventually fade, can in the present be saved by aggregators (Burger, Chaves-Ávila, Batlle, & Pérez-Arriaga, 2016).

3.3.2.1 Information
Aggregators can have access to information (market price signals, when price peaks will occur) and generate forecasts (needed to provide electricity services) that are out of single customers’ reach thus holding them back of participating in the market. Also, aggregators can access to real time energy prices as opposed to actual flat tariff rates (or stair-stepped time-of-use tariffs) thereby benefiting from wholesale and intraday prices.

3.3.2.2 Customer engagement
For a single agent, savings related to reacting to dynamic price signals might not be that substantial. Even though the total cost and capacity savings may be very large when numerous DERs are bundled, the fact of each customer only saving a small sum of money per month might discourage customers to participate from aggregation. Complexities of engaging in such a complex system as the power system will not help customer engagement either. The value that aggregators can create in this situation is engaging in the power system agents that otherwise would not be engaged. They can do this by managing the registration and bidding processes and associated complexities. This added value could potentially transition into an automation services and support provider when IoT unlock such possibility (Burger, Chaves-Ávila, Batlle, & Pérez-Arriaga, 2016).

3.3.2.3 Coordination
The proliferation of DERs represent a coordination challenge for TSO and DSO, who traditionally faced a large set of passive and easy-to-forecast loads and centralized and easy-to-manage, generators. For integrating a large number of DERs into the power system, efficient bidirectional communication with these agents needs to take place in real time. Aggregators can create value by facilitating these communications, coordinating the information exchange between agents. Again, this created value is subject to the debate of if a competitive set of aggregators is a more efficient solution regarding coordination than a monopolistic agent (the SO). This relies mainly in the cost structure of providing this services and the extent to which economies of scale and scope are exhausted (as discussed in 3.2.1). Also, the proliferation of aggregators can avoid a situation in which a monopolistic aggregator provides standardized products (in order to reduce costs) that might leave some agents out of the market (Burger, Chaves-Ávila, Batlle, & Pérez-Arriaga, 2016).

Opportunistic value
Whereas fundamental value can create both private value for each customer and system value, opportunities that arise from unnecessary regulations or regulatory “flaws” only create private value. Therefore this created value can in some cases boost the business case for aggregators despite not creating system value and enhancing system flexibility and efficiency.

3.3.3.1 Balancing services
In the provision of balancing services, agents get paid by remaining available to increase or decrease production or consumption of energy. Depending on the power system, this services
can be mandatory, remunerated or non-remunerated. Also, agents might get paid for remaining available apart from the payment of the energy that might be eventually be dispatched.

If an agent that has committed to provide this services is required to do so and is unable, a penalty will be applied beyond the marginal cost of the activated reserves. If an aggregator is unable to dispatch the requested reserve, he might find convenient to dispatch other available generator whose marginal cost is high (but still lower than applicable penalty) and therefore a generator with a high marginal cost would dispatch (while probably being available other generators with lower non-penalized marginal cost but out of the scope of the aggregator) due to this penalty system.

Hence aggregators can reduce costs associated with failing to provide balancing service penalties on expense of system inefficiencies. Furthermore, there might be small agents that are not willing to participate in balancing services market if not aggregated due to penalties (Burger, Chaves-Ávila, Batlle, & Pérez-Arriaga, 2016).

### 3.3.3.2 Symmetric bidding

When providing operating reserves, in some systems there is a requirement of providing symmetrical products for upwards and downwards regulation. Depending on the generation technology this can be costly; remaining available to regulate upward power for a solar PV installation entails that the installation will not produce at its maximal output. Therefore, this requirement cannot be fulfill by single small-capacity agents such as a residential rooftop PV generator. If this unnecessary requirement is eliminated, any unit could provide reserves in any direction thus not leaving out any kind of actor (Burger, Chaves-Ávila, Batlle, & Pérez-Arriaga, 2016).

### 3.3.3.3 Allocation of balancing costs

The allocation of balancing costs is the way imbalances and imbalances prices are determined. The way in which this is done varies from one system to another. For single units, the cost associated with producing (or consuming) less (or more) energy than scheduled are straightforward. In aggregated units, if one unit produces more energy than scheduled and other unit produces less, the balancing costs can be reduced to the net imbalance of all units.

With the proliferation and integration of VRE and the uncertainty inherent to them, the use of balancing reserves has been increased. In this scenario, some system operators have created thresholds of imbalances under which penalties are not applied, to facilitate the integration of VRE. Aggregators can benefit from this scenario by maintaining a net imbalance below the threshold value and therefore not paying penalties.

Also, depending on the imbalance pricing system applied opportunistic value can be created. Imbalance pricing can be single, where the prices are based on the marginal cost of activated reserves; or dual, where prices are based on the marginal cost of activated reserves of imbalance if it goes in the opposite direction of system’s net imbalance; if it goes in the opposite direction of system’s net imbalance the price is usually based on the day-ahead market.

Whereas single imbalance pricing does not create opportunistic value, dual pricing does create opportunistic value for aggregators by creating incentives for netting imbalances among different units (Burger, Chaves-Ávila, Batlle, & Pérez-Arriaga, 2016).
3.3.3.4 Locational price signals

Even though not commonly used, there is a strong debate regarding whether locational marginal prices should be used. In most cases energy prices cannot be consistent with the actual cost of energy if they are not locational. Such a complex topic will not be discussed herein, the opportunistic value of inefficient implementation of it is considered though.

If locational (or nodal) prices are applied both for load and generation, aggregators with both resources could find benefits in speculating with locational prices by increasing load or reducing production thus driving prices artificially high.

In most power systems, consumers’ tariff have a fixed component related to the peak demand of the installation. In the case of consumers that have similar peak demand magnitudes that offset in time, they can be aggregated and have an aggregated peak demand similar than one single user. This private opportunistic value might threaten the financial viability of network providers (Burger, Chaves-Ávila, Batlle, & Pérez-Arriaga, 2016).

2.4 Prices and charges

Markets need to adapt to the trends of digitalization, decentralization and electrification and the fast changing reality of the energy transition. A market that prices energy and balancing mechanisms correctly and remunerates adequately all participating agents. This adaptation has already taken place as the Clean Energy for All Europeans package includes markets with shorter timeframe and market prices that reflect the real value of energy at each moment, as well as modified dispatch rules, ensured demand side participation for flexibility provision and a enhanced business case for DERs and self-consumption.

Both time and space granularity and redefined balancing mechanisms are key aspects in order to foster a flexible behavior. Pricing and charging scheme modifications like new tariffs, self-consumption and net billing need to be in place in order to keep pace with the occurring transition. In short, appropriate billing schemes need to be in place for enable DER participation in electricity markets through aggregators.

Changes need to happen both in the wholesale market design and in the retail market design. Wholesale markets need to adapt trading rules to allow large share of VRE in the mix, rewarding and valuing flexible behavior to counteract short-term variability and uncertainty inherent to VRE resources. For serving this purpose, enhanced time and space granularity, new ancillary services (incentivize fast acting reserves and ramping requirements) and redefined capacity markets (enabling VRE to participate or introducing flexibility requirements in the capacity markets) are needed.

Transformation of retail market design will occur as the deployment of massive volumes of DERs, which change consumers into active market participants. Time-of-use tariffs are needed to show consumer time-varying price signals for them to actively change their consumption patterns. Shifting consumption from peak periods to valley period based on a price signals is one of the most direct forms of providing flexibility from the demand side. DERs need to be integrated into energy markets and net billing schemes need to be implemented to foster widespread adoption of solar and storage self-consumption solutions (IRENA, 2017).

In short, use and connection charges for electricity should be transparent and non-discriminatory. Operators should work towards innovative grid tariff structures that incentivize
customers to deliver flexibility to the power system. These tariffs are especially important for aggregators, and therefore the implementation of Time of Use tariffs is crucial. Time of Use tariffs could also be used for the capacity component by setting different capacity network tariffs for predefined time schedules (BestRes, 2017).

Cannibalization of renewable energy sources needs to also be kept in sight. As more variable wind and solar are added to the grid, the more wholesale electricity prices fall. Revenues for these generation assets can drop significantly; it is estimated that a 10MW wind farm could face a 34% revenue reduction due to this phenomenon, compared to 2018 price levels (ReCharge, 2019). However, the falling tendency in LCOE in wind and solar generation might set such a big difference in costs when compared to conventional fossil fuel generation that this concern might not be that relevant in the coming years. Also, new ways of taking advantage of excess renewable energy like energy storage or green hydrogen might arise as new revenue streams for those generators (MITei, 2016).

2.5 Regulation

One of the barriers that the implementation of aggregation and VPPs faces are the specific regulatory constraints of each power system. These constraints limit who is allowed to aggregate loads. In some power systems (Sweden, Norway, Netherlands), aggregation is only open to energy retailers; some other power systems (Germany, Austria) only enable aggregation if the agent has signed a bilateral contract with clients’ Balancing Responsible Party. These constraints are important boundaries that difficult the implementation of independent aggregators and thus the emergence of VPPs. Still, some other power systems (UK, Ireland, France, and Finland) allow independent aggregators without any of the previous mentioned constraints (Gaurus, 2018).

In Europe, the Directive 2019/944 of the European Parliament and the Council stated that “All customer groups (industrial, commercial and households) should have access to the electricity markets to trade their flexibility and self-generated electricity. Customers should be allowed to make full use of the advantages of aggregation of production and supply over larger regions and benefit from cross-border competition. Market participants engaged in aggregation are likely to play an important role as intermediaries between customer groups and the market. Member States should be free to choose the appropriate implementation model and approach to governance for independent aggregation while respecting the general principles set out in this Directive. Such a model or approach could include choosing market-based or regulatory principles which provide solutions to comply with this Directive, such as models where imbalances are settled or where perimeter corrections are introduced. The chosen model should contain transparent and fair rules to allow independent aggregators to fulfil their roles as intermediaries and to ensure that the final customer adequately benefits from their activities. Products should be defined on all electricity markets, including ancillary services and capacity markets, so as to encourage the participation of demand response.” (European Commission, 2019)

The above mentioned directive as well as the Regulation 2019/943 were set to entry into force the 1st of January of 2020, with some articles as late as 2021, establishing the framework to ease the widespread emergence of independent aggregators.
2.6 Electricity services provided by a VPP

Understanding the electricity wholesale market

Aggregated DERs will mainly participate in ancillary services markets through Virtual Power Plants. The reason is that those markets have higher retribution and have a lower impact on end-users’ comfort. However, some of VPP, especially large ones with relevant CHP and/or storage aggregated capacity can also bid in the wholesale markets. For that reason the wholesale markets will be briefly described herein.

The wholesale electricity market is the market place where electricity is traded before being it delivered to end users. This trading generally occurs in large energy quantities and involve energy producers on the sell side of the market and retailers and large energy consumers on the buy side. As energy supply and demand needs to be in balance at every moment and the power system needs to be able to hold the traded energy flows, the electricity market is really complex. The TSO supervise the activity that takes place in the market in order to ensure system reliability and exchange viability.

In the electricity market energy can be traded within different time horizons. Thus, we have derivatives markets in which options and futures are sold; a day ahead market in which the energy of the following 24 hours is traded, and short term markets in which energy is traded with a shorter timeframe. In Europe, short term electricity markets are divided into intraday markets, which take place several times a day and continuous market, which have been recently implemented and are cross-border.

The markets in which generated electricity is bought and sold in order to end users to consume it, regardless of the timeframe, are electricity wholesale markets. The market in which the electricity exchange occurs in order to balance the grid, relieve congestion, adjust voltage, amend an imbalance or in short to provide a service to the system operator are ancillary services markets.

The wholesale electricity market is in most power system based on marginal pricing. This means that the price bid by the last generating asset entering the cassation is the electricity price for that time period. For this reason, renewable generators (that will generate energy regardless of the market price) and nuclear generators (with very low marginal costs and high back start costs) enter present zero price bids. Coal, gas and other generators with higher marginal costs usually bid their marginal price. These pricing system is causing some debate recently in power systems with high penetration of VRE; the more renewables in the mix the lower the price as their bid is zero; at lower energy prices, the profitability of the inversion is affected. The energy transition is changing the paradigm of the power system and the electricity market will need as well to adapt to the new scenario.

Energy markets differ broadly from one system to another in technical, regulatory and legal constraints and might have different retribution schemes. A brief description of the wholesale energy markets is provided, but it shall be noted that the description herein might not be accurate for all existing power systems.

3.6.1.1 The day-ahead market

The day ahead market roughly 80% of the energy is traded. Agents present buy and sell offers for the energy of the 24 hours of the following day and the market operator proceeds with cassation; it is usually structured in one session. As these markets are regional, usually nationwide, regulation is system specific. Some aspects, like the smallest tradable unit are key for
participation of decentralized small energy assets, but vary substantially from one system to another. Usually in more advanced power system this volume is smaller than in traditional ones (Fraile, 2017).

In many day ahead markets renewable energy sources have dispatch priority against pollutant sources. Certificates of Origin are issued in some markets to guarantee the renewable origin of the traded energy.

![Day ahead and intraday sessions of the Iberian electricity market (MIBEL) (Andrade, Filipe, Reis, & Bessa, 2017)](image)

3.6.1.2 The intraday market
In intraday markets energy trading occurs in a timeframe smaller than a day. It complements the day ahead market. It enables energy agents to amend undesirable situations in the power system. There are usually various intraday market sessions and the energy traded in these markets is much smaller in volume than the one traded in the day ahead. In some power systems, you must participate in the day ahead market of the day at issue in order to be able to participate in the intraday market sessions, fostering the fact that the goal of this market is for energy agents to correct any possible error in forecasted load.

3.6.1.3 The European Power Exchange Spot Market
The EPEX Spot market is a cross-border intraday market in Europe. It is the largest intraday market in Europe along with the Nord Pool. In this market trading occurs in 15 minute intervals and deals must be closed 30 minutes before the electricity is dispatched. For this reason this market is sometimes referred as continuous market. In some countries, like Germany, this lead time (the time between the moment the deal is closed and the dispatch time) has been reduced to 5 minutes. This increased time granularity in energy markets benefits small decentralized generators as it creates more opportunities for them to provide electricity services.

In the EPEX Spot market the smallest tradable unit is 0.1 MW and the price of 1MWh can range from -9.999 to 9.999€. In this market, renewable sources and fossil fuels are treated the same and no certificates of origin are issued.

Understanding the ancillary services
The control of frequency and voltage in a power system is an integral part of operating the system. For keeping these parameters among adequate values, ancillary services are provided by different agents of the power system.

Ancillary services are needed in every power system regardless of its characteristics, context or regulation. However, depending on which power system these services might be provided in a different manner or might have different names, which can cause substantial confusion when trying to understand the way ancillary services are managed.
In order to achieve a full understanding of VPPs full potential, ancillary services’ technical and economic features are briefly described herein and how these characteristics vary depending on the power system (Rebours, Kirschen, Trotignon, & Rossignol, Ancillary services economic survey, 2007) (Rebours, Kirschen, Trotignon, & Rossignol, A Survey of Frequency and Voltage Control Ancillary Services, 2007).

3.6.2.1 Technical features
3.6.2.1.1 Frequency control

The frequency of a system is dependent on active power balance. A drop in power demand will be reflected in the system as a change in frequency, which may result in the malfunctioning of many frequency-sensitive loads such as induction motors or electric clocks. Therefore, it is important for power system stability to maintain load and generation in balance at every moment.

Any change in active power demand at one point of the system needs to be allocated to generators that are supplying power at that moment; this indispensable service is provided by a speed governor on each generation unit that automatically adjusts the speed of the generators rotor to the changes in demand. This local service is called in most power systems primary frequency control or FCR (Frequency Containment Reserve). Also, there are some ways in which demand can participate in this frequency control as the self-regulating effect of frequency-sensitive loads (such as induction motors) or the load-shedding schemes for severe under-frequency scenarios; however, only the supply-side contribution is taking into consideration when calculating primary frequency reserves.

Generators that automatically provide this service when responding to changes in loads are unable to maintain it for extended periods of time; therefore, it needs to be replaced by other kind of reserve before it runs out. Also, it needs to be distributed uniformly throughout the power system in order to avoid large power transits across the interconnected network.

Secondary frequency control or aFRR (automated Frequency Restoration Reserve) is the service that brings frequency back to target values after primary frequency control successfully contains the imbalance. This control is centralized (although it should be provided by generation units located within the area where the imbalance took place) and provided automatically; it shall be noted that even though most power systems have some kind of secondary frequency control, it is not an indispensable service as frequency can be controlled only by automated primary control and manual tertiary control.

Lastly, tertiary frequency control is a manual control designed to provide restoration to primary and secondary reserves; also, it helps manage network congestions and provides frequency restoration services when secondary reserve is unable to do so. (Rebours, Kirschen, Trotignon, & Rossignol, A Survey of Frequency and Voltage Control Ancillary Services, 2007)
As it can be seen in the table above, the nomenclature of frequency control services in different systems can lead to confusion. Nonetheless, differences go far beyond nomenclature; primary frequency control is divided into different categories of response in some power systems. These variations in implementation, that reflect the context-specific characteristics of each power system, could be a challenging fact for the business model scalability of aggregators.

When dealing with technical features, the most important is time. Three deployment times must be distinguish: the deployment start, which is the maximum time that can elapse from the request of the TSO and the start of the response of the service provider; the full availability, which is the maximum time that can pass from the supplier receiving the signal to the full delivery of the response; and the deployment end, which is the maximum amount of time the service must be provided. These features are common to all frequency reserves, but there are others that are specific of each reserve.

For primary frequency control, the most important technical features are: the accuracy of the frequency measurements, in order to provide just and accurate payment for provided services; the insensitivity of the controller for primary response (which can be intentional or non-intentional), that defines the minimum frequency change needed for a reserve to be called; the need for the droop to be adjustable.
Secondary frequency control can be divided into centralized, pluralistic or hierarchical, depending on if the control is performed by a single centralized agent, by various agents divided into control zones across the system or by a main controller that coordinates other agents.

### 3.6.2.1.2 Voltage control

Voltage needs to be kept within acceptable values in order to assure the safe operation of connected loads. This is not a simple task as the system is integrated with a large number of generating units and an even larger number of connected loads. For controlling voltage, reactive power is used; reactive power cannot be effectively transported through long distances, thus voltage control needs to be done on a distributed manner in most cases.

For controlling voltage, the production, absorption and flow of reactive power is controlled at all levels of the power system. It is a common practice to manage voltage control by a three level hierarchical system: primary voltage control, which is a local automatic that maintains voltage of a generation unit at a given set point; secondary voltage control, which is a centralized control.
of the reactive power injection done by local regulators; and tertiary voltage control, which is the manual management of reactive power injection. Agents providing services in all the three levels need to be able to both absorb and generate reactive power.

The ability of a given unit to control voltage is related to the reactive power that that unit can generate and absorb. Regarding deployment times, voltage control shall be done in a continuous manner in order to maintain voltage within the nominal values. Even tough accuracy in the measurement is not as important as in frequency control, it also should be taken into consideration. (Rebours, Kirschen, Trotignon, & Rossignol, A Survey of Frequency and Voltage Control Ancillary Services, 2007)

3.4.2.2 Economic features

As with technical features, economic features also vary depending on the power system. In most power system, the TSO is responsible of providing all the ancillary services. These ancillary services can be acquired by different methods: compulsory provision, bilateral contracts, tendering and spot market.

<table>
<thead>
<tr>
<th>Service Type</th>
<th>Compulsory provision</th>
<th>Bilateral contracts</th>
<th>Tendering process</th>
<th>Spot market</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary frequency control</td>
<td>ES, PJM</td>
<td>AU, FR, NZ</td>
<td>DE, GB, NZ, SE</td>
<td>AU, NZ</td>
</tr>
<tr>
<td>Secondary frequency control</td>
<td>-</td>
<td>FR</td>
<td>DE, NZ</td>
<td>AU, ES, PJM</td>
</tr>
<tr>
<td>Basic voltage control</td>
<td>AU, ES, DE, FR, GB, NZ, PJM, SE</td>
<td>FR, NZ</td>
<td>GB</td>
<td></td>
</tr>
<tr>
<td>Enhanced voltage control</td>
<td>-</td>
<td>FR, DE</td>
<td>AU, ES, GB</td>
<td></td>
</tr>
</tbody>
</table>

*Figure 17 Procurement methods used in various power systems (Rebours, Kirschen, Trotignon, & Rossignol, A Survey of Frequency and Voltage Control Ancillary Services, 2007)*

Compulsory provision means that an agent that is providing generation services to the grid, in order to be able to be connected to the grid, it needs to fulfill some requirements regarding the provision of ancillary services. Therefore, all agents are required to provide the same type of services within a power system.

TSO can purchase ancillary services via a bilateral contract. When doing this, the TSO agrees with an agent the provision of some ancillary services within a given period of time, which is usually long term due to the expenses and time dedicated to the negotiations of such contracts.

A tendering process means that the TSO invites agents to offer the provision of a given service and the agents with the best offer gets the contract. As oppose to bilateral contracts, in this case transparency is enhanced as the tendering process is open to numerous participants.

The creation of a spot market can also be the solution for the TSO acquiring the needed ancillary services. In this case, standardized and short term products would be exchanged.

Also, there are different remuneration methods for this services. These can be non-remunerated or paid via a regulated price, a pay as bid price or a common clearing price. When a non-remunerated system is used, it tends to be sub-optimal due to the fact that the costs are integrated into the price of other services and therefore paid regardless of being called or not.

On the same basis, a regulated price would probably be also sub-optimal as it does not reflect the actual cost of providing such service; in a pay as bid system, providers will pay the bided price which is adequate when the cost of providing such service is highly different from one agent to another. On a common clearing price, services would be paid at the price bided by the last accepted offer, the same way as in wholesale electricity markets in most systems.
In order to be able to note the differences between power systems in remuneration methods and economic features, the below tables are provided (Rebours, Kirschen, Trotignon, & Rossignol, Ancillary services economic survey, 2007).

![Figure 18 Remuneration structures and methods in various power systems (Rebours, Kirschen, Trotignon, & Rossignol, A Survey of Frequency and Voltage Control Ancillary Services, 2007)](image)

As it can be seen, there is no uniformity among different power systems. There are some services that in many cases are compulsory, as voltage control. There are others that is common to be traded using a spot market such as secondary frequency control. In some cases services are remunerated only when utilized and others are paid already by their availability.

In order to a business case to emerge for aggregators and VPPs, context-specific economic and technical features would need to be closely analyzed in order to assess its viability. Also, it shall be noted that the unification of some of these features would probably help the emergence of such businesses. (Rebours, Kirschen, Trotignon, & Rossignol, A Survey of Frequency and Voltage Control Ancillary Services, 2007) (Rebours, Kirschen, Trotignon, & Rossignol, Ancillary services economic survey, 2007)

### 2.7 Data security
Aggregation of demand side loads and VPP operation needs large volumes of data to be accessed and shared. This raises the need for adequate privacy and security protocols in order to guarantee appropriate data protection. The data needs to be protected at source, in transit and at rest. There is a broad agreement on the fact that data privacy regulation needs to be in place. However, it is not clearly defined which agents can have access to which data, and this scheme might differ from one system to another. From an aggregators’ point of view, having access to end-users in house consumption data, as well as behavior patterns are crucial for forecasting and scheduling algorithms to work. In this sense, aggregators need to ensure (and customers must trust) that the aggregator’s measurement, communications and control equipment are protected against cyber security threats. This is crucial for end-users to engage in market participation (European Commission, 2019).

Cyber security concerns and risks are varied and technological solutions to address them are also diverse and technically complex. Further evaluation of this matter is out of the scope of this work.

### 2.8 Barriers and challenges
Aggregation, DERs and demand side flexibility find challenges of different types when trying to access relevant energy markets.

Participation of demand side assets is strongly dependent on user acceptance and engagement. Therefore, customer centric technical solutions are needed that are simple in use and offer
proper return on investment for end-users. Standardization and interoperability are also key in order for energy managers to be able to incorporate various business cases at once. In addition, standardization entail that costs will go down when scaling up.

It is also important to raise customer awareness of available opportunities for their energy assets. In many cases, end-users are willing to participate in some kind of demand side market participation program but they are not aware of how to engage in those programs. There is a lack of information regarding what is technically and regulatory possible, what is on offer and what kinds of advantages customers can benefit from. When customers look for energy services and assets, the main concern usually is saving money or obtaining a proper return on the investments. The raising complexity that the new paradigm raises makes more difficult for customers to navigate among the various offerings available in the market.

One of the main drivers for aggregation and VPP success is the financial incentives that exists. There must be an adequate monetary incentive for end users in order for them to be willing to engage into a demand side aggregation platform or a VPP. For this to happen, the flexibility that these agents can provide needs to be appropriately valued by the market and for that to happen a power system with strong flexibility needs (and not many cheap flexibility providers) needs to be in place. Engaging in demand side response programs have a cost and a risk, especially for C&I customers. If the benefits are not big and clear enough, client engagement might hopelessly fail. Also, in some cases price signals for price-responsive demand response might not be clear or immediate enough to incentivize a change in behavior.

The different technical requirements, standards and prequalification methods in every power systems is a strong barrier against scalability, endangering the viability of the business case. There is also a lack of a clear framework for aggregators in many systems. Allocation of energy volumes and balance responsibility, the baselining methodology and remuneration methods are not always clear or transparent for aggregators and might not be treated the same than as for generators.

Also, when a customer is engaged with an independent aggregator to provide explicit demand response and with its supplier to provide implicit demand response, it might not be clear which part of the demand response realized is the effect of which agent.

Lastly, data access and data sharing are crucial for operation of demand side loads. Fair market competition needs to be enabled by level playing field in which data access and data sharing needs are equally ensured to all players (European Commission, 2019).

2.9 Energy resources that can be aggregated into a VPP

As it has been stated across this document, a VPP is a system that relies upon software and a smart grid to remotely and automatically dispatch retail DER services to a distribution or wholesale market via an aggregation and optimization platform (Navigant Research, 2017). DERs, which stand for Distributed Energy Resources are usually defined as those assets located at the distribution level that can provide electricity services either via direct generation or via consumption shifting or adjusting. However, there is not a single and widespread definition for which assets are considered as DERs and which ones fall out of its scope. In this work, any device or asset that can be aggregated and could potentially have an impact on the grid will be considered. In the following lines a brief definition of each of the assets considered is made. It is not the goal of this section to evaluate the potential implementation, profitability and impact
of each of the technologies mentioned below, but just to illustrate and provide a brief insight on each of them to better understand the management of a VPP.

**Solar PV**

Solar photovoltaics (PV), which is the conversion of sunlight into usable energy forms, is bound to lead the expansion of renewable power capacity in the following decades, accounting for 60% of the expected growth (IEA, 2020).

![Renewable capacity growth between 2019 and 2024 by technology (IEA, 2020)](image1)

In 2018, solar accounted for 3.0% of the generation mix in the OCDE, showing the highest relative increase out of all electricity sources, increasing from 274.0 TWh to 325.8 TWh (+18.9%). This growth was led by the US (+25.2%), Japan (+21.8%) and Germany (+17.4%) (IEA, 2018). In some cases, like Spain (REE, 2017) (REE, 2018) and Italy (Bianco, 2018), solar generation decreased due to lower solar irradiation despite capacity additions.

According to the IEA, in 2050 up to 16% of total electricity generation could be provided by Solar PV:

![Solar PV estimated growth by region, (IEA, 2014)](image2)

Regarding rooftop solar PV, with the rapid growth in deployment, module prices have declined by 80-85% between 2009 and 2016. Utility-scale solar PV projects have seen a drop in LCOE in this same period of 65% (IRENA, 2017). Due to this cost reduction, residential consumers have
cost-competitive options to satisfy their energy needs by reducing their energy bills and selling the excess output in the energy market through a VPP.

However, PV generation in residential systems is, on average, about 70% more costly than utility-scale PV plants (MITei, 2015) and residential users may need estate subsidies to reduce rooftop solar installation costs.

Also, when distributed PV grows to account for a significant share of overall generation, its net effect is to increase distribution costs (and thus local rates). This is because new investments are required to maintain power quality when power also flows from customers back to the network, which current networks were not designed to handle (MITei, 2015).

An example of complexities introduced in the grid management when a high penetration of solar PV occurs is the ‘duck curve’. The ‘duck curve’ was named by the California ISO (CAISO) after the shape of the net load graph due to PV penetration. Usually peak demand takes place after sunset, when solar power is no longer available. Thus, the power system needs to transition from a situation of high solar generation and low demand to a no solar generation and high demand in just a few hours. Therefore the system operator needs a resource mix that can react quickly to adjust electricity production to meet the sharp changes in electricity net demand. The need for ramping flexibility can be quite demanding in some cases (CAISO, 2016).

![Figure 1](image1.png)

*Figure 21 “Duck curve” caused by high penetration of solar PV in California (CAISO, 2016)*

Also, the expected increase in solar PV deployment will need to be evaluated against the availability of the needed raw materials. Scarcity of such could lead to high costs and redefined expectations. Regarding solar PV, some elements needed for its manufacturing like tellurium or gallium are simply not very abundant anywhere in the Earth’s crust. The supply risk of this materials is to be taken into consideration when planning for future energy scenarios (European Commission, 2014).
Micro wind turbines

As opposed to large wind turbines in wind farms, micro wind turbines are small wind turbines used for small scale generation of electric power. Usually ‘small wind’ turbines range from 1kW to 300kW (Canadian Wind Energy Association, 2013). Small wind turbines are appropriate for rural and suburban areas, where there is no limitation on tall structures and there is enough space and wind available. They are mostly used to provide electrification in remote areas, pump water or charge batteries (American Wind Energy Association, 2010).

By 2017 there was a cumulative of almost 1 million small wind turbines installed around the world (WWEA, 2017). Small wind can contribute to the power supply, especially in combination with solar and storage. However, not substantial investments are being made and the growth is facing a downwards trend in the recent years. The failure to scale down wind energy or the bad wind conditions that can be found close to the ground are among the reasons of the scare success of this technology.

Demand Response

Demand side management, which includes everything that is done in the demand-side, is considered an integral part of the smart grids. Demand Response (DR) consists on end-users changing their normal energy-consumption habits encouraged by changes in electricity price changes over time. By doing this, the demand profile can be smoothened, reducing peak-load consumption and increasing off-peak consumption, which can lead to end-users’ savings due to reduced prices in electricity and reduced VRE curtailment due to consumption when VRE generation is higher (Siano, 2014).

Domestic consumers’ responsiveness would need to be automated, which means that AI, machine learning, IoT and other digitalization technologies need to be mature in order to
maximize the benefits and encourage end-users to utilize this service by making it less hindering. An aggregator could remotely control the operations and energy consumption of certain domestic appliances such as lighting, thermal comfort equipment, pumps, refrigerators and other. Those who hire an aggregator company to manage their load could decide which appliances or loads can be switched and which ones shall fall off the aggregators’ control.

When customers participate in DR, their usage of electricity can be changed in different ways:

- Shifting energy consumption from peak hours to off-peak hours.
- Reducing consumption by load curtailment (i.e. lighting dimming, decreasing heating set-points, etc.)
- Using onsite stored energy, limiting their dependence on the main grid

Also, augmenting the time granularity in electricity retail and wholesale markets would make demand response a more attractive business model for aggregators, as flexibility provided is fast-response and revenues depend on the price of electricity over time (Siano, 2014) (Conejo, Morales, & Baringo, 2010).

Customers that use DR services can range from large commercial and industrial users to residential users, but also considering both individual EV users and fleets of EV which may play an important role in DR when electrification of mobility is in an advanced state. Each of them would need tailored controlling devices for managing their loads and would need different algorithms to automate their response according to the assets they provide to the grid.

Regarding DR, distribution system operators will have to assume an active role in the management of power in the distribution grid, to support load shifting and a secure DR operation avoiding grid congestion (Albadi & El-Saadany, 2018).

End-users might be encouraged to use DR programs not only because of monetary savings, but also due to the aspiration to help provide flexibility to the grid and therefore allow VRE integration as a sign of responsibility with the environment. Also, there are some concerns that could discourage the use of DR, like the uncertainty of price response programs or the willingness to maintain the usage of some appliances during a DR event. Flexible and smart DR programs are needed to avoid these concerns (Siano, 2014).

Demand response, despite being a ‘hot topic’ in the context of energy transition and flexibility, is not something new. TSOs sometimes utilize demand response with industrial consumers to balance load and generation (REE, 2020) or even with residential loads (Transpower, 2020). However, the use of demand response has been short and in some cases controversial (Lucera, 2020). The new focus for demand response aims for a more widespread use to provide a real service to the grid. Currently mostly industrial loads are taking part in demand response; nevertheless, there is a huge potential in residential demand response due to its aggregated capacity and scalability.
Despite its potential, DR is a minor player in most ancillary services markets. Advancements in technology through research and development efforts and increased market adoption can jointly help bring down the cost of automation and control technologies and communication infrastructure, making participation more cost effective. Also, the increasing availability of smart metering data may help improve load modeling, thus enabling small residential loads to enter the bid (Ma, y otros, 2013). In any case, demand response will be a major participant in the provision of flexibility in scenarios with a high penetration of VRE.

Distributed (stationary) battery storage
One of the most straightforward ways of energy storage is battery storage. Although battery storage has been around for years, the drop in costs in the last decades and the improved performance (and the increased need for system flexibility) have driven this technology to the center stage.

Battery storage can be deployed fast, is flexible, has many applications, it is highly scalable and can produce numerous value streams. In the last decade, the costs of li-ion batteries have gone down by almost 90% and are expected to keep going down (Deloitte, 2017).

Nowadays, the vast majority of lithium-ion consumption is dedicated to consumer electronics, with a substantial and growing share for electric vehicles. The share of energy storage systems is almost non-existing (Sun, Hao, Zhao, & Liu, 2017).

Batteries can provide electricity services from both behind-the-meter and in-front-of-the-meter. Front-of-the-meter batteries or utility scale batteries, that can range from a few MWh to
hundreds of MWh (IRENA, 2019) are not further considered, as despite being a source of flexibility are not usually within the scope of a VPP because there are not in the distribution level. Behind-the-meter (BTM) batteries can help consumers decrease their electricity bills. Aggregated BTM batteries can also provide support for system operator while deferring network and peak capacity investment (IRENA, 2019).

BTM batteries are installed at the residential level and can storage energy that is either generated onsite via distributed generation or is drawn from the grid when electricity prices are low and is used when prices are high. In many cases, residential solar PV systems are being installed with BTM batteries to enhance its performance (IRENA, 2019).

From an aggregator’s perspective, BTM batteries are a really attractive assets. The aggregation of a large number of residential batteries can unlock a large amount of the so needed flexibility. However, further research needs to be done regarding battery management systems to enhance batteries life that could substantially decrease due to numerous life cycles when integrated into a VPP.

Also, attention must be paid to the fact that in most energy transition scenarios a high penetration of electric vehicle is taken into consideration. Some scenarios aim to more than a 30% share of electric vehicles (KPMG, 2019). In this scenario, the need for Lithium and other raw materials will increase exponentially thus reshaping the residential battery market and forecasts. Second life batteries or recycling batteries to get back raw materials might emerge in this context to mitigate this issue. Recently, Volkswagen packed 50 used EV batteries to power a bus station in Hamburg; they are also considering battery swapping as they have some electric buses under its heavy vehicle division MAN (Electrive, 2018). On the other hand, Tesla believes that it is better to recycle EV batteries (Electrive, 2019).
Also alternatives to lithium-ion batteries such as flow or lead batteries may emerge as competitive options.

Apart from the mentioned benefits BTM batteries owners can benefit from, this assets can also provide services to system operators. Aggregated BTM batteries can be used for frequency regulation services, by being allowed to rapidly ramp up or down its output. Regulation needs to be adapted to allow this assets to participate in such markets, as it is already being done in some systems (CAISO, 2019) (Eneco, 2016; 2018).

BTM batteries can also have a positive impact in the power system by deferring network investment. As energy demand grows, networks need to be adapted to peak demands and a slight increase in energy demand may result in a substantial upgrade in the network. BTM battery adoption can help shift consumption and smooth the demand curve, thus decreasing the need for grid reinforcements (IRENA, 2019).

Also besides the technological development and upfront costs reduction needed for the widespread adoption of BTM batteries, the regulatory framework needs to be adapted to allow time-of-use tariffs and therefore justify the business case for BTM batteries.

Electric vehicles (V2G)

One of the most transformational shifts in the energy transition is taking place in the mobility sector. Electric Vehicles are obviously the most relevant disruptive force driving such change, but also connected and autonomous vehicles and on-demand mobility services are key trends that will redefine the mobility industry in the coming decades.

In 2018 there were more than 3 million EVs worldwide (IEA, 2018). Although this is only 1% share of the total number of cars, the growth rate of EVs, the forecast of EV penetration for the next decades, the falling costs (Deloitte, 2017) and improved performance in lithium-ion batteries and the bans and penalization for internal combustion engine vehicles (MITECO, Gobierno de España, 2020) (CNET, 2019) (Reuters, 2019) (CNET, 2019) (Autoblog, 2019) (Independent, 2017) (The Guardian, 2018) (Wiredbugs, 2019) (BBC, 2017) are driving electrification of vehicles to the center of the energy transition agenda.
EVs are being adopted by consumers mainly because of three key motivations: (1) to reduce carbon footprint, as people are getting more environmentally conscious, (2) to benefit from aids afforded by governments to EV users and (3) to save costs, as even tough EVs are nowadays significantly more expensive than internal combustion engines, in some specific cases with the help of government subsidies EV can be cheaper the fossil fuel cars (McKinsey, 2014).

When talking about EVs, we can distinguish between plug-in EV and non-plug-in EV. Non-plug-in vehicles are hybrid vehicles that charge the battery with the output of the internal combustion engine. From an aggregation perspective, the only interesting ones are the plug-in ones. Also, according to some studies (ANFAC, 2017) the forecast for the new car production in the decades is to come is for non-plug-in to decrease and being substituted by battery EVs and hybrid plug-in EVs.

![Vehicle sales prevision (in million units) per fuel type, (IEA 2018)](image)

Figure 27 Vehicle sales prevision (in million units) per fuel type, (IEA 2018)

Regarding the provision of electricity services and VPP integration, along with the forecasts of massive electrification of mobility it also emerges the idea of a new business model: vehicle-to-
grid (V2G). Before defining V2G, it is necessary to talk about smart charging. (It is not intended to deeply define smart charging and V2G and all of its variations, as it exceeds the scope of this work. Instead, these will be briefly defined herein to better understand its potential integration in a VPP)

Smart charging consists on the vehicle-grid integration for a correct management of EV loads. If charged smartly, EVs cannot only avoid adding stress to the grid but also provide services to fill flexibility gaps at different levels by operating as grid-connected storage units and alternating their charging patterns to flatten peak demand. In short, smart charging is needed to allow a massive integration of EVs without the need to oversize the power system (IRENA, 2019).

V2G takes smart charging one step beyond; it consists on using connected EV to provide grid services. When the potential provision of grid services is taken into consideration, it is estimated that smart charging only captures 40% of the value of V2G. For enabling the provision of electricity services, V2G chargers that allow the bidirectional flow of energy and information are needed. Then, aggregated V2G units can provide services by load shifting, energy exporting or a combination of both, and participate in the energy markets or ancillary services market (CENEX, 2019).

![Figure 28 Aggregation of V2G units to trade electricity to energy markets via a VPP, (CENEX, 2019)](image)

Also, the electrification of mobility could have an impact on the adoption of residential batteries as EV’s second life batteries can be used for residential purposes, as it is being demonstrated in ongoing projects in Germany (Electrive, 2018) or the US (CleanTechnica, 2020).

However, there are still challenges that need to be overcome in the EV industry, like the need for a solid charging infrastructure (Jochem, Szimba, & Reuter-Oppermann, 2019), the standardization of charging plugs and communication protocols or the potential scarcity of raw materials when mass adoption of EVs takes place (Llamas, 2020). Also, innovation like the wireless charge of EVs might make way for new business opportunities in the future (Carmagazine, 2020).

All in all, EVs and their interaction with the grid will be a major concern for the power system in the coming decades.
Microgrids
A microgrid is an electricity network based on digital technology that is used to supply electricity to consumers via two-way digital communication. It includes a variety of Hardware technology enabling a dynamic operation and energy measures including DC connections to avoid thermal losses as well as Power Electronics for an automated control and grid-to-microgrid coupling.

Microgrids and VPP have in common the aggregation and optimization of DERs. They differ in that a microgrid has a confined network boundary and can disconnect from the larger grid to create power islands. VPPs, on the other hand, can stretch over a much larger geography and can grow or shrink depending upon real-time market conditions (Guidehouse Insights, 2017). In short, a microgrid is small scale and focused in optimization of self-consumption whereas a VPP is large scale and focused in providing services to the grid through the markets. Thus a microgrid can be a VPP portfolio asset.

Figure 29 Microgrid and VPP approaches to DER management, (Horta, 2017)

Distributed gas/diesel generators
Distributed natural gas generation is not new to the market. Combined Heat and Power (CHP) has been out there for years and it is a reliable source of energy, accounting for 11.4% of generated power in 2019 in Spain (REE, 2020). CHP, although being distributed gas generation, will be treated separately. The success in scaling down gas generation and the emergence of new technologies such as fuel cells, micro turbines and microgrids are driving attention to distributed gas (Grand View Research, 2020). Diesel generator sets have long been the face of distributed generation. However, as a result of various factors, including increasingly stringent environmental regulations and cheap natural gas, the market is opening to other technologies (PowerMag, 2020).

Natural gas, even though it is a pollutant energy source, it has a substantially reduced carbon footprint when compared to gas or fuel generation and it can provide locational flexible and fast-ramping energy dispatch. The reliability of this energy resource makes it really attractive for
a VPP integration, especially in scenarios with a high penetration of VRE sources (as explained before, the ramping requirements in systems with a high penetration of solar) with the drawback of not being a clean resource.

![Figure 30 Potential renewable energy curtailment scenario, (Union of Concerned Scientists, 2018)](image)

There are several key factors for distributed natural gas to become a major trend in the near future: (1) the existence of inexpensive and abundant natural gas, following the inertia of the unconventional gas revolution in North America, (2) the growth of intermittent renewables, that will continue to drive demand for increased levels of flexible generation, (3) software developments in IoT and control to enable integration of DERs in the grid and (4) the localization of electricity supply sometimes referred as the increased spatial granularity.

**Fuel cells**

Hydrogen has the potential to become a substantial source of power and heat for homes and industries. Stationary fuel cells are emerging as a viable alternative to combustion engines for the production of electrical power and the co-generation of heat as part of micro combined heat and power systems (European Commission, 2015).

The present applications of hydrogen are mainly industrial ones (oil refining, ammonia production, methanol production). However, opportunities are emerging for hydrogen use in transport, buildings and power. For heating, the blending of hydrogen and natural gas could be a solution for carbon footprint reduction in buildings in dense cities where conversion to heat pumps is not practical. In the longer term, hydrogen boilers or fuel cells could be used for heating purposes, but this is mainly dependent on infrastructure upgrades and measures to address the hydrogen related safety concerns (IEA, 2019).

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<tr>
<th>Strategy</th>
<th>Advantages</th>
<th>Requirements</th>
<th>Examples</th>
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<tbody>
<tr>
<td>Blending</td>
<td>Low-cost</td>
<td>5-20% blending ratio</td>
<td>GRHYD, France</td>
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<td></td>
<td>Compatible with existing gas infrastructure</td>
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<td>HyDeploy, UK</td>
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<tr>
<td>Methane produced from clean hydrogen</td>
<td>Full decarbonisation of gas if low-carbon hydrogen and low-carbon CO₂ inputs.</td>
<td>Investment in methanation plants</td>
<td>STORE&amp;GO, EU</td>
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<tr>
<td></td>
<td>Compatible with existing gas infrastructure</td>
<td>R&amp;D to improve efficiency</td>
<td>Carbon source</td>
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In brief, whether it is via fuel cell or as hydrogen boilers, or by hydrogen-methane blend firing, this power source at the distribution level could be taken into consideration for VPP aggregation.

Also if adoption of hydrogen gains boundless traction, the widespread implementation of large electrolysers to produce green hydrogen can be a significant load for demand response programs.

**Small scale hydro generation**

Hydropower plants range in size from some kilowatts to a few gigawatts. Thus, they can be differentiated into large (more than 30MW), small (less than 10MW) and micro (up to 100kW). Small-scale hydropower has been used as a common way of generating electricity in isolated regions since the end of the XIX century. It’s negligible environmental impact, low upfront costs and versatility makes it a promising option for producing sustainable, inexpensive energy in rural or developing areas (SSWM, 2012). As small scale hydro means no need for dams and not interfering in the river’s flow, it is considered as a more environmentally-friendly option.

Small scale hydro has some drawbacks, like the lack of the capacity to store energy (as opposed to large-scale dam hydropower) or the unpredictable nature of river flow. A variety of small hydropower projects could be placed throughout the grid. The development of new technologies that enable cost-effective integration of small-scale modular power generation into existing water infrastructure (such as conduits and pipelines) may open up new opportunities for hydropower. Thus, small hydropower has the potential to increase the deployment of distributed energy resources (US Department Of Energy, 2016) and therefore it might be taken into consideration when designing a VPP portfolio.

Also, studies have been conducted to evaluate the feasibility of small-scale modular pumped storage hydropower, concluding that it could be viable to carry out these projects, although further research is needed (Witt, Hadjerioua, Uria-Martinez, & Bishop, 2015).

**Energy communities**

Energy communities, even though it is not strictly a resource, it can unlock a major source of flexibility in the power system and could potentially enlarge the available assets for a VPP. Energy communities is a business model that arises where collective ownership and management of energy assets is preferred over individual ownership. These schemes encourage distributed generation deployment and energy usage from sustainable, local renewable sources. There are currently more than 4000 community ownership projects globally (IRENA, 2019).

**Combined Heat and Power (CHP)**

Combined Heat and Power (CHP) or Cogeneration consist on generating electric power and useful thermal energy at the same time and place. Instead of buying electricity and converting it into heat, CHP does both in an efficient single step. CHP units tend to be installed along with...
certain heat-intensive industries, like refineries and chemical plants, to meet its heat demand (EIA, 2012).

CHP is distributed by definition as it is installed in conjunction with certain industries and they are usually medium to low in scale (7MW average in Spain (ESIOS, 2020); in the US 50MW average and 7MW median (U.S. Department of Energy, 2020)) when compared to conventional CCGT. Therefore, it can add a substantial amount of capacity to the VPP as it is suitable for aggregation. CHP generators are usually flexible as they can rapidly ramp up and down. Also, as they are installed within energy intensive industries, there might arise an interesting synergy between industrial demand response and CHP units.

Despite being a pollutant source of energy, it is a more efficient option than coal, fuel or even conventional CCGT plants as they have a higher efficiency due to the use of the thermal energy (European Commission, 2011). Also, micro-CHPs can be used to reduce imbalances of small decentralized VRE installations when integrated into a VPP some studies show (Zapata, J.Vandewalle, & W.D'haeseleer, 2014). Other studies evaluate the potential benefits from the integration of Combined Heat and Power and District Heating into a VPP (Zapata, Bruninx, Poncelet, & D’haeseleer, 2015).

Figure 32 CHP, waste and bio-power generation in Spain (ESIOS, 2020)

Energy Management System (Home, Building, Commercial, etc.)

An Energy Management System (EMS) is a device that monitors, controls, optimizes or analyzes the energy consumption for residential, commercial and industrial users. EMS has gained attention in the last years, especially in the residential sector, where it is seen by relevant stakeholders as a component of the connected smart home. For many hardware and software developers smart home devices are a natural progression of their businesses. Regarding energy management in the home context, smart thermostats, controllable lighting and water heaters represent the most attractive loads. In the commercial and industrial segment, EMS solutions are not as scalable as in the residential sector and a more tailored and context-specific approach needs to be made.
In a first approach, EMS solutions can provide users ‘passive’ services, mainly consisting in monitoring and reporting services to aid users in energy related decision making. In a more advanced approach, with AI, machine learning and IoT developments, automation and optimization of consumption can be achieved. Lastly, when EMS are aggregated and integrated into a VPP users can not only benefit from energy efficiency cost savings but also experience interesting monetary incomes when providing services to the power system through the mentioned VPP.

The most relevant part of an EMS is the intelligence of the algorithms and the data analytics capabilities. EMS needs to access both internal information (load, generation, battery state of discharge, consumption forecast) and external information (market price signals, weather forecast and labor calendar) in order to effectively optimize energy consumption.

A strong dependence between EMS and VPP is identified in order to unlock the full potential of both business models. Integration of EMS and VPP into the same core platform could arise as a relevant business opportunity for relevant players.
Controllable loads / Smart loads

Controllable loads are those loads whose consumption can be adjusted or controlled in order to react to price signals or users' preferences. Load management can generate benefits at both sides of the meter: behind the meter by reducing energy bills due to energy savings as a result of adjusting consumption when time-of-use tariffs are in place; and in front of the meter by smoothening the load curve as a result of users switching their consumption from peak hours to off-peak hours.

Regarding its aggregation and integration into a VPP, there is a large potential especially in the residential sector. However, it is under the scope of an EMS where it mostly makes sense. Thus, an EMS is composed of various smart loads that are ‘aggregated’ within each home and then various EMS are aggregated in conjunction with other DERS to form a VPP.

Biogas MGT

Biogas micro-gas turbines (MGT) can be a valuable distributed resource. Feedstock for biogas production is widely varied. This organic waste that is used for anaerobic digestion for biogas production is located in a decentralized manner. For this reason, biogas MGT do not make sense for grid scale generation in many cases; rather, they find interesting business case for energy generation onsite in different agriculture and industrial facilities. For this reason, if adequate incentives are in place, MGT can emerge as interesting decentralized energy assets. Also, this turbines operation is equal to the ones that operate with natural gas. Biogas, as it has much more CO₂ in its composition than fossil natural gas, has lower heating value and the output of the turbine is not the same. However, a lower energy output is no inconvenient for aggregation and market participation and this assets can be especially relevant as they still have the flexible characteristics of conventional gas turbines (Lopez, 2020).

Power-to-X

Power-to-X installations can also enroll into VPP. Power-to-X means that generated electric power is transformed into other types of energy (heat, hydrogen). In the case of hydrogen, electrolyzers are attached to renewable generators and generate clean hydrogen when there is excess generation in the system. Even though the business case for green hydrogen is not yet clear, a few examples of these types of installations can be found in Europe (See Next Kraftwerke use case in corresponding Section). As electrolyzers are a large load, can effectively be used for demand response while the Power-to-Hydrogen installation can benefit from the forecasts provided by the VPP. Power-to-heat can also benefit from VPP participation by storing energy as heat when there is excess generation; for example, Centrica, the UK utility, utilizes decentralized hot water tanks to store excess energy while providing frequency regulation to the TSO (Centrica, 2019).
2.10 DERs capability to provide electricity services

As it has been stated before the ancillary services differ from one power system to another. Sometimes the difference is merely in the name, but in most cases deployment times or service characteristics are different from one system to another. In this subsection a brief evaluation of the capabilities of each DER within a VPP to provide electricity services is done, in order to identify different VPP designs depending on which services plans to provide.

The different resources have been evaluated and classified into three levels of suitability for providing each considered service. Attention shall be paid to the fact that each of the considered resources may be in a different stage of development; CHP, for example, is a consolidated resource that accounts for more than 10% of the energy demand in Spain (REE, 2020); fuel cells are in an early development and it is not clear the performance and market penetration it will have in the future; micro wind turbines is a developed technology that seems to have been dismissed by the market. All these factors have not been taken into consideration in the analysis, as the focus is to understand the technical potential of each to provide electricity services when aggregated into a VPP; whether if this resources end up having a relevant role in the energy industry in the future is subject for a more wider analysis and falls out of the scope of the present work.

The energy communities have not taken into consideration as collective owned energy assets can be of any types, ranging from batteries to wind turbines or solar farms. Regarding the services considered, even though they may vary substantially among different power systems, the main characteristics of each have been taken into account to elaborate the following graph. There might be other characteristics either in the services or in the resources that could possibly change in the coming years; thus this analysis shall only be seen as merely indicative.

In short, for a DER to be suitable for wholesale market participation it needs to be schedulable and it needs to generate energy (energy consuming assets are excluded). Also, it does not make sense for an energy consuming asset to be bided as a load in the day ahead market and then participate in the intraday market because that would be redundant. For these reasons, only CHP are appropriate for wholesale market participation (in fact, they do participate nowadays in some power systems). All assets including flexible energy storage (any kind of battery) and small scale generating assets can also participate, but it is more complex and also it makes more sense for those assets to be involved in self consumption schemes, so the portion of the energy
they could trade would be smaller and subject to end-user consumption pattern and variable behavior.

Regarding reserves, primary reserves are for fast acting assets that can function in an automated way. Batteries, demand response and CHP (with automated actuator on the generator’s rotating shaft) emerge as the more attractive options. Secondary and tertiary reserves open for more participants, as the constraints to be allowed to participate are lighter. Secondary reserve stands as the most attractive market, as in many power systems agents are paid only for staying available even if the load reduction is not called.

Voltage control needs energy assets that can inject reactive power into a specific node of the grid. Congestion management is especially interesting for batteries, as they can act as Virtual Power Lines and reduce grid congestion (IRENA, 2019).
Figure 36 DERs suitability to provide electricity services, own elaboration

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<th>Day-ahead</th>
<th>Intraday</th>
<th>Primary reserve</th>
<th>Secondary reserve</th>
<th>Tertiary reserve</th>
<th>Voltage control</th>
<th>Congestion management</th>
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<td>Small hydro</td>
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<td>CHP</td>
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<td>EMS &amp; Smart loads</td>
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3 Virtual power plants
The energy landscape is rapidly changing to a scenario in which distributed energy resources are increasingly relevant. Those DERs might interact differently with the grid: they can consume, store or generate electricity. The innovation efforts in the last decade have led to development of the needed software tools to enable control, optimization, aggregation, forecasting and dispatch of diverse decentralized energy assets.

Just recently, Virtual Power Plants are moving away from theory and put into practice in many countries. Real projects are taking place and the VPP envelop is being pushed. The VPP concept brings up added value in many steps of the energy value chain and aims to change some crucial aspects of the energy scenario: shifting to a more collaborative relationship between asset owners and grid operators and enhancing value for asset owners. VPPs are needed in order to avoid chaos in a grid with large numbers of decentralized assets and promote the greater good for the power system. The place VPPs will hold in the market in the coming years is uncertain; many companies are innovating and developing disruptive solutions to create win-win scenarios and increasing DERs relevance for the grid. Virtual Power Plants aim to align the DERs managing benefits with economic interests and environmental concerns, while creating value for a broadening pool of stakeholders.

3.1 What is a Virtual Power Plant?
Defining the concept of Virtual Power Plant is somehow difficult as there are many different definitions and nuances. Some of the different available definitions are provided herein.

According to Navigant Research, a Virtual Power Plant is defined as

“...A system that relies upon software and a smart grid to remotely and automatically dispatch retail DER services to a distribution or wholesale market via an aggregation and optimization platform” (Navigant Research, 2020).

As for Next Kraftweke, one of the pioneering VPP operators and owner of the largest VPP in Europe, a Virtual Power Plant is defined as:

“A network of decentralized, medium-scale power generating units such as wind farms, solar parks, and Combined Heat and Power units, as well as flexible power consumers and storage systems. The interconnected units are dispatched through the central control room of the Virtual Power Plant but nonetheless remain independent in their operation and ownership” (Next Kraftwerke, 2020).

It shall be noted that Next Kraftwerke’s definition relies heavily in generating units while less importance is given to consumption and storage assets. The reason for this is that Next Kraftwerke is a German VPP operator that started running its VPP in 2009. As it will be seen in section 5, the most feasible way of VPP, both technically and economically, is the one that aggregates decentralized generators (CHP, biogas, back-up generators, etc.) and renewable mid and large-scale generation units (wind, solar, hydro, etc.). Including demand-side flexible consumption assets and energy storage systems is today still disruptive and avant-garde; however, it is the current trend for born-today VPPs.

IRENA defines a Virtual Power Plant as
“...basically a system that relies on software and a smart grid to remotely and automatically dispatch and optimize distributed energy resources. In orchestrating distributed generation, solar PV, storage systems, controllable and flexible loads and other distributed energy resources, VPPs can provide fast-ramping ancillary services, replacing fossil fuel-based reserves” (IRENA, 2019).

This definition is more complete and state-of-the-art than the others and introduces the concept of VPPs being thought to replace fossil fuel reserves in the ancillary services. This is an important concept, as generation-based VPPs can participate in roughly any available energy market as they behave no differently than standalone generation units. However, mixed asset VPPs or even state-of-the-art consumption asset based VPPs have limited market access, both from a regulatory and a technical point of view.

After extensive desk research, market evaluation and benchmarking more than a hundred VPP solutions; and for the purpose of this work, a Virtual Power plant will be defined as follows:

A Virtual Power Plant is a system-of-systems comprising distributed energy resources of different kinds that are managed in a coordinated manner by an operator that might (or might not) use installed hardware gateways to control the energy assets and leverages in an aggregation platform based on advanced market modeling algorithms and intelligent predictive models to optimally dispatch and trade in different energy markets the aggregated capacity.

For further definition of the different VPP business models refer to the corresponding section. The need for hardware gateways to control the distributed energy resources is subject to controversy. While the ideal VPP is hardware-agnostic and the devices to enable remote control and dispatch are integrated into each asset, most VPPs today need the installation of some sort of proprietary hardware device to enable central control of the asset through the VPP’s central control room. Many VPP platform developers establish partnerships with OEMs and technology providers for their manufactured assets to be compatible with their VPP platforms.

Also, depending on the available resources, specific regulatory context and market design the aggregated capacity of the VPP will participate in one or other market. As a rule of thumb, less disruptive generation-based VPPs will participate in wholesale markets while state-of-the-art VPP will participate in ancillary services and local flexibility markets.

From the definition above, it can be extracted that the VPP value chain is comprised of (i) Distributed Energy Resources or more broadly just assets; (ii) hardware gateways that might or might not be needed, but for most cases with the technology available they must be in place in order to enable control of each DER, (iii) software platform that manages the control and optimally dispatches the capacity in the target markets, (iv) the aggregator, which is the operator of the VPP and (v) the market agent, which is the one that bids and trades the energy in the markets; in some markets, depending on the regulatory requirements, the aggregator and the market agent might be the same agent. However, this is not the case today in other markets and aggregators cannot participate directly in the markets and need to sell the energy to a utility or market agent.

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Figure 37 The VPP value chain, own elaboration
3.2 The VPP value chain

The assets

Distributed energy resources are the foundations of a VPP. As explained in section 3, these can be from various types and as it will be further explained in section 5, they define the type of VPP as this can be supply-side, demand-response or mixed asset. The most commonly used assets for operative VPPs today are CHP plants, industrial back-up generators, bio-gas and other types of distributed generators; mid and large scale renewable energy resources and commercial & industrial (C&I) demand response. As innovation and technological development keep moving along, other assets will gradually be more commonly included into the VPPs portfolios, like rooftop solar PV, flexible thermal loads and energy storage systems.

It shall be noted that the volume of installed DERs is increasing at a rapid rate. Different estimations project that before the end of this decade, the new additions of DERs will largely outpace the new additions of centralized power plants (Navigant Research, 2020).
The hardware gateway

Hardware gateways are installed in each asset in order for it to become controllable. There are different types of hardware architectures and communication protocols that are used for this purpose. It is a common thing for companies running VPPs to design and produce their own hardware gateway and install it at no cost at each customer’s premises. For industrial demand response, gateways might interact with legacy SCADAs. For residential demand-side management a clear example of hardware gateway is a smart thermostat that controls the output of the HVAC and can be remotely controlled through the internet. Energy Management Systems, which actively or passively control the energy consumption of a household or a building can also be considered as control gateways.

The ideal VPP and the current trend lead to hardware agnostic VPP. Hardware agnostic means that the system does not rely on specific hardware to be installed in order for the system to work. With ongoing and projected technological disruption, mainly regarding Internet-of-Things and 5G related technology, a hardware agnostic VPP can be implemented as assets can be controlled through the internet or telecom networks leveraging in installed connectivity capabilities. This type of VPP shows a clear competitive advantage against hardware-based VPPs as scalability is clearly enhanced if there is no need for any hardware installation. However, this type of connectivity brings up data security concerns that will also need to be addressed.

The aggregation platform

In order to optimally manage a large portfolio of distributed energy resources a software aggregation platform is needed. These platforms serve utilities, electricity retailers, renewable energy project developers and energy service providers to deliver reliable energy in a system with distributed energy resources. For doing so, innovative technologies such as Big Data, Artificial Intelligence and Machine Learning, Internet-of-things and advanced market modeling and predictive algorithms are needed.

These software platforms are independently developed by software companies and have different architectures and characteristics. It is a common thing for them to be modular, as this enables better scalability and integration into third party’s systems. For examples, a modular aggregation platform can have different modules for demand response, energy storage management, distributed energy resource management, market trading or virtual power plant services.

These platforms are usually commercialized as white-label products for energy related companies to use within its portfolio of energy assets. A subscription fee or a fraction of the income generated by using the platform is usually billed. More insights about the business model related to the development and commercialization of aggregation platform are given in section 5.

As these platforms are created independently and do not follow any standard, it is hard for them to be classified. The market is currently lead by a few market leaders that operate in different geographies; there are also small emerging start-ups developing platforms and piloting or operating locally. The country-specific market and regulatory know how is key and often holds back small companies from international expansion.
Among the different software platforms, we can differentiate DERMS, VPPs and other services. A VPP platform integrates and optimizes the dispatch of technologies such as demand response, solar PV systems, batteries, back-up generators, HVAC systems, EV charging stations and conventional CHP and other generators. These assets are bundled and deliver services to the grid in an aggregated manner. One key aspect of VPP platforms is that they are able to control heterogeneous distributed energy resources to make them provide services as if they were a conventional and dispatchable centralized power plant. This advanced software systems help DER portfolio managers to mimic the services provided by a conventional fossil or nuclear power plant but with a smaller carbon footprint by leveraging in artificial intelligence based algorithms.

VPP platforms are used to deliver energy either in the form of MW or MWh. They are designed to optimally control local DERs and make them reach bundled generation, consumption or storage targets. When doing so, VPP platforms connect the grid and prosumers via the wholesale or ancillary services markets.

A DERMS (Distributed Energy Resource Management System) platform is, as defined by Navigant Research:

“A DERMS is a control system that enables optimized control of the grid and DER (to the extent that a utility may be able to dispatch and control DER). To minimize disruptions and the presence of phantom loads, utilities need to manage the grid more proactively. Common use cases include Volt/VAR optimization (VVO), power quality management, and the coordination of DER dispatch (when possible) to support operational needs.”

(Navigant Research, 2019)

From the definition above, the main difference between a VPP and a DERMS platform is that the second allows for localized active power management of specific resources in the grid. This solution goes one step further than the VPP platform, allowing not only energy management but also voltage regulation and congestion management, as these are local operations. Also, it shall be noted that a DERMS platform has a Top-down approach, which means that control hierarchy flows from the top (the utility) down (the resource) whereas a VPP platform has a Bottom-up approach; the user of the distributed energy resource enables some sort of control under some specific circumstances to the VPP operator.

In short, DERMS platforms are designed for utilities and DERs portfolio managers, that need visibility and control of each asset, that are usually proprietary; VPP platforms, on the other hand, are designed for aggregators that partner with plenty of prosumers to bundle their capacity and go to the market. DERMS usually need to re-optimize DER with less frequency than VPPs.

There are also other services and features that aggregation platforms can provide like integration into other platforms, market trading optimization or system inertia measurement. All these service can be separated into modules of the same software and commercialized to different stakeholders in the market. The aggregation platform is the cornerstone of the Virtual Power Plant; VPPs will be increasingly feasible as disruption and innovation takes place in the aggregation platform space.
The aggregator

The independent aggregator is a figure that is positioned between prosumers and the energy markets. Although the utility supplying the energy to the prosumers would be the logical aggregator, other agents are able (and in fact they are) to become aggregators. The role of the aggregator needs to be clearly defined under rules and regulation, as aggregators’ decisions impact the energy and balance position of other agents, like utilities and suppliers. Aggregators, like VPPs, can be supply aggregators (mainly utilities) or demand aggregators, which aggregate mainly behind-the-meter assets and can provide services to the TSO or sell their output in the market.

Aggregators can be involved into B2C (Business-to-Customer) and B2B (Business-to-Business) relations. They are involved in B2B when they provide, for example, tertiary frequency reserves to a Balancing Responsible Party (BRP) through the aggregation of C&I back-up diesel generators and Uninterruptible Power Supply (UPS) systems. As these units are only used in emergency or outage events, they are most of them left available for providing grid services. In this example, a company providing maintenance services for those assets could choose to become an aggregator and enlarge their service offering by involving in the aggregation business. Aggregators can become, if regulation allows to do so, a BRP and provide those services directly in a B2B to the TSO.

An example of the B2C model would be an aggregator providing primary or secondary control reserves through the aggregation of electric vehicle charging capacity. As electric vehicles are usually charge during night-time and require high amounts of energy, the aggregator could offer electric vehicle owners energy costs savings by allowing their electric vehicle charging stations to be used for providing grid services. In this example, an electric vehicle fleet manager could chose to become an aggregator and reduce operation costs (USEF, 2015).

In short, the aggregator is the figure that acquires flexibility from prosumers, bundles it into a flexibility service and offers this bundled service to a market agent. For this purpose, flexibility is defined as the difference between the actual use and an agreed baseline reference.
The market agent

The market agent is a figure that stands between the aggregator and the market. In most EU countries, only a Balancing Responsible Party can offer flexibility services to the TSO. This occurs because the TSO needs to have a party to hold responsible for the imbalance in case that the output of the portfolio of aggregated DERs differs from the expected and agreed result.

For whatever the reason, if the aggregator cannot directly participate in the market and needs to do so through a third-party, this will be referred as a market agent. In some contexts, the aggregator can become itself a BRP and be its own market agent. This is the case, for example, of Next Kraftwerke, a VPP operator mentioned previously in section 4.1.

### 3.3 VPP control

VPP components are coordinated using networking infrastructure for them to operate as one market entity, despite not being located on the same physical network. For this matter, the VPP can have a centralized or decentralized control.

VPPs under centralized control are based on one central controller (Virtual Power Plant Controller), which is not necessarily installed physically in one of the controllable sites. The VPP
controller optimizes the energy output of the portfolio assets by selecting those generation units and flexible loads that will be served. The VPP controller sends control signals to the local controllers or hardware gateways and are based on the calculated electrical and heating/cooling demand of each site, the output prediction of renewable resources based on weather forecasts, the electricity and fuel market prices and the availability of existing flexible loads.

Under this architecture two way communication take place between the VPP controller and local controller of each distributed asset. Local control gateways sent their operation costs or bid the curtailment of their flexible loads at frequent intervals. The central controller takes into consideration the gathered information and sends energy market prices and the set points. This information exchange is crucial for deciding the marker price above which flexible loads are curtailed and the electricity generation of the distributed energy resources. In the figure below a typical information exchange in a centralized VPP controller is shown.

![Figure 44 Typical information exchange in a centralized VPP Controller, own elaboration](image)

A decentralized controlled VPP implements distributed management of information for taking similar control decisions on the distributed assets and flexible loads. A common approach for this type of implementation is by MAS (Multi Agent System) (Dimeas & Hatziargyriou, 2007). MAS are a new and promising area in the field of distributed artificial intelligence, as well as in the mainstream computer science. These systems are compound of relatively autonomous and intelligent parts, called agents (Badjonski & Budimac, 1999).

In both systems, economic scheduling follow some basic principles to decide which distributed generation units generate and which flexible loads are shed. Renewable generators are prioritized over other generation assets under the legislative framework of most European countries and their dispatch ability is dependent on the accuracy of the weather forecasting tools (Giakoumelos, 2008). The units producing electricity only, produce power when their operating cost is lower than energy market prices. Regarding Combined Heat and Power units, these meet the heat demand of specified end-uses taking into account temperature and fuel consumption. If the demand is higher than the CHP heating/cooling capacity, then the unit...
operates at its maximum production; otherwise, the operating point of the CHP is the one that meets the heating/cooling demand. If more than one CHP units are used to meet the thermal/cooling demand, this demand is dispatched to these units according to their capacity and their fuel efficiency curve. The selection of the production level is based on a priority list, a method widely used in practice (Momoh, 2001), so that the heat demand is met at the most economic level. The amount of load to be curtailed at each time-step is determined by the load bid compared to the electricity market price. If the bid is lower, the load is curtailed (Burger, Chaves-Ávila, Batlle, & Pérez-Arriaga, 2016).

In short, a centralized controlled VPP is one in which the overall performance of the system is optimized from a central controller, remaining the ultimate control of each DER in the VPP controller. A decentralized controlled VPP shows a hierarchical architecture that combines a central controller that ensures security and economical operation of the system and local controllers that optimize the DER output. Lastly, a fully decentralized VPP is one in which the central controller is only responsible of the exchange of information between the local controllers and the market. Under this last architecture, which corresponds to the ultimate version a VPP, all assets can be seamlessly integrated and aggregated.

Even if the fully decentralized controlled VPP has the most flexible configuration, to develop a model that suits current transmission and distribution electricity networks is challenging. Therefore, the centralized and distributed types of VPPs are also appropriate models in the cases when the DERs transfer the responsibility for the decisions to the VPP with the expectation of additional profit (Kulmukhanova, 2018).

3.4 The added value of VPPs

Virtual Power Plants offer a way of creating new mechanisms to enable a reliable and safe management of the physical properties of electric current. By implementing smart designs to manage DERs complexity, VPP can foster a system in which a complete portfolio of grid services are provided by a set of heterogeneous DERs. Despite this being a challenging goal, the changing paradigm of the energy sector forces us to try to put it into practice.

For a long time since the first time the term VPP was coined, the added value of VPPs was merely conceptual (except from demand response, that has been for a long time a consolidated mechanism of demand side participation). Nevertheless, VPPs are demonstrating that they can create real and substantial value in the current energy markets. Some of the ways in which VPPs are creating value are listed herein.

Under the VPP scheme, plenty of different load resources are enabled to participate and provide services in the electricity markets. This load diversity goes far beyond the conventional demand response programs. In the residential sector, smart thermostats are emerging as a relevant load flexibility enabler for VPP participation and are creating significant savings to end-users. Electric vehicle charging points, both in residential and commercial facilities, can also emerge as a huge source of flexibility and transition from becoming a relevant concern for system operator to becoming a valuable asset for the grid. In commercial and industrial facilities HVAC systems, chillers and boilers can now create recurring revenue streams or substantial savings to their users, helping them reduce their energy bills. Advanced software control are enabling all these diverse loads not only to participate but to participate more effectively, by allowing load consumption modulation as opposed to classical demand response which was limited to on-off
control paradigms. These new control enables near real-time tracking of market conditions. This bundle of diverse resources try to mimic the output of a conventional power plant but being much more efficient and less capital intensive.

Another way in which VPPs create value streams are by offering fast acting ramp rates to fill in the gaps and fluctuations of variable renewable energy supply. Conventional power plants take up to 30 minutes to come online. These value can be taken down to 10 minutes when combining the action of peaking plants and natural gas generators. A VPP can respond to signals in a few seconds and deliver relevant fast ramp rates, that will in each case depend on the aggregated assets. This ability to quickly respond to the physical needs of the grid at each moment is one of the most attractive value propositions of the VPP, as it brings together diverse resources to fix common grid issues.

Virtual Power Plants also represent an interesting opportunity to consolidate a firm source of energy with zero fuel costs, by incorporating a diverse portfolio of supply-side distributed renewable generation and replace traditional peaking capacity fueled by diesel or gas and its associated economic and environmental cost. A carbon-free VPP can be assembled by creatively combining a mix of supply, load and different forms of energy storage.

In addition, the CAPEX associated to building up new power plants is quite large. The capital cost of a nuclear power plant is $6-9 billion for a 1.1GW plant (Schlissel & Biewald, 2008) and the decommissioning costs can be up to $500 million. In the case of a coal fire power plant, the capital costs are around 3,636$/kW; for CCGT, it is close to 1,000$/kW (EIA, 2016). These projects, that may have a 20-30 years project life, face risks about environmental regulation that might show up. As VPPs take advantage of the potential of diverse sets of existing assets, the cost per unit of power can be much lower. Also, the investment in VPP technology is not threatened of new environmental regulation or the risk of stranded investment. As new markets are created for the increasingly needed grid services, the VPP value can not only not decrease but increase dramatically. Investing in traditional centralized supply side generation assets has associated the risk of long-term devaluation and substantial stranded costs.

Lastly, the creation of conventional new power infrastructure usually comes together with fierce opposition of different stakeholders as generally people living close to a planned project might not want a polluting or potentially risky (even though the risk might rather perceived than real) power plant to be built in the vicinity of their households. These issues can emerge not only for fossil fuel or nuclear power plants, but also for grid scale renewable farms. VPPs are virtual instead, as redundant as it sounds. The power output of the VPP is the result of the creative aggregation and optimization of existing assets within the power grid. Small and scarce energy assets rarely encounter public opposition. For this reason, the Not-in-my-back-yard issues are not a concern for VPPs (Navigant Research, 2017).
Part 2: VENTURE CREATION

Venture creation

noun

ECONOMICS, FINANCE

“the process of turning a new idea or technology into a business that can succeed and will attract investors” (Cambridge Business English Dictionary, 2020)
In this section, the creation of a venture for an energy player in Spain is considered. As it has been explained, flexibility by itself is not a business case, as margins are kept low and do not justify investment in new assets. For this reason, the proposed business model is defined for an incumbent energy player, as an additional source of potential revenues, complementary to its core business. The case is defined as a mid or large sized energy utility willing to disrupt the market by implementing this type of business. Sections before this serve as an introduction. In order to assess the venture creation process, first, a market overview is performed, consisting on market sizing, trend analysis in other geographies, competitive landscape evaluation and customer segmentation. Second, the different business models will be evaluated and a business model will be proposed for addressing this opportunity in Spain, meaning the selection of a customer segment, evaluation of evolving regulatory framework, scenario analysis and a product and implementation road map. Then a high level model considering the participation in the intra-day market will be evaluated.

1 Market overview

The market for Virtual Power Plants have experienced significant growth in the last years. The flexibility needs are increasing as VRE penetration grows in every power system. For the purpose of evaluating the suitability of enrolling in a new venture in this business, the market for VPPs will be evaluated, with a focus for the European and Spanish market.

Market sizing

VPP aims to offer a tool for players in the energy sector to monetize flexibility from demand-side energy assets, benefiting from economies of scale and scope and allowing market participation when aggregated. New market designs trends include increased time and space granularity, redefined ancillary services with incentivized fast acting reserves and ramping requirements and new capacity markets that foster VRE participation and introduce flexibility requirements. In this context, ESCOs, retailers, utilities and independent aggregators can leverage in aggregation platforms to deliver the needed and valued flexibility, either through ancillary services, intraday markets or local flexibility markets.

Quantifying global VPP market is somewhat difficult as power system differ broadly from one country to another. It is commonly estimated that global VPP market revenue could reach $1 billion by 2022, reaching a maximum figure of $6 billion by 2028. Europe stands out as the most important market for VPPs in the mid-term, with Asia-Pacific (with Australia playing a major role) and North America following. Each of these markets have different characteristics, with Australia leading the way to residential and solar with storage VPPs, US with widespread demand response and back-up generators and the European Union moving to mixed asset VPPs.

Regarding the different energy markets in which VPPs can participate, for demand-side VPPs today the most lucrative ones are the ancillary services markets, as it has the lesser impact in

![Figure 45 Total VPP Market Revenue 2019-2028, (Navigant Research, 2018)](image)
end-users behavior while being more lucrative on a €/MWh basis. Supply-side VPPs, as they mainly aggregate front-of-the-meter generation assets, they can participate in wholesale markets as well. Ancillary services market are more adequate for demand aggregators as in some ancillary services’ mechanisms both capacity and utilization is remunerated. This fact differs from one system to another, but this is commonly true for aFRR (automatic Frequency Restoration Reserve) or secondary regulation. Primary regulation or FCR (Frequency Containment Reserve is usually compulsory for synchronous generators and not remunerated, while tertiary reserves or mFRR (manual Frequency Restoration Reserves) are only paid when utilized.

In Europe, the VPP envelop is being pushed. Aggregation platforms are being developed to provide new services in the continent, maximizing the value of flexibility with sophisticated capabilities. In the first years of VPP implementation, European VPPs were characterized for being centered around renewable energy integration. The ongoing projects aiming for integration of European ancillary services (IGCC, PICASSO, MARI and TERRE projects) represents a great opportunity for VPPs to grow, as they could extend their offering cross-borders. In Europe, it is estimated that 200 TWh of energy are managed in the ancillary services, which accounts for a current market size for flexibility services of around $10 billion (Lopez & i-deals, Flexibility market sizing, 2020). Recently regulation is transforming and new market places for flexibility are being enabled like local flexibility markets, local energy communities or P2P energy trading.

The need for flexibility in Europe is following an upward trend, as a result of the integration of the grid increasingly shares of VRE. The last available data from the ENTSOE shows that in the 2016-2017 period the total volume of energy contracted in the ancillary services grew from 3.75 TW to 4.56 TW, meaning a 21.4% year-on-year increase. Also, it is estimated that the integration of the balancing markets across ENTSOE TSOs could generate more than €400 million a year of additional social welfare benefit. Congestion management spending has also seen a significant increase from €999 million in 2015 to €1.27 billion in 2017 (ENTSOE, 2019).
DER availability is also key for the success of VPP implementation. In Europe, almost 4GW of distributed solar capacity was installed in residential and commercial rooftops in 2018 (T-Solar, 2019); Energy Management Systems will penetrate into 15% of households by 2025, enabling aggregation of residential flexible loads (Statista, 2019); 1.3 and 2.9 million EV chargers are needed in 2025 and 2030 respectively to keep pace with the electrification of mobility (Transport & Environment, 2019); and 6.6 GWh of residential energy storage is expected to be installed by 2024 (Wood Mackenzie, 2019).

From the $10 billion market for flexibility in Europe today and its potential grow in the short and mid-term, VPPs will reach a fraction thereof as they will compete against CCGT, renewables and other flexibility providers. For the above mentioned facts, both flexibility needs and availability of distributed energy resources, the market for European VPPs is expected to grow substantially in the coming years, reaching annual projected capacity additions of 14,000 MW and market revenues of $3 billion by 2028.

For the shake of completeness of this market sizing evaluation, two specific markets will be evaluated: on the one hand, one mature pioneering market will be evaluated and on the other hand, an opening emerging market will also be analyzed.

The most European VPP market is, without any doubt, Germany. The German market is the largest and most mature VPP market; it is the leading region in current deployments and is expected to continue holding that position over the next decade. Many leading companies in the VPP market, like Next Kraftwerke, Energy2Market, GreenCom Networks and many others are based in Germany. This country has anticipated to its surrounding competitors and is expected to capture about one-third of the total VPP market’s annual capacity by 2028, reaching approximately $1 billion in annual market revenue and over 4,000 MW of incremental annual capacity additions. The world’s largest VPP traces back to 2009 and has grown to over 4,500 MW in size; it is expanding in stages across the entire European continent. With its Eurocentric focus on energy trading, technologies used for financial transactions, tracking, and settlements are setting the stage for future VPPs throughout Europe (Navigant Research, 2019).

On the other side of the coin we have the Spanish Market. In Spain, the market has just recently opened to aggregation of demand-side assets through energy retailers. According to the latest

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**Figure 48 Annual VPP Total VPP Capacity, Implementation Spending and Market Revenues 2019-2028, Navigant Research**
report of the Spanish TSO, in 2019 the total energy managed in the ancillary services was 15,126 GWh; the price for these services depends on which kind of reserve is considered and if it was an upward or downward service. The price breakdown below adds up to a total €900 million market size for ancillary services. According to Spanish NECP projections, wind and solar generate 50% of the electricity in the H2025 target scenario, which doubles the 2019 figure. This predicted growth in variable renewable resources raises uncertainty and variability of the generation mix, incrementing the flexibility needs of the system and probably projecting a larger Serviceable Addressable Market. However, this impact cannot be measured as there are many other variables influencing this issue. It shall be considered which portion of the flexibility that is needed can be provided from demand-side assets and in which of the available ancillary services these assets participate when aggregated.

![Ancillary services breakdown in Spain in 2019, REE](image1)

![Ancillary services price breakdown in Spain in 2019, REE](image2)

On a first approach, demand side assets will participate in Spain in the secondary control reserves, as those are the most profitable and advantageous for demand side participants. Participation in tertiary control reserves, although less profitable, is also possible. The TSO remunerates secondary control reserve providers both for availability and utilization. Tertiary control reserves are only remunerated when utilized. Primary reserves are compulsory for all generators and not remunerated. Apart from control reserves, every year the Spanish MITECO auctions the interruptibility service. For 2020 1,000 MW were auctioned to the 120 electro-intensive industries that participated, adding up a total of €10 million. These services, that have been historically underutilized and overvalued, are being gradually integrated and more frequently used. This industrial demand response can be integrated into CASE’s aggregator platform and thus shall be considered.

The secondary and tertiary control reserves along with the interruptibility service adds up to a market size of €225 million. In the provision of those services VPPs will face competition from CCGT and renewables. Also, the portfolio of dispatch able demand-side assets is today still limited, as self-consumption schemes will add up to only 50 MW in 2021 (ANPIER, 2019), electric vehicles will be less than 1% (ANFAC, 2018), homes with energy management capabilities will
be close to 10% and residential energy storage will still be lagging. In this context CHP generators, which accounted for 12% (REE, 2020) of the generated electricity in 2019 are the most attractive portfolio assets along with C&I demand response in the Spanish market. The Spanish market is currently unexploited with just a few early stage players developing VPP solutions.

**Demand-side flexibility markets in Europe**

The penetration of distributed energy resources in Europe and particularly in Spain is rapidly growing and enabling new ways of providing flexibility from the demand-side. In Europe almost 4GW of solar capacity was installed in residential and commercial roofs in 2018 while solar PV self-consumption schemes experienced an 80% growth in number of installations and 40% in installed capacity in Spain in the same period. EMS will penetrate into more than 15% of households by 2025 in European households and 1.3 and 2.9 million EV chargers are needed in 2025 and 2030 respectively in Europe in Spain there are currently 4,545 EV chargers and more than 100k and 300k are needed in 2025 and 2030 respectively. Also, 6.6 GWh of residential energy storage to be installed by 2024 in Europe while in Spain, according to NECP, 6GW of storage technologies (hydro-pumped, solar, batteries, etc.) are needed in 2030. CHP accounted for 12% of the generated electricity in Spain in 2019 (ENTSOE, 2019) (REE, 2020) (Statista, 2019) (ANPIER, 2019) (Wood Mackenzie, 2019).

However, demand side flexibility is not equally enabled in all European regions. Based on the latest report of SmartEN (SmartEN, 2019), the figure below summarizes which European markets are more suitable for the implementation of demand-side flexibility solutions, in which VPPs are included.

For the figure below, the following definitions apply:

Value stream availability and accessibility for DSF: markets scoring highly indicate that multiple value streams are open to DSF, with low barriers to entry. In markets where this value is low, value streams are limited in number and/or accessibility for DSF.

Monetization of DSF in value streams: in highly scoring markets, there is evidence of DSF being monetized in the majority of available value streams. Typically there are hot spots in value streams, across all markets. There are a few examples of DSF not being monetized in open value streams given high barriers or lack of economic incentive.

The breadth of asset diversity used for DSF: in highly scoring markets there is evidence of activity in the majority of asset types, with some hot spots usually around industrial loads and behind-the-meter generation. In lower scoring markets, there tends to be limited activity across asset types, or significant activity in very few asset types.

The breadth of customer segments engaged with DSF: in countries scoring highly we have found significant evidence of activity in all three customer segments. Lower scoring countries may still have strong engagement, but this will be limited to one segment, or limited engagement across multiple customer segments.

The competitive landscape for DSF: the score here is based on the number of stakeholders active in demand side flexibility. We tend to see more innovative business models in the highly scoring markets (i.e. including those with a high-medium score).
In short, the most mature markets for implementing VPP projects in Europe are the UK, Germany and France.

Other markets
One of the leading markets in DER platform implementation is Australia. They have been implementing DER microgrids for quite a long time. Australian consumers are now shifting to the value proposition DERs can make when adequately managed while connected to the grid. Innovation is crucial in a country in which electricity prices have been historically high and the rate of rooftop solar PV penetration is among the highest globally. Australia stands as one of the most relevant regions for VPP implementation in the Asia-Pacific region.

As the energy per capita in Australia is one of the highest in the world, opportunity for flexible loads to emerge and the monetization of such flexibility through VPP seems feasible. Recently the innovation giant Tesla built a VPP in Australia with the cooperation of the Southern Australian Government. The project, that aggregates over 50,000 residential batteries (Tesla Powerwalls) started operations in late 2019 and has been said to outperform expectations (CleanTechnica, 2020).

With the highest solar PV capacity per capita and with expected massive deployments of residential energy storage solutions, Australia is one of the most attractive markets for the implementation of residential VPPs.
Other relevant market in the Asia Pacific region is Japan. Standing as the most industrialized economy in the region and with firm bets for innovation in different fields, Japan is also an appealing market for VPP implementation. The reliability of the grid in neighbor countries is nowhere near the reliability of the robust Japanese grid. Even though the energy sector relies heavily in centralized nuclear and coal power plants, the public opposition to nuclear power, the dependence on coal and LNG imports and the ambitious objectives set to 2030 (24% renewables) set the scene for a change towards DERs and ultimately towards VPPs.

There are a few ongoing projects for developing VPPs in Japan, most in the Tokyo region. TEPCO, the largest utility in Japan that operates in the Tokyo region is currently developing a Virtual Power Plant in collaboration with the energy storage solutions Sunverge and Stem Inc. The company Osaka gas also started implementing a VPP in late 2018 in collaboration with the start-up Geli. Also, the market leader AutoGrid is currently working with the Japanese Eneres in developing what they call “the largest VPP in the world” that aims to aggregate 10,000 assets in the 2020-2021 period and rapidly scale in the subsequent years.
Lastly, it cannot be forgotten the US market. The US is the leading market for demand response, especially in those regions in which the energy sector is unbundled and deregulated (PJM, CAISO, ERCOT, MISO, NYISO, etc.). The demand response capacity controlled by VPPs in the US is approximately 680 MW, and is shifting to a greater reliance on mixed-asset VPPs (Enbala, 2019).

*Figure 54 VPP Capacity forecast in the most relevant markets, own elaboration based on (Enbala, 2019)*
Main players in the VPP market

Figure 55 VPP main players globally, own elaboration
As part of the market evaluation of the Virtual Power Plant business, a desk research identifying both most relevant players and promising new entrants was performed. The analysis accounted for more than one hundred VPP solutions; after evaluation and by applying several exclusion criteria, the list was reduced to 58 solutions. The most relevant solutions are herein identified.

**Opus One**
Opus One is a software engineering company from Canada that creates value by enabling real-time energy management in the smart grid. Through its offering GridOS, they deliver enhanced visibility and control to electricity distribution through sophisticated engineering analytics designed to solve and optimize complex power flows. Seamlessly integrating with utility data systems, their proprietary engine provide powerful grid management capabilities and unlocks greater potential for distributed energy resources including renewable generation, energy storage and responsive demand. GridOS further facilitates the implementation and management of microgrids from homes to communities for unparalleled grid resiliency and value to the electricity customer.

**Enbala**
Enbala is a software company from Canada that develops and commercializes a DERMS and VPP SW platform for TSOs and utilities in a B2B model. The platform enables DERs integration at MV lines, maintain grid balance and manage flexibility aggregating C&I process loads (Demand Response), energy storage and renewable energy sources. The Canadian start-up is one of the market leaders for aggregation platforms and has received $9 million in several funding rounds.

**AutoGrid**
AutoGrid is an American software company that provides a platform with a suite of flexibility management applications (DERMS, VPP, DR, and Storage). It is oriented to open new revenue streams to utilities and energy service providers (B2B) by managing and optimizing DERs at scale and in real-time while engaging customers and enhancing reliability. They have optimized 5GW of DERs from more than 40 utilities worldwide. AutoGrid is, along with Enbala, the leading player in the VPP platform business and has received funding from Shell, Total, E-on, Energy impact ventures and other relevant players in the energy sector.

**Blue Pillar**
Blue Pillar is a software company founded in 2006 in the US that provides an IoT technology software platform that networks DERs (solar PV, smart meters, backup generators) and other energy systems (building energy systems). It allows electricity providers to offer innovative energy services such as Automated DR to their C&I customers. Blue Pillar has secured $24 million in funding for its software platform.

**Enel X (formerly EnerNOC)**
EnerNOC was one of the largest C&I demand response aggregators in the US. Enel acquired EnerNOC in 2017 for $250 million to incorporate into its offering their demand response aggregation capabilities and position themselves in the aggregation business. Enel X offers C&I customers an EaaS (*Energy-as-a-Service*) approach, managing on-site generation to curtail grid consumption or directly reduce demand to participate in DR programs. Enel’s DEN.OS software acts as a proprietary DERMS while provides an Energy Management SW Module for end-users. Enel X acts as the innovation subsidiary of the Italian giant Enel and includes in its offering other solutions related to energy apart from VPP services.
**MP2 Energy**

MP2 Energy is a certified Retail Electricity Provider and a Qualified Scheduling Entity in ERCOT and a Curtailment Service Provider in PJM. MP2 Energy provides Demand Response services in those markets for C&I users, standing as one of the pioneering companies in providing demand response services in the US. It was acquired by Shell in 2017 for an undisclosed amount, making a move into the American VPP market.

**AMS**

Founded in 2013, Advanced Microgrid Solutions (AMS) commercializes a white-label DERMS trading platform for utilities. The SW platform uses AI to manage the operation of DERs, enabling automated bidding of energy assets in wholesale markets, scheduling and dispatch of mixed asset portfolios and operation of fleets of behind-the-meter resources, with a strong focus on energy storage integration. It operates mainly in the US and Australia, and has raised $52.7 million from Engie, General Electric, AGL, Energy impact partners and other relevant investors.

**GreenSync**

GreenSync is an Australian software company that provides a platform to enable peer-to-peer and local energy markets, as well as large scale trading. They offer a proprietary full stack platform built in-house called Decentralized Energy Exchange (deX) that helps energy market players buy, sell and store energy. It has worked with utilities and DSOs in Europe and Australia and has raised $22 million in funding through various venture rounds.

**ABB**

ABB is technology giant from Switzerland with more than 130 years of history and that is publicly traded. Among its offering ABB has developed OPTIMAX, a platform that aggregates and optimizes decentralized energy resources into virtual power plant.

**Siemens**

Siemens is a German cluster of technological firms, standing as one of the largest industrial manufacturing companies globally. They have developed their own VPP solution, the EnergyIP DEMS which is a DERMS platform that enables demand and supply management of distributed energy resources for a wide variety of use cases.

**Tiko**

Tiko is a Swiss software company that was recently acquired by the French utility Engie and operate in various European regions. Tiko delivers a white-label end-to-end aggregation solution for utilities and OEMs. They integrate hardware controllers (smart plugs, EMS) as well as DERMS and VPP software platforms that enables utilities to participate in balancing markets with the aggregation of domestic EMS and DERs.

**Energy Pool**

Energy Pool is one of the pioneering VPP players in Europe. The French start-up builds and operates demand-side management solutions through a DERMS platform that enables real time frequency regulation and optimal aggregation of flexibilities. They operate the platform for electricity end-users and offer it in a SaaS mode to utilities and system operators. Energy Pool operate in Europe, Japan, Turkey, Malaysia and other regions and was the first aggregator to provide a balancing service to the French TSO (RTE).

**Kaluza (an OVO company)**

OVO is a British utility that has recently step up to become one of the big energy retailers in the UK by acquiring SSE Energy Service’s retail business. OVO has recently developed a proprietary
solution to address the flexibility market, Kaluza, that connects, controls and optimizes distributed domestic devices leveraging an Artificial Intelligence based software platform. By aggregating the connected devices at scale, Kaluza can support the grid by providing flexibility to TSOs in balancing markets and DNOs in local markets.

**Limejump**
Founded in 2013, Limejump had raised $4 million before being acquired by Shell for an undisclosed amount. Limejump is a market agent aggregator that participates in different market mechanisms in UK’s power system through a cloud-based SW connecting IoT HW and leveraging energy market knowledge and intelligent trading models in a VPP platform aggregating batteries, small generators and demand loads. Limejump operates the largest VPP in the UK and was the first agent to participate in National Grid’s (UK’s TSO) Balancing Mechanism with energy storage battery assets.

**Centrica Business Solutions (Formerly REstore)**
The British utility Centrica acquired the Belgian start-up REstore in 2018 for $81 million. They incorporated their business into Centrica’s core business and rebranded it under the name Centrica Business Solutions; under this name, they provide a modular SW platform for other utilities and aggregators in a B2B model, to aggregate a large pool of industrial loads and CHPs into a VPP for market participation with Intelligent market models enabling flexibility delivery without compromising C&I demand requirements. They also act as their own aggregator and market agent, standing out as one of the most complete and relevant players in the business.

**Vattenfall Flexibility Solutions (Formerly Senfal)**
Senfal is a Dutch start-up that provides energy services by aggregating DERs using their proprietary software platform. Based on the amount of flexibility that is available, each customer pays a subscription fee and benefits from the savings derived from participating in the market. It was acquired by the Swedish utility Vattenfall in 2019 for an undisclosed amount and rebranded as Vattenfall flexibility solutions.

**Peeeks**
Peeeks is a Dutch company that detects and connects flexibility in assets and appliances such as boilers, storage and district heating grids, so that energy systems can perform optimally, aggregating these flexible assets to participate in ancillary services markets. Peeeks is a joint venture among Peeeks, Ampard and Eneco CrowdNett, with the Dutch utility Eneco as the Venture owner.

**E2m**
E2m is a German aggregator and market agent, founded in 2009 as one of the first start-ups to step into the VPP business. e2m acts as an independent power trading company that manages and optimizes a 3.7 GW portfolio of generators, consumers, suppliers and grid operators. They operate a VPP that aggregates decentralized power and flexibility bringing it to the market. They also offer distributors white-label packages and software solutions under a VPP-as-a-Service model.

**Next Kraftwerke**
Next Kraftwerke is a VPP operator that aggregates small generators and CHP, C&I flexible loads, storage and renewables to participate in energy markets and grid frequency control. Next currently operates 7.5 GW of aggregated capacity throughout Germany, Belgium, France, Italy, Switzerland, Poland and Austria. They also offer their proprietary software platform for
customers that want to operate their own VPP. Next Kraftwerke has the Dutch utility Eneco as its lead investor, owning 35% of the company’s shares.

GreenCom Networks
GreenCom Networks is a Software-as-a-Service company, offering white-label solution for utilities and energy service companies (ESCOs) to aggregate distributed energy resources through an IoT energy platform. Their software monetizes flexibility using advanced asset trading (energy demand, supply and storage) and automated demand response. Founded in 2011, the German start-up is active in Germany and France and has secured investment from relevant actors such as Centrica and SET Ventures.
New entrants in the VPP market

Figure 56 Emerging start-ups in the VPP business globally, own elaboration
As well as the most relevant players in the VPP market, some promising start-ups and their disruptive solutions have also been identified.

**Origami Energy**
Origami Energy is a UK-based software company that has developed a Software-as-a-Service platform with configurable and pre-built applications, helping energy companies to increase the value created from DERs. Founded in 2013, has raised $40 million in funding and has various ongoing projects in the UK.

**Grid Beyond**
GridBeyond is an ESCO from the UK that enables businesses to participate in demand side response programs in the UK through a unified platform that uses machine learning technology to connect generation and storage assets in order to automatically adjust power consumption in real-time to balance the grid. It’s operating in the UK, Ireland and the US and has raised €13.8 million from relevant investors such as Total and EDP.

**Reactive technologies**
Reactive Technologies is a British start-up that has developed an energy optimization software platform with demand response and dynamic PPAs functionalities. This trading platform enables renewable generators and C&I users to access relevant market opportunities and benefit from reduced imbalance and price risk. Reactive Technologies has worked with UK’s National Grid in helping them accurately measure grid’s inertia and with Total in developing dynamic PPAs. The start-up has been backed by the Norwegian oil giant Equinor.

**Voltalis**
Voltalis is a French start-up that works with residential and small/medium sized C&I aggregator and connects electrical appliances, applying micro-shedding across a large portfolio of connected assets to provide grid services. Customers participating in Voltalis platform do not participate from revenues but benefit from energy savings and monitoring services, while Voltalis earns from selling the flexibility in the energy market. Voltalis is active in various European geographies, including France, Sweden, Finnland, UK and Belgium and it is one of the few players effectively aggregating residential loads.

**Ampere Energy**
Ampere Energy is a Spanish start-up that develops energy storage solutions for the residential sector. They are developing a VPP platform (AMPERIA) to aggregate resources such as their smart EMS (inverter+batteries+EMS) for solar PV self-consumption and EV (V2G). The main objective of the platform is to optimize the operation of the system for both the user and the grid. Ampere Energy is backed by the Oil & Gas players Repsol and Copec.

**Steamy Energy**
Steamy Energy is an early stage start-up that provides a cloud-based solution for energy service providers, utilities and big customers, focused on managing DERs, wholesale electricity market bids and ancillary services markets. The solution enables energy management for individual buildings, network of aggregated buildings and microgrids.

**CASE**
CASE is an early stage initiative based in Barcelona to create a software platform to aggregate demand side assets and participate with them in the energy markets. The software platform is aimed towards utilities and energy retailers and plans to take advantage to the recently enabled Spanish demand-side participation market.
Lumenaza

Lumenaza is a German start-up that has developed a DERMS platform which is able to operate Local Energy Communities for small scale renewable power exchange. They provide a SW platform that connect consumers and producers within a regional marketplace, enhancing transparency from both sides and enabling small producers to trade locally. Lumenaza is one of the pioneering start-ups in creating local energy communities and enabling peer-to-peer trading and is backed by two major German utilities like e.on and EnBW.

GridX

GridX is a fast-growing German startup providing IoT solutions for the energy industry. GridX provides a software platform with flexible and scalable and energy IoT solutions to digitise energy infrastructure. The DERs management system is based on the gridBox (IoT edge gateway), gridOS engine and cloud infrastructure. Their future plans include the development of VPP functionalities. It is backed by the German utility Innogy.

Enervalis

Enervalis develops a DERMS software that integrates electric vehicles, buildings, and microgrids. Enervalis offers a Software-as-a-Service approach for their platform, which monitors available energy sources and users, predicts future demand and supply of energy and enables control and optimization of the output of the distributed energy resources to maximize renewable generation, peak curtailment, cost reduction, etc. This Belgian start-up has secured €4.2 million funding from relevant partners such as ABB, Elia (TSO in Belgium) and the European Institute of Innovation & Technology.

Sympower

Sympower is a Dutch start-up that has developed a SW platform that integrates DERs to provide grid flexibility. The SW enables real-time balancing of electricity supply and demand through demand response. Their main services are grid balancing provided to TSOs, with ongoing projects in Germany with the TSO TenneT, in Finland with Fingrid and in Sweden with Svenska Krafnat; they also provide congestion management services to DSO/DNOs.

SwitchDin

Founded in Australia in 2014, SwitchDin provides a white-label software platform which enables VPP participation through the aggregation of solar PV and battery storage. It also enables virtual control of demand side enabled devices (such as air conditioners, water heaters and EVs) and microgrid management. They have also their own Energy Management System solution that acts as a hardware gateway to enable VPP connectivity.

Voltus

Voltus is a US based start-up that provides energy management products and services, such as demand response, energy purchasing, and energy efficiency programs, to industrial, commercial, and institutional customers, as well as grid operators and utilities. They provide these services through a one-page commercial agreement, using their own software platform. Voltus has secured $10.1 million in funding in various venture rounds.

Geli

Geli is a start-up founded in 2010 in the US and currently backed by Shell and Siemens, among others investors. They offering includes a financial analysis tool to evaluate feasibility and return-of-investment in solar + storage projects, a control tool to optimize to output of the solution and a modular DERMS platform for market participation. The integration module
optimizes solar + storage DERs based on load profiles and tariff structures and serves as a control gateway for participation in grid services.

**Logical Buildings**

Logical Buildings is an early stage start-up from the US that has developed an Energy Management System solution for facility management. This solution enables consumption control and optimization in buildings and large facilities; the facilities can then be aggregated into Virtual Power Plants and participate in the energy markets through a software platform developed by the start-up. Logical Building currently acts as a demand response aggregator in the NYISO balancing area (New York Independent System Operator).

**David Energy**

David Energy is a start-up that creates value from optimizing distributed energy resources such as CHP, solar, battery storage, HVAC controls, and others. Their solution is mainly focused towards the residential sector and monetization of the distributed energy resources located in residential and commercial buildings. Founded in 2017 and based in the US, has raised $1.5 million in funding in a seed round.

**Leap**

Leap has developed a software platform for trading the energy output from distributed energy resources, such as solar PV, batteries, EVs and smart inverters, following a demand response strategy. Grid operators pay Leap’s VPP just as they do for traditional power plants, and Leap pays its partners for participating. Founded in 2017, has raised $10.6 million in funding and is currently active in the CAISO area (California Independent System Operator).

**BluWave ai**

Founded in 2017 in Canada, BluWave-ai offers a platform for grid energy optimization that connects to IoT sensors and meters and uses historical and real-time data to provide Artificial Intelligence-assisted optimization of local energy generation and storage to communities, corporations and utilities. Currently at a seed stage, has raised $3.4 million in funding.

**Use cases**

Virtual Power Plants are being deployed globally by different actors. Different regulation, market characteristics and technology maturity result in different VPP models. For the purpose of illustrating some success cases, the following use cases are provided:

**Technology Platform use cases**

**Opus One**

Opus One has worked with National Grid (US utility) in creating a technical and financial platform for distributed energy resources and provide real-time forecasted pricing signals and valuation for those resources. Also, the solution provides dispatch abilities to National Grid, allowing full techno economic optimization and serving as a central communication portal between the Distribution System Platform and participating DERs.

Opus One has also worked with the Ontario System Operator (ieso) in creating time and location specific pricing signals for DER operation based on their net benefit to the grid as determined by a combination of regulator, DNO, and participant input. The solution also allowed for evaluation of the effectiveness of using DERs to provide energy and ancillary services and creation of DNO- TSO communication and coordination mechanisms.
Among the extensive list of clients that have worked with Opus One are also included: Ameren (US utility), Scottish Power Energy Network (UK utility), ComEd (US utility), Southern California Edison (US utility), Hawaiian Electric (US utility) and many others (OpusOne, 2020).

**Autogrid**

The Dutch utility Eneco Group uses Autogrid software solutions to forecast, optimize and control a vast network of distributed energy resources in real-time and at scale integrates flexibility from customer-owned Combined Heat and Power (CHP) units in greenhouses, industrial demand response, and other flexible distributed energy resources into a single, reliable resource. With this 100 megawatt (MW) dispatch-grade resource, Eneco can react in real-time to market signals from Dutch wholesale electricity markets run by the Dutch Transmission System Operator (TSO), optimize a large portfolio of distributed generation assets and trade in these markets at any time. This capability allows Eneco to integrate more renewable energy resources into its generation portfolio and reduce imbalance costs associated with renewable intermittency, helping it to cost-effectively reduce its greenhouse gas emissions.

Gexa Energy, a US utility from the ERCOT balancing area (Texas) has used Autogrid’s software solutions to launch various demand response programs among its retail clients. The platform provides business customers the opportunity to lower their energy bills by adjusting their energy consumption, manually or with an automated solution, during times of peak energy demand or high wholesale electricity prices. Customers can choose to manually participate in these programs or automate some or all of their participation by connecting their energy assets — building management systems, heating, ventilation and air conditioning systems, lighting systems, backup generators, uninterruptible power supply, and energy storage systems — to the online demand response platform, provided by AutoGrid.

Autogrid has also worked with many utilities and ISO (Independent System Operators) in the US (AutoGrid, 2020).

**Enbala**

Alectra, the second largest municipal utility in North America, was the first utility to develop a microgrid offering for its customers. It developed a small commercial-scale microgrid and then a utility-scale microgrid, the latter at its own headquarters in Ontario. This utility-scale microgrid integrates a variety of DER while also featuring the ability to island. Quite small in scale in terms of loads and installed capacity, the diversity of DER initially incorporated into the microgrid is one of the most significant achievements of the project as it includes 17kW of Solar PV, 1.8 kW of small wind turbines, 35 kW of natural gas generators, 23 kWh of lead-acid batteries, 5 kWh of lithium-ion batteries, 12 kWh of sodium nickel chloride batteries, 40 kW EV chargers and a 14 kW controllable load bank. In order for the utility to adequately manage such a heterogeneous portfolio of DERs they use the Enbala engine (Navigant Research, 2019).

Enbala has also worked with Portland General Electric, a US utility, in building a VPP in order for them to be able to reach their climate goals. In collaboration with Enbala, PGE has created a technology agnostic, interoperable VPP that enables control, optimization and demand management of an entire fleet of distributed energy resources (DERs) across various customers, vendors and programs. This multiprogram, multi-vendor-ecosystem allows for customization across DER asset-types, location, participation schedules and service offerings, while providing visibility into — and integration of — data to create the smartest and cleanest energy system.

The VPP project plans to add 77 MW of distributed flexibility by the end of 2020 and up to 200 MW by 2025, representing approximately 5% of peak load in both summer and winter seasons.
This will include water heaters, thermostats, advanced demand response, behind-the-meter energy storage and electric vehicle smart charging. To date, PGE’s VPP includes over 100 large industrial loads, large commercial loads and small commercial loads; over 150 commercial smart thermostats, and more than 3,000 multi-family smart water heaters. By 2020, PGE will have added over 8,000 smart water heaters (Enbala, 2019).

In the figure below the main VPP platforms are shown. A differentiation has been made regarding software typology, as this can be oriented towards aggregators (VPP DERMS), TSO/DSO (SO DERMS) and can or cannot include trading platforms for market participation (SO Trading, VPP Trading).

From the figure the following conclusions are drawn: (i) start-ups lead the VPP platform market and compete directly with technology giants like Siemens and ABB, (ii) this type of platforms are being implemented mostly in Europe and the US, with Japan and Australia as other relevant markets, (iii) VPP DERMS platforms for aggregators and utilities are more common than platforms for TSOs and (iv) market leaders combine both approaches in complex modular solutions.

Aggregator use cases

**Sonnen**

Sonnen provides smart, distributed energy storage solutions for residential customers. Through the aggregation of the deployed batteries, Sonnen participates in the ancillary service markets by partnering with utilities. One clear example of the use of residential batteries for VPPs is the partnerships between Sonnen and Centrica. The UK-based utility uses the software platform of its acquired REstore to actively managed 100 sonnen batteries. The systems has been approved by National Grid (the TSO in UK), enabling the aggregated batteries to participate in the balancing mechanisms.

Sonnen is also involved in various VPP projects in Germany, the US and Australia. The german company sells batteries for residential use that can be aggregated with other batteries from the same brand in a VPP and provide flexibility services to a market agent, creating a recurring revenue stream for end-users and reducing the payback period for the home energy storage solution.
**Peeeks**

Peeeks developed a smart electric boiler module in cooperation with its mother company Eneco and T-systems. This module allows remote steering and monitoring of hot water boilers. Unlike traditional models that pre-heat at night, the smart e-boilers heat just-in-time for the customer’s warm water consumption. This reduces radiant heat losses and results in energy cost savings. Furthermore, the electric boiler module connects to Peeeks’ platform and can be turned on when there is a surplus of wind or solar power. Thanks to the solution, the utility Eneco can directly use the boiler fleet to help balance the electric infrastructure – while improving the customer’s comfort levels.

**Market agent use cases**

**Next Kraftwerke**

Next Kraftwerke runs one of the largest VPPs in Europe and aggregates capacity in various European countries, including Germany, Belgium, France, Austria, Switzerland and Italy. The start-up was founded in 2009; in 2012 started operating loads using ABB’s aggregation platform Optimax. Since then, the company experienced a dramatic growth going from a pool of 20 aggregated units to more than 5,400 units today, managing a global of 4.5 GW. Next aggregates mostly energy supply assets, including solar PV, small-scale hydro, biogas plants, diesel back-up generators and biomass generators, among others, ranging from a few kilowatts to up to 20MW.

Just recently, Next Kraftwerke added to its portfolio a installation comprising of a wind farm with an electrolyzer attached; when there is excess wind energy, this installation generates clean hydrogen that is then injected into the gas pipelines. By enrolling into Next Kraftwerke’s VPP, the generated energy is traded and the electrolyzer (Next Kraftwerke, 2020) can be used for demand response; also, Next Kraftwerke gives wind forecasting and information about the load of the local gas infrastructure.

As a result of their success, Next Kraftwerke decided to expand its business and develop and commercialize their own VPP platform, called NEMOCS, which was launched in early 2018 and now has several customers around the world. Next Kraftwerke is today one of the most complete and relevant VPP companies; they are a qualified Balancing Responsible Party in Germany and operate as an aggregator in other countries.

**Limejump**

The recently Shell acquired Limejump is a relevant player in the VPP market as it is the largest VPP operator in UK; the British power system is one of the most relevant markets for demand side participation as it is adapting regulation and modifying market mechanisms to enable it. For this reason, plenty of start-ups in the flexibility business are emerging in that region.

An illustrative use case for Limejump consists on the integration of a large number of gas engines into its VPP. These gas engines are part of Biffa’s assets; Biffa is one of the largest waste management companies in the UK. They use gas engines as part of their operations, and by enrolling in Limejump’s VPP they benefit from recurring revenues for participating in National Grid’s Dynamic Frequency Response (Limejump, 2019).

Limejump also integrates batteries into its portfolio of aggregated assets. In 2018 they incorporated into their VPP one of the largest battery farms of the UK, accounting for 10 MW, becoming the first battery asset to participate in National Grid’s Balancing Mechanism (Limejump, 2018).
**Enel X (formerly EnerNOC)**

EnerNOC was one of the largest demand response aggregators from the US that was acquired by the Italian utility Enel for $250 million and rebranded as Enel X. Under the brand Enel X, the Italian giant bundles all the innovative solution for the energy industries, in which VPPs are included. Enel X is therefore a complete solutions, acting as an aggregator, market agent and also commercializing their proprietary software platform for aggregation.

Enel X has implemented VPP solutions in various countries. An illustrative case study is the VPP they created from one of New York’s largest owners of apartment buildings, Glenwood Management. Glenwood has worked along with Enel X in storage-based demand response across multiple residential properties to participate in Con Edison’s (US utility) demand response programs using Enel X’s DERs Optimization Software. Enel X has also worked with Temple University, who participates in various PJM (TSO in one balancing region in the US) demand response programs to optimize their energy consumption which resulted in $14.5M of savings and revenues over 10 years.

Enel X also accounts among its offering with solutions other than VPPs, like EV chargers, energy storage, efficiency solutions and others (MOI Global, 2017).

**Strategic positioning of energy players**

Both major European Oil & Gas and Utilities are positioning themselves in the VPP business either by investing or by acquiring start-ups and consolidated companies. In the table below an overview of the competitive landscape regarding the VPP market is shown.

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**Figure 58 Oil & Gas players’ strategic positioning, own elaboration**
O&G companies are entering the VPP market with main IOCs (i.e. Shell, Total) investing and acquiring VPP startups; European companies show more commitment into clean technologies and specifically into Virtual Power Plants than their US counterparts.

Some OEMs (Original Equipment Manufacturers) are developing and testing its proprietary technology (i.e. Siemens, ABB) while other are investing in startups to improve their own product offering via their CVC arms (i.e. Schneider SE Ventures investing in Autogrid, Energy Pool)
Utilities (i.e. Statkraft, Eneco, Enel x, Centrica) are already operating VPPs in the market with large capacities (GW), with an active collaboration / acquisition of VPP startups.

Some of the most relevant investment and M&A movements are shown in the figure below; as it can be seen, the VPP business is attractive not only to energy players like utilities and Oil & Gas players, but also to external players like OEMs or investment funds.
In short, utilities are trying to keep pace in the changing scenario by broadening their service offering while Oil & Gas players are trying to diversify their business out of oil and into electricity markets. They are both taking positions in the new energy paradigm by investing in VPPs as part of their strategies to become less carbon intensive.

Return on Investment

As the fleet of available DERs keeps growing, the return on investment (ROI) of VPPs is likely to be more appealing over time. VPPs are shifting from demand response and generation assets to a more heterogeneous set of resources. Each resource type adds unique characteristics and creates value in a different way. Network effect and the aggregation platform contribute to enhance the ROI of the VPP.

VPPs can create value in both unbundled and bundled markets as well as in those markets in which grid services are provided by independent parties. From a market perspective, a VPP can provide the same capacity, energy and flexibility services than a regular utility. In the case of ancillary services, these are increasingly valued in systems with high penetration of VRE. As an
example, the clearing price for fast response regulation in the PJM territory was in 2017 of 17$/MWh/h, including payments for regulation, capacity, performance and mileage (PJM, 2020). As for European figures, the yearly average FCR price in the joint Dutch and German markets was in 2018 12.8€/MWh/h. For aFRR the price was 8.9€/MWh/h (Tennet, 2018). Assuming a capacity factor of 85%, a VPP providing this service could achieve a potential revenue of about 12.07-14.45$/MWh/h.

It needs to be taken into consideration that a VPP will also create value by reducing end-users peak loads resulting in substantial savings in the electricity bill.

As the costs of the technologies that make up the VPP continue to fall, better results in ROI can be expected. New market designs and regulation schemes favoring flexible behaviors will also impact positively the ROI. The exact ROI is dependent upon the specific asset mix portfolio of the VPP and the ancillary services that is providing. When compared with the costs of creating the VPP, the expected returns could easily be around 25$/$kW/yr – 75$/$kW/yr (Navigant Research, 2017).
2 Business model proposal

Providing flexibility through aggregation stands out as a great opportunity to match power system needs in a low capital intensive and environmentally friendly manner. However, finding the right scheme to monetize available flexibility, targeting the right customer segments and perceiving appropriate revenue streams in order for the business to be sustainable is crucial.

Depending on where to position within the flexibility value chain, the business model is substantially different. For this reason, the most relevant strategic positioning are described and then an adequate business model to exploit this opportunity in the Spanish market is developed.

The flexibility value chain

As it has been stated all over this work, distributed energy resources’ underlying flexibility can be exploited through different players.
Implicit demand side flexibility, which is the one that responds to market price signals, is valued by ESCOs. ESCOs (Energy Services Companies) are companies that monetize this flexibility from DERs and are paid a fraction of the created value. Explicit demand side flexibility, which is the one that responds to direct requests for flexibility, is valued by aggregators that have already been extensively discussed. Aggregators, leveraging in a VPP platform, orchestrate the distributed flexibility from DERs and sell bundled flexibility services through Balancing Responsible Parties or Market Agents. These energy is traded either in wholesale markets or ancillary services markets.

Under this scheme, value is created all throughout the value chain. DER owners face value creation by benefiting from energy monitoring, in-house optimization, reduced electricity bills, increased self-consumption and recurring revenue streams from energy assets. ESCOs monetize price responsive flexibility that lays unperceived in end-users’ assets. VPP platforms sell their products to all sorts of portfolio managers and aggregators benefit from the emergence of a solid business case for VPP operation. Balancing Responsible Parties trade the bundled flexibility in the markets, where is valued by other BRPs or by TSOs and DSOs. Also, BRPs can reduce their imbalance costs by coordinately managing their aggregated assets. DSOs, as they are responsible for the installation and maintenance of distribution grids, can optimize its operation by avoiding congestion using DERs management while avoiding or deferring costly grid reinforcements. VPP platforms commonly include features for TSOs/DSOs to increase their grid visibility and therefore allowing them for an optimal use of existing infrastructure, obtaining higher revenues while maintaining current levels of CAPEX and OPEX. Lastly, TSOs can access new environmentally friendly and economically viable sources of energy for the provision of the ancillary services needed to ensure grid reliability.

Within this context, three main business models are identified for explicit demand-side flexibility, depending on the strategic positioning within the value chain: aggregator, software platform and market agent. Several sub-business models are also identified and there might be even more, as each company has its particular point of view and there are nuances between two companies in the same model. Before defining a specific business model for the target market, the main characteristics of each of the most relevant strategic positions are described herein.

Positioning within the flexibility value chain

Aggregator

As explained throughout this work, an aggregator is the figure that creates flexibility services based on the aggregation of demand-side and supply-side flexibility. The aggregator brings the aggregated flexibility to the market where it can be monetized. Aggregators can benefit from B2B and B2C relationships, as it has been explained in Section 4. As in many power systems today electricity services are provided by Balancing Responsible Parties, the aggregator provides the flexibility service to the BRP; there might be cases in which the aggregator can become a BRP and become a market agent itself.

The aggregator can provide services to different market actors but does not sell at own risk to buyers since the aggregator has no balancing responsibility. Depending on the services the aggregator provides and the assets aggregated, we can differentiate various sub-business models. VPPs can provide forecasting, trading and curtailment services to renewable portfolio managers; they can also aggregate renewable generation and dispatch it in a coordinated manner. In these models, diverse resources are bundled and orchestrated to mimic the services that would provide a single power plant.
An aggregator can also simply aggregate demand response and trade the explicit demand side flexibility. This is the most mature form of VPP, where firing up fossil fueled generators is substituted by ramping down loads in real time. The largest demand response market is the United States.

State-of-the-art residential VPPs will focus on the residential sector and aggregate assets within this market segment. This type of VPP is the one utilities and distribution system operators can mostly benefit from. The target assets are rooftop solar PV, residential storage, controllable HVAC and electric vehicle charging. This type of VPP can provide solutions to grid congestion problems and contribute to peak shaving. For this VPP to be feasible, a sufficient financial incentive for residential customers needs to exist, as end-user will not allow third parties to access their loads at any price.

Lastly, mixed asset VPP are a combination thereof. Mixed asset VPP are the ultimate goal of VPP as it brings together generation, storage and loads and benefit from the synergies created when dispatching the diverse pool of assets in a coordinated manner. This is the market segment that has experienced dramatic growth in the last years.

For the purpose of illustrating the aggregator business model the business model canvas tool is utilized.

![Business model canvas for an aggregator, own elaboration](image)

Key activities and key resources can be split into three categories: (i) demand response, (ii) renewable generation and (iii) storage. Large and medium-size C&I and residential loads can be used to offer demand response while generation assets can be bundled and benefit from participating in the markets as large aggregated volumes. Demand response is the more mature
technology for VPP participation and it has potential in all sectors: industrial, within steel, chemical, refinery, paper and other electro intensive industries; tertiary, within commercial refrigeration, air conditioning, space & water heating and ventilation; and residential, within refrigerators and freezers, washing machines, dishwashers, HVAC, heating systems and water heaters. Whereas C&I demand response is becoming increasingly common, demand response for the residential sector is still lagging and can only be feasible with automated services.

The customer segments addressed by an aggregator are divided into two groups: on the one hand, from the side of the assets there are the customers that benefit from being aggregated to participate in the energy markets; on the other hand there are those agents that benefit from the bundled flexibility and pay for the flexibility services the aggregator provides. The customers from the asset sides are the owners of the assets identified on the ‘key resources’ block. The customers that can buy services from an aggregator can be a BRP, the TSO and DSO through the balancing markets and ancillary services markets; aggregators can also participate in the wholesale electricity markets and sell the energy to any participant thereof.

The revenue streams of an aggregator will be dependent on by which mechanism does he monetize the flexibility. If the bundled flexibility is sold through the ancillary service or similar mechanism to the TSO/DSO, it will be standardized and have a fixed price based on availability and utilization. The price might be the result of an auction or determined by the market, but it will be defined through a standardized procedure. If the flexibility is sold to a BRP or a third party the price does not need to be standardized and conditions of the transaction will be defined in the signed contract or purchase order.

The most important cost for aggregators is the remuneration paid to flexibility providers. Generally aggregators will charge a fraction of the income generated to the asset owners. Aggregators also need to pay for platform utilization or can develop their own platform, with the development costs associated to it.

For emerging startups finding channels to reach clients and establishing successful client relationships might be challenging. Aggregators that are also energy retailers or suppliers an already have in place a network of energy end-users can find less difficulties for doing so. In any case, sales and awareness can be reached through social media, cold and warm phone calls and visits on site.

In short, an aggregator business model is feasible as long as regulation enables aggregation, distributed energy resources are available, efforts are made to develop a network of potential clients and the flexibility needs of the power system are high and therefore flexibility is adequately valued and priced.

Technology platform

Developing an effective platform to enable the aggregation and market participation of distributed energy resources is technically complex and costly. There are several software companies focused on developing software solutions and selling them as white-label products to utilities, TSO/DSOs and independent aggregators. There are also aggregators that develop own proprietary solutions for their aggregation activity. Some of these companies might eventually sell the platform to others to create an alternative revenue stream. Some companies start borrowing the software from a platform developer and eventually pivot to an own
proprietary platform. In all cases the software platform is the cornerstone to build a successful virtual power plant.

Orchestrating large volumes of diverse distributed energy resources requires large computational capacity, advanced artificial intelligence based technology, market trading algorithms and predictive models. Many different fields of computer science need to be integrated into the platform to be operative and perform adequately. As developing such a complex platform requires a know-how that is quite different from the one needed to operate a virtual power plant, it is common for smaller companies to outsource this job and buy a fully operative platform to reduce personnel costs, risk and time-to-market.

There are two main different solutions for an aggregation platform, as it has been explained in section 4. The VPP platform, with a bottom-up approach reaching prosumers, end-users and generators and taking them up to the energy markets; and DERMS (Distributed Energy Resource Management System) platform, with a top-down approach addressing the TSO/DSOs and utility needs to manage portfolios of distributed energy resources. For further takeaways on the difference between these two platforms refer to section 4. There are also integrated platforms that can comprise the two functionalities and even add other like inertia measurement or local energy community capabilities.

The software development part of the VPP value chain is the most scalable one, as one platform that has been proven in one electricity market can be modified to perform in another power system. The large number of companies developing this kind of solutions demonstrates its feasibility.

The business model canvas tool is used for the purpose of illustrating the technology platform business model:

![Figure 66 Business model canvas for technology platform, own elaboration](image)
The key activities performed by a company willing to create a platform for aggregation of DERs is the obvious platform development and the commercialization of the developed platform. How technologically advanced and intelligent the platform is will define its competitive advantage against other platform developers. For doing so, a team of expert computer science engineers assessed by engineers with specific know-how of the energy sector is required. Also, regulatory and market knowledge of the specific power system the platform is designed for is also crucial. Eventually, the company might find necessary to fill patents application and protect its intellectual propriety. Also, most of the platforms in the market today are cloud-based; moving to multi-cloud system is a trend among many companies and aggregation platforms need to fit into cloud schemes. Lately, a sales team to effectively commercialize the platform is also important.

The technology platform provider will address TSO/DSOs and utilities mainly if the product is a DERMS and independent aggregator and energy retailers if the product is a VPP platform. Customers will see value in the monetization of the flexibility of their portfolio assets and in the visibility, control and optimal dispatch of their portfolios of DERs. Building a modular software architecture is generally a good option as it increases marketability options, scalability and might enable integration into third party’s software platforms. Also, opting for modular architectures can smooth the way for custom-made platform developments for specific customers.

Revenue streams will mainly be a fraction of the generated incomes due to the utilization of the platform. This form of billing customers is adequate as in many cases the price of the generated flexibility is not known in advance, as it is the results of the market or of auctions. Customers might also be charge a fixed periodic fee for the utilization of the platform and technical assistance services that might arise. For custom made platform solutions ad-hoc fees are paid.

The cost structure for this type of company is based in low operational costs as the main costs are salaries and costs associated to cloud services. As the needed team needs to be highly skilled and with expertise, associated salaries might be high. However, the cost structure remains virtually the same regardless of the number of clients reached.

Regarding the customer relationships, the platform development company needs to perfectly understand the needs of the potential customer segment so as to be able to offer them valuable products. For this reason, customer segments in each power system and in each country might have slightly different needs and therefore specific know-how of each market is relevant. The channels for reaching these customers are the regular social media, websites, cold and warm calls and on-site visits. For this kind of highly technical product, relying on an extensive network of potential clients can be differential for commercial success.

In short, the development of an aggregation platform is a technically complex activity that requires specific and deep computer-science know-how. The feasibility of the business model can be achieved due to keeping associated operation costs low as the cost structure remains almost the same regardless of the customer base reached.

**Market agent**

In many countries the independent aggregator needs to become a BRP in order to directly participate in the market. This is required for the following two reasons: (i) only BRP can offer flexibility services to the TSO; (ii) the aggregator may cause an imbalance if the realization of the demand response activation differs from the expected and agreed output. The TSO needs to
have an agent that holds responsible for the imbalance; therefore the aggregators’ flexibility portfolio needs to be part of a BRP’s portfolio (USEF, 2015).

The Transmission System Operator is the one that holds the responsibility for maintaining the instantaneous balance between load and generation. In many power systems, this responsibility is outsourced to BRP. A Balancing Responsible Party is defined as a private legal entity that overlooks the balance of one or multiple access points to the transmission grid. The BRP portfolio is also called the balancing group. The BRP composes a balanced portfolio by combining injection, off-take, exchange with other BRPs and possibly in- or export to another control area. Each generator and off-taker in the grid is obliged to have a contract with a BRP. Alternatively, they can be their own balancing responsible party (Next Kraftwerke, 2020).

A BRP needs to make sure that its balancing group is in balance, by managing power injection and load consumption among its portfolio and by trading with other BRPs through the power markets. If a BRP has excess generation and other BRP has energy shortage, these can reach an agreement to balance their balancing group. The resulting imbalance that is not settled is resolved by the TSO through the contracted reserve power providers. BRP are charged a tariff for the imbalance caused.

Aggregators that combine the role of aggregator and BRP are here referred as market agents. Relations between aggregators and BRP or other aggregators are not clearly defined in most European countries. These can cause conflicts related to caused imbalances and financial compensations. In some cases, aggregators need a contract with a BRP, which hinders market entrance. For these reasons, market agent aggregators are better designed for today’s market as they face less barriers for market participation.

If the role of the independent aggregator and BRP are combined, two BRPs are located on the same connection point: the independent aggregator as the BRP and the supplier as the BRP. The aggregator has an agreement with the consumers of the supplier and the supplier will have to be compensated for the electricity that was sourced on day-ahead or other markets. For this reason, it might be challenging or impossible to know the correct sourcing costs of the supplier to perform a correct financial transfer. Furthermore, there might be practical implications when the aggregator contracts with multiple customers from different suppliers. Finally, the imbalances of BRP (supplier) and BRP (independent aggregator) need to be adjusted.

The business model canvas tool is used for the purpose of illustrating the market agent business model:
As it can be seen from the figure above, the business model is quite similar to the business model of the independent aggregator, with the key difference in holding responsibility for keeping its balancing group in balance and the costs associated to any imbalance that might occur. Ultimately the virtual power plants are thought to directly participate in the market; however, if this possibility is more feasible than just being an independent aggregator needs to be further explored.

In brief, there are different ways of creating value from the concept of the virtual power plants. Regulation needs to be adapted to enable some of the herein referred business models. In any case, as it will be further explained in section 6, business models around VPPs are feasible and the market is experienced dramatic growth in the last years.

**New venture business model for the Spanish Market**

The Spanish market is considered for creating a new venture because: (i) it is unexploited, with only a few players at early stages of development, (ii) there is high renewable resource available, the weight of wind and solar in the energy mix is large and has ambitious VRE penetration objectives, (iii) national regulation is starting to open markets for demand-side and aggregator participation in 2020, (iv) Europe is fostering, among other things, the implementation of this type of solutions to various regulations and directives included in the EU Network Codes and the more recent Clean Energy Package and (v) specific know how of the Spanish market due to current location and expertise. Also, this business case is designed for an energy player, ideally
a utility, who wants to disrupt the market and strategically position themselves in the Spanish emerging flexibility market.

**Previous considerations**

**The energy mix**

Getting to know the specific energy mix for the target market is crucial as the implication it have in the system flexibility needs are quite relevant. Installed capacity and electricity generation in Spain present quite different figures, as the Spanish power system is largely oversized. CCGT are the source with the more installed capacity and historically has not been one of the main sources for electricity generation; however, just recently Spain strongly committed to phase out coal and therefore the contribution of gas to the generation mix has been increasingly relevant. Renewables are growing in the mix every year, while nuclear keeps being a reliable and important source despite not being that impressive in terms of installed capacity. Even tough Spain will not build new nuclear capacity in the future, current operating reactors are expected to keep running at least for two more decades. As coal is being phased-out, the 26 GW of gas generation will be kept as a reliable and fast acting source of backing power in a mid-term with higher penetration of wind and solar.

![Figure 68 Installed capacity and electricity generation mix in Spain 2019 (REE, 2020)](image)

The current generation mix is expected to face dramatic transformation in the starting decade. In 2019, the renewables accounted for 39% of the generated electricity whereas the Spanish NCEP foresees this figure to grow to up to 74% (MITECO, Gobierno de España, 2020). This will be possible by the growing importance in the mix of wind and solar, the promotion of pumped hydro storage and other energy storage resources. Having an energy mix with such a high penetration of VRE means that it will be common for the electricity generation to reach 100%
renewable at some point. If this scenario materializes, the systems needs for flexibility source will probably skyrocket.

DERs penetration

Spanish NECP also fosters distributed generation, self-consumption, energy storage, demand-side management and local energy communities. The proliferation of these new agents in the energy landscape will create a broadening pool of potentially available energy resources to be aggregated and provide energy services. A regulatory framework is being developed to enable DSOs to manage the provision of balancing services from distributed resources at a local level. This local energy markets, that will probably be up and running before the turn of the decade, are already in testing in Spain with IREMEL project (OMIE, 2019). Self-consumption, both individually and at a community level, was already promoted and to some extent ‘enabled’ by the RD 244/2019 (Ministerio para la Transición Ecológica, 2019) which eliminated the so called “tax sun” and recognized the figure of self-consumers.

From 2018 to 2019 the number of distributed solar installations grew at an 80% rate, whereas the installed capacity only grew by 40% (ANPIER, 2019). In any case, the trend for distributed solar is showing dramatic growth. Distributed energy storage systems, on the other hand, are lagging in Spain but might also experience noticeable growth as unit costs are reduced and customer awareness raises. High efficiency CHP which is also fostered by Spanish NECP and perceives a specific retribution scheme just as renewable sources will still be a relevant energy resource in the mid-term. The penetration of electric vehicles and charging infrastructure is also relevant, as electric vehicles will be an important distributed energy resource as smart charging and V2G capabilities are developed. Predictions foresee 1.3 million EV chargers by 2025 in Spain (Transport & Environment, 2019).

In short, the potentially available distributed energy resources in the mid-term in Spain creates an appealing business case for VPPs.
Regulation

Substantial regulatory push is needed in order for participation of the demand-side to gain traction. The implementation of effective regulatory frameworks and adequate incentives for the enabling demand-side participation and aggregation are crucial to widespread implementation of Virtual Power Plants.

Liberalization and unbundling of energy markets is seen as a fundamental prerequisite for a market to be adequately suited for VPPs. A liberalized market means that all customers can freely choose their electricity supplier, and that new agents can enter the market as suppliers or generators. A market that is not liberalized would not allow for independent aggregators to enter the market and therefore implementation of VPPs would be limited. Unbundling means that supply, transmission and commercialization of energy is done by separated agents. This is a necessity as VPPs would only participate in the supply-side of the chain.

There are other regulations that need to be in place in a liberalized and unbundled energy market in order to create an appropriate ecosystem for VPP to emerge. Regulation that supports smart meter rollout in order to enable Time-of-Use tariffs and potentially direct load control and appliance standards for widespread demand response functionalities among assets. However, the most important policies and regulation are found in the market rules and network regulatory framework.

In Europe, the framework under which energy markets operate is the Third Energy Package, which came into force in 2009 and is now being replaced by the Clean Energy Package, with an ongoing implementation that will take from 2019 to 2021.

European Union electricity markets are all liberalized and unbundled (except from Bulgaria and Malta). They are also required to ensure the implementation of smart metering under EU energy market legislation in the Third Energy Package (European Commission, 2020).

As for market designs and network regulation, the main challenges are represented by (i) being able to bundle enough small energy assets to meet market minimum bid sizes, (ii) increased uncertainty in asset availability due to long lead times between the offer and the asset being called, (iii) the imbalances caused by the difference between the agreed response and the actual response and (iv) the needed response length and speed of return to load (UK’s Department for Business, Energy & Industrial Strategy, 2017).

The most relevant regulation affecting the development of aggregation and VPP are the EU Network Codes, especially the Commission Regulation 2017/2195 establishing a guideline on electricity balancing; the Clean Energy Package that relieves the previous Third Energy Package and in Spain the recent Climate Change Law.

Figure 70 Evolving regulatory framework, own elaboration
The Clean energy for all Europeans package

In Europe, the Clean Energy Package, which was first proposed in 2016, addresses some of these issues. It is a package composed of eight different legislative proposals that aims to redefine the energy markets in the member states working towards four areas (Linklaters, 2019):

i. New electricity market designs.
ii. Encouragement and integration of energy from renewable sources.
iii. Energy efficiency.
iv. Institutional framework.

The eight legislative proposals are:

i. Internal Electricity Market Directive; will have to be transposed into national legal systems by the end of 2020 and replaces the Directive 2009/72/EC.
ii. Internal Electricity Market Regulation; will be binding and applicable in January 2020, replacing Regulation No. 714/2009.
iii. Recast of the ACER Regulation; replaces Regulation No 713/2009.
vi. Energy Efficiency Directive; revises existing directive 2012/27/EU and modifies existing articles directly related to achieving the 2030 targets and introduces some new articles to extend customer rights.
viii. Regulation on the Governance of the Energy Union

Each of the legislative proposals have different implementation times; some are regulations (which are binding without being transposed to national legal system) and others are directives (which need to be transposed into national legal system within a deadline). In order to evaluate the regulatory framework for aggregation and demand-side management, the aspects addressing these issues in the different legislative proposals will be evaluated.

Figure 71 Transposition of the regulations and directives of the Clean Energy Package, own elaboration based on (Linklaters, 2019)
2.1.1 Regulation on the Internal Electricity Market

The goal of the regulation on the internal market for electricity is to set the basic guidelines for the correct operation and the integration of the electricity markets, allowing nondiscriminatory market access to all players. This regulation came into force in July 2019 and is regulatory binding since January 2020.

This regulation sets the principles that will govern the national electricity markets in the coming years. Under this framework, the core principles of the energy markets should guarantee that all customers are empowered to participate in the energy markets. Aggregation of generation or load to provide bundled offers needs to be allowed and incentives for energy efficiency need to be provided. Demand, storage and generation are to be treated equally and in a non-discriminatory manner in the market.

As for the market, caps or floors shall not be introduced. Short market intervals shall be implemented and small products with bid sizes of less than 500 kW in order for demand, storage and small generators to be able to participate. All market participants shall individually or by aggregation have non-discriminatory access to balancing markets. Information about balance requirements and system imbalance needs to be published by system operators as close as real time as possible. Market participants shall be responsible for the imbalances caused and may delegate this responsibility into a third party (Balancing Responsible Party).

Dispatching of electricity generation and demand response shall be non-discriminatory, transparent and widely market-based. The access to the network shall be equally established to any kind of market participant, regardless if it is generation, storage or aggregation and regardless if it is connected at the transmission or distribution level. The figure of the DSO shall be created, which may, among other tasks, facilitate the integration of demand side flexibility and cooperation with TSOs.

The Regulation also foresees the creation of network codes that address, among other issues, aggregation, demand-side management, energy storage and rules for cyber security (UK’s Department for Business, Energy & Industrial Strategy, 2017).

In conclusion, the come into force of this European Regulation will strongly benefit the case for Virtual Power Plants, as minimum bid size and timeframes within energy markets are reduced and all market participants will be equally treated. It also establish the framework for TSO-DSO
cooperation and incentives for the use of local flexibility markets for efficiency and congestion management, in which aggregators will play an important role.

2.1.2 Directive on Common rules for the internal market for electricity

This directive’s goal, which is a recast of Directive 2009/72/EC, is to adjust the energy system to the new paradigm that the energy transition creates. For that purpose, the directive asks member states to create a competitive, end-user centric and flexible power system. This directive must be transposed into national law system by the end of 2020.

This directive looks to position the consumer in the center, by empowering them and forcing distributors to offer price dynamic tariffs and facilitating their enrollment into aggregation programs and the switching between suppliers and aggregators.

Consumers should be fostered to become prosumers and actively participate in the energy markets and ancillary services provision, either directly or delegating into other parties. It also facilitates the creation of energy communities and exalts the labor of the DSO in the new flexible power system.

The directive also fosters the creation of local energy communities as a result of the proliferation of distributed energy resources and customer empowerment. Energy communities are focused on sustainable and affordable local energy production and trade as opposed to traditional profit-driven central energy supply.

Lastly, demand response capacity shall be audited before the construction of new generation capacity is approved (European Commission, 2019).

This directive will also greatly impact the potential deployment of Virtual Power Plants, as VPPs are mainly about empowering small end-users to participate in the energy markets when aggregated at scale. By empowering consumers and putting them in the center of the energy paradigm, the system will be able to benefit from the value created when small decentralized assets are aggregated.

2.1.3 Other directives and regulations

The other regulations and directives included within the mentioned Clean Energy Package do not address directly aggregation or demand-side management and therefore are not as relevant.
as the documents mentioned above. However, they are also indirectly related as, for example, the requirements of a minimum 32% renewable share of gross final energy (Directive on Energy from Renewable Sources) will have an impact on the overall flexibility requirements of the system and therefore benefit the emergence of solutions such as VPPs. This Directive also promotes energy self-consumption and the sale of the excess energy through aggregation (European Commission, 2018).

The Directive on Energy Efficiency (European Commission, 2018) and Directive on the Energy Performance of Buildings (European Commission, 2018) will also indirectly affect the penetration of demand-side response, as cutting consumption instead of generating surplus energy is a clear measure towards efficiency.

The adoption of the Clean Energy Package will have a substantial impact in the forthcoming energy transition and in the deployment of flexibility solutions. However, as the nature of the Clean Energy Package is high-level, specific national regulations will be needed in the coming years to amend and compliment the European regulations and directives and will influence the development of the power system in each region.

Harmonization of ancillary services within the ENTSO-E

The Commission Regulation 2017/2195 establishes a guideline on electricity balancing and creates a framework for the creation of a harmonized market where TSOs can exchange the resources used to maintain balancing within the ENTSO-E [160]. The ENTSO-E is the European Network of Transmission System Operators of Electricity. It was created in 2008 and its main goal is to create a unified electricity market within the European Union. One of the most important ongoing projects that the ENTSO-E is undertaking is the harmonization of the European balancing services. Creating standardized balancing products and other ENTSO-E efforts for cross-border interaction between neighbor power systems will boost market scalability of Virtual Power Plants. VPP are now in most cases limited to one geography as making the leap of operating in other power system with different regulation and defined market products is a strong barrier.
These projects are:

- **IGCC**: International Grid Control Cooperation, for harmonization of imbalance netting process.
- **PICASSO**: Platform for International Coordination of Automated Frequency Restoration and Stable System Operation for harmonization of automated Frequency Restoration Reserves.
- **MARI**: Manually Activated Reserves Initiative for the harmonization of the manual Frequency Restoration Reserves.
- **TERRE**: Trans-European Replacement Reserves Exchange, for harmonization of Restoration Reserves.
- **FCR Cooperation**: for the harmonization of the Frequency Containment Reserves.


The International Grid Control Cooperation is a project for strengthening the maintained balance in power systems by establishing procedures for avoiding the usage of simultaneous opposite balancing mechanisms between neighbor TSOs. The project, which was launched by the ENTSO-E in 2016, is currently operative in 20 member states’ balancing areas (ENTSOE, 2016).

The Platform for International Coordination of Automated Frequency Restoration is the project for creating a unified market between the ENTSO-E TSOs to be able to exchange frequency restoration reserves that are called automatically while integrating the European aFRR markets and fostering economic and technical efficiency within the limits of system security (ENTSOE, 2017).

As defined in the European Electricity Balancing guideline the Manually Activated Reserves Initiative is the project for the implementation of a platform to allow the exchange of mFRR reserves. This unified market’s purpose is to secure economically efficient purchase and in time activation of balancing energy by simultaneously ensuring the financial neutrality of the TSOs. For serving this purpose standardization and cooperation between TSOs is needed (ENTSOE, 2017).

The aim of the Trans European Replacement Reserve Exchange project is to establish a unified platform for the exchange of long lasting reserves, namely Restoration Reserves. The Electricity Balancing Guideline sets the regulatory framework to standardize and define technical, operational and market rules for the cross border long term reserves exchange. From all the
ancillary services harmonization projects TERRE is the most advanced one and aims to share the acquired knowledge with the other ENTSO-E balancing projects. The IT platform being developed for the purposes of this project is called LIBRA (ENTSOE, 2017).

Lastly, the Frequency Containment Reserve cooperation project aims to establish a common market for the procurement of automatic fast acting reserves. These project is currently backed only by the central European TSOs. As FCR is traditionally provided by synchronous generators with a governor in a compulsory and non-remunerated manner and due to the fact of the fast evolving energy mix towards renewable generators that communicate with the grid through inverters, this project is facing constant evolution (ENTSOE, 2017).

In short, the standardization, harmonization and creation of unified platforms for the exchange of all the different balancing products is seen as positive for the adoption of Virtual Power Plants, and these will potentially participate in the provision of such services and could see enhanced growth as a result of the adoption of these initiatives.

Implementation in Spain roadmap
According to Spanish TSO, TERRE project has already gone live in the first quarter of 2020 whereas the IGCC projects is scheduled to go live in the second quarter. During the third quarter regulatory and prequalification tests will take place in order to permit demand side assets to participate in balancing provision, both individually and aggregated. In this line, minimum capacity requirement has been lowered from 10MW to 1MW. Caps and floors have been eliminated from balancing markets, IT and metering infrastructure is being adapted and aFRR reserves are switching from a pro-rata activation mechanism to a common merit order list (REE, 2020).

![Figure 79 Electricity balancing implementation roadmap (REE, 2020)]
Creation of an internal market for electricity within the EU

One of the goals of the European Commission is to create a unified market for electricity within the member states. By doing so, the global reliability and economic efficiency of the power system is enhanced. Even though many power systems in Europe are in the same synchronous zone, the main limiting factor concerning the creation of such market is the interconnection capacity between neighbor power systems. This limiting capacity also affects the implementation of common platforms for the trade of standardized ancillary services, as no energy can be traded between systems if the line is congested most of the time.

Synchronous areas mean that energy can be exchanged directly via AC power lines. Energy can also be exchanged between non-synchronous areas by implementing DC lines. DC power lines are not exclusive to non-synchronous energy exchange as they are also utilized for long distance and subsea energy transmission.

The first step in this initiative was the implementation in 2018 of the Cross-Border Intraday project, as a result of the implementation of European Regulation 2015/1222 Guideline on Capacity Allocation and Congestion Management (European Commission, 2015).

The aim of the Cross Border Intraday project, known as XBID, is to create a pan-European unified cross-zonal intraday market. It is identified as a key component for creating the European Internal Energy Market. As the penetration of renewables keeps increasing, the added intermittency to the supply side of the scheme creates the necessity for additional tools to help the different agents keep their positions balanced. For this reason has been created the XBID market (Amprion, 2018).

The increased reach of energy markets is seen as positive for the development of Virtual Power Plants, as it creates more opportunities for larger aggregation of loads and enhances the opportunities to increase the overall efficiency of the power system.

Climate Change Law

The Climate Change Law project has been recently send to the Spanish parliament and is in process of being approved. The draft, which has already been released, lays the regulatory groundwork for the energy transition in Spain as sets ambitious targets and initiatives. Some of the key aspects of this draft are:

- The energy transition in Spain is expected to create between 250,000-350,000 jobs and will contribute to the GDP with between €16,500-25,700M annually.
- The target of renewable energy in the generation mix is now set in 70% by 2030, as opposed to the 74% figure that was stated in the NECP.
- The Electric Sector law is modified to introduce the figures of the energy storage facility owner and the independent aggregator. Until the figure of the independent aggregator

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is developed and recognized in the applicable regulation, aggregation will only be allowed through retailers. So as this law is not yet approved, there is no contradiction with the Electricity Balancing guideline that states that aggregators will be able to participate in the balancing markets in the third quarter; however, until this law is approved and the figure of the independent aggregator is completely developed, only retailers will be able to perform aggregation activities.

- An additional retribution scheme for renewable generators will be developed in order to raise stability and predictability of incomes and ensure return of investment for new generation capacity, in order to guarantee in the future the security of supply.
- Pumped hydro storage will be promoted.
- Energy efficiency and building rehabilitation will be fostered.
- Only zero-emissions vehicles will be allowed to register by 2040, and only zero-emissions vehicles will be allowed in the roads by 2050.
- No more subsidies and permits will be awarded to fossil fuel exploration, development and research and public institutions will start a process of divesting in fossil fuel companies.

Under this context, Spain shows its commitment to become a spearhead in the energy transition, creating a level playing field for aggregation and distributed energy resources and bolstering the business case for VPPs.

Business model proposal

In order to address the described opportunity in the Spanish market, a sustainable business model needs to be designed. For doing so, addressing the target customer segment through an adequate value proposition is needed. Also, a product map for developing the defined product features and a business plan for implementing the business unit also need to be outlined. For the definition of both the product and the business model solutions capitalizing demand-side flexibility have been scouted and analyzed. Most solutions that are currently experiencing noticeable traction in the markets are addressing this opportunity with EMS (Energy Management System) and VPP solutions.

An EMS is any product or service that monitors, controls, or analyzes energy in a building. This definition includes home/building automation services, personal energy management, data analysis and visualization, auditing, and related security services. Despite EMS not being necessarily an integral part of a VPP, they act as a control gateway for the means of a VPP and optimize energy use at a local level. For this reason, EMS solutions are identified as a precursor and a key driver for the emergence of a business case for VPPs. Also, this venture creation is planned for an energy player, potentially a utility; EMS are systematically used by this type of companies as a tool for customer engagement and retention, both as own-developed proprietary solutions and third party’s EMS. For the above mentioned reasons EMS are also considered as a potential tool within the business model.

Product definition

After extensive desk research and screening analysis of more than 100 solutions to address demand-side flexibility, most of them in more mature markets, the following conclusions are withdrawn:

- Regarding the product:
Best in class solutions are designed to manage future energy scenarios regardless of current market situation. A clear energy trading orientation (VPP) influences EMS purposes and configuration.

Entities developing VPP solutions also have their own EMS to reach their customers’ assets, both monitoring and acting on them to provide services within the electric market.

Batteries and Solar PV systems are currently very mature although their penetration in residential and tertiary markets is progressively growing. Best in class solutions are beginning to develop capacity in DR, but these capabilities are not fully developed nowadays.

From the above takeaways we conclude that when designing a product a strong dependence between EMS and VPP is identified, embedding their shared software infrastructure (data architecture) within the same core platform.

Regarding the customer segments:

A clear differentiation is highlighted between residential and industrial solutions. Residential developments show higher scalability and repeatability, whereas industrial solutions involves tailor-made implementations.

Less scalable solutions focused on particular key features deploy business models based on differentiation, allowing them to reach specific customer segments or provide energy services more effectively.

As a conclusion, it is identified that best in class solutions are scalable ones built from core platforms, which enhances their market reach and service offering, and include value added differentiation features.

Regarding the strategic approach:

EMS solutions including DERs and loads operation as well as smart devices are the baseline offering to efficiently reach the residential market.

Tailor-made EMS solutions including DERs and loads operation are the baseline offering to reach particular commercial and industrial market segments.

VPP solutions connected to the energy market aggregating DERs and loads are the baseline offering to enable energy trading.

In short, differentiated product offering strategies to each of the target customer segments will boost profitability, while combining EMS and VPP management through a single core platform seems an appropriate approach to first reach customers in both residential and C&I segments and then operate the VPP once the needed critical mass is achieved.

For this reason, the proposed product offering consists on an EMS/VPP integrated solution. Even though EMS and VPP are two independent products, sharing a common core platform can be the needed source of competitive advantage to outperform competitors within the industry.
Figure 82 Value Proposition Canvas for the defined product, own elaboration

For doing such a thing the combined solutions will need to account for the following module features:

- Data storage, Data acquisition and Software architecture: the way in which data obtained internally (e.g. smart meter data) and externally (e.g. weather forecast, grid status) is structured for the algorithms to run it. A general IT understanding may probably be enough to prepare data correctly for its subsequent analysis. Leveraging in cloud computing and edge computing to lighten the in-house EMS device can differentiate the product from competing ones.

- Connectivity: the extent to which assets/devices are capable of communicating amongst each other. Degree of compatibility with different home communication protocols. A specific business-level knowledge is required to define device-level communication standards. Internet-of-Things seems the most promising way of accessing all sorts of assets.

- Predictive modelling & Optimization: specific algorithms used to obtain results from data in a specific period of time. How data from various sources is combined to create predictive data models. It is needed for reducing to a minimum the impact of demand-side management in end-users’ comfort, imbalance costs due to inaccurate renewable output or demand forecasts and maximize market trading outcome. This is a critical factor towards the successful formulation of EMS/VPP solution.

- User interface: Front-end dedicated to customer interaction and data visualization. This is not a critical element of the EMS/VPP platform and may be developed externally. However, in order to reach and keep the residential mass market a user friendly interface and features that enhance customer experience are seen as a determinant factor.
• Security: Degree of security protocols required to prevent third party non-authorized interventions. This is a crucial aspect of the EMS/VPP solution, since the high levels of asset connectivity through a central inter-connected platform infer a higher potential of external unapproved access to data. Specific know how on cybersecurity are needed in order to develop a completely secure system. Blockchain is commonly referred as a solution for data privacy and secure transactions, however, specialized personnel shall validate which is the best approach.

• Electronics: All the necessary electronics required to satisfy connectivity between devices such as sensorization, solar PV inverters, etc.

Considering all the above, the defined product is in fact two different products integrated into a unified core platform. The EMS, with mature technology and customer acceptance in other markets, serves as a first approach to engage customers. The EMS can itself be divided into three different products: an EMS for the residential segments, which shows high scalability but the managed load is smaller in size; and an EMS for the commercial and industrial segments. While commercial EMS will be more focused on large HVAC systems and EV charging infrastructure, industrial EMS will require a tailored approach to each specific industry but will make possible to manage large industrial loads. Once the EMS is sufficiently mature and a relevant roll-out has been achieved, deploying VPP functionalities by aggregating the previously installed EMS can differentiate from competing players with VPP solutions that need to build a portfolio of DERs from scratch. Introducing the VPP functionalities to end-users will be easier if a user friendly interface has been used and a correct market strategy is followed, as customers trusting the VPP operator to shift their loads and control their DERs to some extent is crucial.
A source of competitive advantage is created by defining specific products that cover all customer segments and integrating the management platform of the DERs gateway (EMS) and the VPP. The residential EMS, which needs to focus on scalable solutions that can actively control mainly HVAC, electric boilers, hot water tanks and other large electric devices. The C&I EMS needs to focus on specific industrial loads and large HVAC devices. Also, the marketing approach is completely different, as the residential product needs a mass campaign whereas C&I needs local salesforce to approach individually each of the target customers. It also needs to be considered that each of the technological developments will follow a different product map.

**Business model structure**

Before defining the business model to go on on the venture, as this venture is proposed for an utility, it needs to be decided if the new venture will be an independent spin-off company or if it will be a business unit integrated into the utility’s core business. How to implement innovative and disruptive business models within long-established organizations is a recurrent issue for companies managing multiple business models. For this reason, a choice needs to be made within whether to integrate the business models, create autonomous business units or run separated companies. In order to evaluate this issue, according to Osterwalder’s strategy (Osterwalder, 2010), the similarity of the business models, potential for conflicts and potential for synergies needs to be considered. For this reason, the business model for the new venture is illustrated above. The business model of a generic utility is also shown.
In the figure above, blue notes refer to the VPP product; yellow ones refer to the EMS product whereas green notes are transversal to both products. In the figure below, a generic utility’s business model is shown:

In the figure above, blue notes refer to the energy supply business, yellow notes refer to the energy retail business whereas green ones refer to both. This distinction needs to be made as due to European regulation players performing activities in different parts of the electricity supply chain need to be differentiated entities.

From both figures, it can be noted that the business model of the retail business is not very different from the EMS product; at the same time, the supply business model shows some
similarities with the VPP product. Synergies from integrating both solutions are easily found, as the EMS product can serve as a customer engagement tool whereas the VPP product can optimize generation assets’ utilization. Also, the enhanced efficiency of such integrated solutions will foster brands’ awareness and environmental commitment, as perceived from the customer base. As there are clear synergies and no conflicts between activities can be found, the best decision would be to integrate the new venture within the firm’s core business.

As for the strategic positioning in the value chain, developing a proprietary software platform for aggregation is seen as the best option. The reason for this is that the main source of competitive advantage is the integration of the EMS and VPP into the same platform, and therefore developing and owning the core platform is needed. Also, the company could see additional revenues by selling their platform modules to third parties and providing maintenance service. Due to the fact that the Spanish market only allows aggregation through retailers, and considering that this venture is designed for a utility, both the aggregator and market agent positioning will also be covered. This strategy is validated by other market leaders in the VPP business such as Centrica, Enel or even others that are not utilities like Next Kraftwerke are also equally positioned in the three steps of the value chain.

As it can be seen in the canvas, the main value proposition of this venture is related to monetizing flexibility, both for end users and for the system and market agents that need that show certain willingness to pay for the underlying flexibility. The EMS product creates value by monitoring and controlling the energy consumption of households and businesses whereas through the VPP product end-users can access the energy markets while TSOs can benefit from low carbon ancillary services. According to that scheme, target customers segments will be households, C&I consumers and TSO, DSO, and other market agents that will pay for the provided flexibility services. The benefit of creating the EMS product is twofold, as it enlarges the customer base for the VPP and at the same time serves as a customer retention and engagement tool for the utility’s core business, as the new customer acquisition costs are usually relatively high. Develop specific EMS solutions for each industry is key in order to unlock scalability in that sector.

Lastly, it is crucial to regularly assess the business model, in order to allow the company to analyze and evaluate the health of its market positioning and adapt accordingly to its most suitable market fit at each moment in time. This evaluation might become the basis for incremental improvements, or it may trigger a serious intervention as a business model innovation initiative.

In conclusion, for a utility, creating a disruptive product such as the one proposed and integrating it into the core business might sound as a risky strategy. However, it is a great opportunity to apply the Blue Ocean Strategy (Kim & Mauborgne) and therefore for switching from competing in crowded competitive markets to creating new industries through fundamental differentiation. This can be done by increasing value for customers by offering them new products and services while at the same time reducing costs, in this case both for customers (energy optimization) and for the core business (optimized market participation). Utilities can take advantageous positions in the new energy paradigm by creating new, uncontested market space through value innovation rather than outdoing competitors in terms of traditional performance metrics.
Business model environment

A good understanding of the firm’s environment is key in order to successfully implement an innovative business model. The changes in the environment need to be detected by continuous scanning in order to effectively adapt to the ever changing scenario. For this reason, mapping the main areas that externally affect the business model of the organization is necessary.

From a market perspective, different market forces need to be analyzed. Customer landscape is changing driven by the widespread awareness of the climate change and energy transition. Residential customers are increasingly adopting home automatization solutions and large electro intensive industries are seeking for new revenues streams, especially in the Spanish market, where the interruptibility services, which traditionally sort of subsidized industries, is bound to disappear. Industrial segment have the largest loads to be aggregated and viability is closer in time than the residential segment. Also, the market is demanding flexibility from different sources and fostering the participation of new enabled agents. Customer switching to competitors might be hard first due to lack of involved agents in the business; however, European directive 944/2019 empowers the customer and sets switching costs to a minimum. Lastly, revenue of participating into VPPs needs to be sufficiently attractive for customers to engage in such programs.

From an industry point of view, the Spanish market has no incumbent players positioned in the VPP business. This makes sense as the markets have not yet been regulatory enabled. However, the electricity market is dominated by five large utilities: Iberdrola, Endesa, Naturgy, Repsol and EDP (EDP’s retail business has just recently been acquired by the major Oil & Gas player Total). As soon as markets are enabled, incumbents will probably gradually position themselves in the market, especially considering that Endesa is a subsidiary of Enel or that Total is positioned in this business in other geographies. As for new entrants, there are just a few that have been previously identified in the market overview section. In any case, developing and commercializing products as soon as regulation is adapted is key and can be a relevant differentiator factor.

As from a trend analysis point of view, the energy sector is facing an unprecedented transformation, from a fossil fuel based industry to a renewable and environmentally friendly industry. Energy supply is switching from centralized large generators to decentralized small generators. Regulation is evolving to accompany this transformation while societal and cultural trends are widely aware of the need to abandon pollutant power sources. Sector coupling, mainly heat and mobility, will increase the relevance of energy consumption management and digitalization trends will enable unprecedented control, monitoring and predictive features. Also, current uncertain socioeconomic situation will probably raise the need of reducing common expenditures, such as the electricity bill.

Lastly, from a macro-economic standpoint the world is currently facing another unprecedented event: the pandemic crisis caused by the coronavirus disease. This crisis has collapsed oil demand and therefore oil prices. Energy demand in general has also decreased due to hibernated economic activity. The economic crisis foreseen is uncertain and despite its effects, most experts agree that it will only last until 2022 in the worst scenario. Also, it is a common thought that the energy transition can be used as a key driver for the economic recovery. Spain, which is one of the countries that has been hit the hardest in this crisis, is also one of the best positioned countries to lead the energy transition due to abundant availability of renewable resource. Further, the current Spanish government is committed with the energy transition, which is clearly reflected in the recently proposed Climate Change Law.
In short, a business model adequate today might become obsolete in the future. Developing solid understanding of the business’ environment is key to dynamically adapt it to the specific situation at each moment in time. Current uncertain situation emphasizes such need. For this reason, evaluating different scenarios is a tool that can be used to evaluate how the proposed business model might behave in different hypothetical situations. In any case, the current early stage situation of the Spanish market, the energy transition and lack of competitors validate to some extent the rational of this proposed venture.

**Product map**

In the following figure, the different product features development and commercial implementations are illustrated.

![Product Map Diagram]

Once the Minimum Viable Product is developed and corresponding pilot projects have been undertaken, at a first stage a Virtual Power Plant integrating renewable generators and CHP, biomass and other small thermal generators. Meanwhile, an EMS that includes energy monitoring and energy management services for electro intensive industries; at the same time, a first approach to the residential sector can be accomplished providing energy monitoring services. Once this product is validated by the market, at a second product version the EMS and VPP platforms are integrated by adding C&I loads into the Virtual Power Plant. In the residential sector, energy monitoring services are complemented by local optimization and enabled customer control features on thermal loads, rooftop solar, electric vehicle charging and energy storage devices. On the last product version, all products are integrated into a unified platform and last optimization features on the residential sector are unlocked. By doing this, optimal timing can be achieved between technological development and widespread adoption of the different energy technologies, regulatory framework evolution and portfolio critical mass achievement to effective VPP operation. It shall also be noted that technological development goes beyond the MVP, and commercial products needs to be constantly updated and upgraded in order to maintain the source of competitive advantage.

**Implementation roadmap**

In order to go from the market opportunity to a consolidated market positioning, three main stages are envisioned. The first stage consists on exploring the target market and defining the
business strategy; this first stage corresponds with this work. Once the strategy is approved and the company decides to carry on with the venture, the second stage consist on conducting pilot projects and learn from the key takeaways of the piloting activities. Lastly, once the business strategy is running and the business model is validated the company can focus on growing their customer base and develop its market fit. The figure below illustrates the process.

In conclusion, by implementing the proposed solution the utility can adapt to the new energy paradigm and offer a complete Energy-as-a-Service product, by offering under the same brand the energy itself, consumption optimization features, asset control and market participation. By offering such an integral solution, switching costs for customers are high and a competitive advantage is created against those players offering standalone solutions. Also, with the electrification of end-use sectors energy management will become increasingly important for consumers and the demand for integrated energy services will be high.

Challenges
Despite the attractiveness of addressing the opportunity of monetizing flexibility through VPPs, there are still some challenges that arise. These challenges can be grouped into three categories: (i) related to the regulatory framework, (ii) related to the technology required and (iii) related to the business model.

Regulatory challenges
As for the regulatory framework, as it has been already explained in this section, it is evolving and the extent to which it will change the current paradigm is uncertain. There are regulations at European and National level and different implementation and transposition times. For this reason, there is a need for adapting to the dynamic regulatory framework and the foreseen new network codes regarding rules on bidding, zone configuration, cross-zonal transmission risk, demand response, aggregation, energy storage and sector-specific rules for cyber security. As
new players like self-consumers, prosumers, independent aggregators and local energy communities are being brought to the level playing field by emerging new codes, keeping the pace with evolving regulation and anticipating and integrating these new roles is key.

Coming down to specific aspects on which regulation might suppose a challenge for players positioned somewhere within the flexibility value chain, it can be highlighted that: regulation states that all market agents, including newly enabled ones, are bound to take financially responsibility for the imbalances they cause to the system; customers are empowered, which raise the need for customer centric solutions, as those engaged in aggregation have the right to switch from market participant within no longer than 24 hours by 2026; all market agents may be required to pay financial compensation to other market participants if those market participants are directly affected by demand response activation; In Spain, demand aggregation will only be available through retailers until the figure of the independent aggregator is developed.

In short, current and forthcoming energy policies and regulations are unlocking the participation of flexibility from demand-side aggregators in different markets but are also raising challenges for those participants.

**Technological challenges**

Flexibility solutions require advanced design practices to tackle existing challenges. There will be a great variety of asset types (from rooftop solar PV to industrial boilers), lack of standardization between vendors and market differences between countries. Flexible designs are needed to address this challenge; the use of APIs can ease integrations with different assets and vendors and designs based on modular architectures allow to adapt the solution to particular needs. There are some reference players with flexible solutions, like for example the German GreenCom Networks, whose solution is based in open APIs and modular architecture.

Real-time data management and asset orchestrations is also difficult from a technical standpoint. Forecasting and communications are essential as thousands of diverse assets have to be coordinated in real-time. This can be tackled by leveraging in cloud-based computing solutions that enable a quick deployment across regions and provides the ability to easily scale up or scale down the operation needs (data storage, computation capacity). A reference player in this field is the US-based market leader AutoGrid, whose cloud based suite (partnering with Amazon Web Services) enables for a rapid response and scalability.

Ensuring secure operations and transactions are also key, as more and more players are taking part in the aggregation model as it scales-up. Cybersecurity risks appear when connecting smart devices. This challenge raises the need for resilience configurations, which allow for high availability and fault-tolerant designs that grant the required availability in all energy trading, distribution, and transmission grid markets. As a reference in this field we could name the Canadian Enbala, whose products and services meticulously meet security standards and procedures.

Lastly, the ICT, metering and control infrastructure that is needed to deploy a VPP, specially a residential one aggregating large volumes of small loads, could be enormous. The business case for such a VPP might be hampered for this reason. This can be tackled by leveraging in hardware agnostic and vendor-neutral solutions, which enable monitoring and control without the need of in-site hardware installations. For serving this purpose, massive deployment of IoT enabled assets is crucial.
Business model challenges

The need for a sustainable and viable business model to tackle the opportunity of flexibility is mandatory. The existence of a financial incentive sufficiently relevant to engage end-users to participate into aggregation programs is perhaps the most relevant challenge that VPPs face. Enrolling into the portfolio of a VPP requires end-users to change their behavior and be willing to resign to some of their comfort in exchange of money. For this reason, the way markets value demand-side underlying flexibility needs to be competitive enough so as to offset the value end-users give to their use of electricity plus a margin corresponding the remuneration of the VPP. Even though this incentive seems to be competitive enough for the industrial sector, it is not yet confirmed the same for end users located in the residential segment.

Also, there are other relevant challenges related to the business model. The number of dispatchable demand-side assets is increasing but remains small. Electric Vehicles, energy storage and smart appliances boom is close but has not yet arrived. For this reason, companies should focus on consolidated flexible assets (CHP, C&I, small generators and renewables) to achieve the needed critical mass and gradually adopt disruptive flexibility sources as they mature.

It also needs to be considered that flexibility value chain is complex and involves a strong level of coordination between different agents and rarely can be fully covered by one player. Companies need to define an adequate strategic positioning to address the value chain in its most convenient step for the company.

In order to achieve a clear business case the solution needs to be scalable enough to be able to reach a substantial customer base while keeping operational costs low. Relying in hardware deployment can hinder scalability. Interoperability should be ensured by partnering with OEMs and technology providers. Establishing solid communications protocols and leverage in cloud/edge computing can also boost scalability (hardware agnostic solutions). Modular software architectures can generate additional revenue streams by being sold to third parties.

Also, there is no one-fits-all solution as each customer segment require a different approach. Residential demand is quite price-inelastic while C&I customers are more likely to adopt flexibility solutions. The residential sector can be addressed with enhanced user experience focused scalable solutions while C&I customers need an industry-specific tailored approach.

Specific regulatory and market know-how is needed. Players of more advanced markets can enter in emerging markets increasing the level of competition. For this reason, local players should encourage their country expertise and relationships, develop go-to-market strategies and design proprietary solutions adapted to its country-specific particularities to maintain their competitive advantage.

Lastly, product differentiation is key for gaining market relevance. Flexibility players experience difficulties in differentiating their products forcing them to low tariffs and lose potential margin. To tackle this, AI, predictive models and market algorithms are key differentiators. Also, flexibility solutions can be combined with other assets (e.g. smart chargers or thermostats) to achieve high value-added solutions and raise awareness about flexibility potential.
As illustrated above tailor-made incentives designed to meet customers’ expectations are key to encourage the adoption of flexibility from different customer segments. Also, a deployment strategy is required to scale-up capacity in a cost-effective and sustainable way, starting from consolidated assets to gradually adopt new flexibility sources. Lastly, high value-added solutions achieved through product ecosystem, partnerships and best-in-class technology are essential to beat the competition.

**Scenario analysis**

Business model innovation combined with scenario design can help a firm prepare for the uncertain future and identify those situations that can suppose a threat to the proposed model. For doing this, the business model needs to be projected into concrete and potential futures. In each of the potential scenarios the business case needs to be justified. In order to design four different scenarios, two criteria are considered: economic recovery from the coronavirus crisis and the pace of the energy transition in Spain. In each of the four scenarios, the best practice regarding the proposed business model is identified.
In scenario A, Spain keeps on track with the commitment made in the NECP and goes for an aggressive energy transition, aiming for a 75% electricity generation from renewables by 2030. The coronavirus crisis hits the Spanish economy harder than expected; GDP falls dramatically and unemployment skyrockets. As a consequence, wages fall and purchasing power of middle classes weakens. In this scenario, VRE penetration is high and thus the balancing needs for the system are important. Regulation enables demand participation and aggregation and overall energy demand falls slightly due to reduced economic activity. The adoption of distributed energy resources is low, as the return on investment they offer is too long to be affordable for the middle class. In this situation, focus shall be on developing C&I EMS solutions, as industries and other businesses with large consumption figures will need to optimally manage all their expenditures. Offering them tailor made solutions to decrease energy consumption and capitalize system flexibility needs could be a profitable business. The lack of DERs contributes to the lack of competition in the EMS and VPP business. Also, supply side VPP to optimally orchestrate small generators and renewable farms, while gradually integrate the C&I EMS solutions seem feasible in this scenario.

In scenario B, Spain follows the same trend regarding energy transition than in scenario A. The penetration of VRE drops the price of the pool, but regulated pays established to ensure the ROI of renewable generators maintain stable the electricity bill for consumers. The TSO’s demand for flexibility is high and different flexibility options compete for these services. Lithium-ion battery costs keeps the downwards trend to become massively affordable and grid-scale storage solutions are common. Regulation fosters investments in pumped hydro storage and Spain, due to its strategic geographic position and abundant renewable resource becomes one of the main hubs of hydrogen. Regulation favors all different flexibility providers and therefore competition for providing the so needed balancing services is fierce. The fast economic recovery contributes to widespread adoption of DERs and home automation solutions are increasingly common. In this scenario, both C&I and residential EMS are justified. Competition in the VPP business will be strong and therefore leveraging in a large portfolio of aggregated assets in order to be able to
provide ancillary services without remarkably affecting the end-users comfort. Also, the VPP will need to gradually adapt to aggregate the new technologies that are being enabled such as storage, electrolyzers, V2G and others.

In scenario C, like in scenario A, the economic recovery from the current crisis is slower than expected. The Spanish government decides to prioritize measures to reactivate the industry and puts off the energy transition. Penetration of VRE keeps increasing driven by the phase out of current power plants and decreasing prices for generated electricity, but the commitment of the NECP is not met. Regulatory framework slowly adapts to the changing scenario. The flexibility needs of the system are not as high as in other scenarios and the global economic crisis has made gas prices go to minimums and thus oversized CCGT capacity in the Spanish system are used to provide such services. The residential segment does not invest in DERs as end users need to reduce their expenses to face the recession. In this scenario, which is the worst of the four scenarios analyzed, the only feasible solution in the mid-term is the development of C&I EMS solutions, as businesses will digital solutions that can help boost their profitability whereas lower flexibility needs and hampered purchasing power of the middle class weakens the business case for VPPs and residential EMS.

Scenario D is probably the least probable of them all. The Spanish and global economy manages to recover from the economic shock but for some reason the strong commitment with the energy transition does not materialize. In this scenario, rooftop solar and energy storage solutions are more common and electric vehicle penetration is driven by purchasing power and environmental awareness. The fact that the system does not urgently need massive volumes of flexibility and the lack of environmental commitment makes regulation to be lagging to some extent. In this scenario EMS solutions for the residential sector can be implemented, as the willingness to pay of consumers will validate the business case for this solution. C&I EMS solutions can also find market traction, as technology allows to implement digital solutions to optimize businesses energy expenditures.

In short, the firm implementing this venture needs to constantly understand the business environment and adapt to the ever changing scenario. Different trends and events might

\[\text{Figure 91 Scenario analysis, own elaboration}\]
hamper the feasibility of one product feature or services while fostering another. Being aware of how the scenario, the system needs and the customer preferences are changing is key in order to sustain an economically feasible business model.
3 Model

Participation model

For the purpose of illustrating the operation of a Virtual Power Plant, a simplified model is herein evaluated. The aim of this section is to show an interaction model between various agents participating from a VPP. The model will be evaluated using the event timeline of the Nord Pool intraday market. The reason for illustrating the model in a market different than the Spanish is twofold: first, the Nord Pool market is one of the most advanced globally and VPP are currently operating in various geographies; the Spanish market is not yet adapted and corresponding system operating procedures need to be proposed and approved before VPPs start operating; secondly, one of the main trends of the European Commission is to create a unified market for electricity. This is reflected in the regulations and directives that are being approved that affect the electricity sector. In this scenario, as the proposed business model will take some time to develop and implement and in order to illustrate how a VPP could operate today, it makes more sense to evaluate it in a more advanced market. Thus, the Nord Pool is one of the largest and most relevant electricity markets worldwide. First the operation of this market is briefly explained and then the model of the VPP is presented.

The Nord Pool

The Nord Pool market was acquired by Euronext in January 2020; before that, it was owned by several Nordic TSOs: Statnett (Norway), Svenska Kraftnät (Sweden), Fingrid (Finland), Energinet (Denmark), Elering (Estonia), Litgrid (Lithuania) and Augstsprieguma Tikls AS (Latvia). The total volume traded in the Nord Pool market was 524 TWh and generated €40 million revenue. Euronext, who since recently owns the market, is the leading pan-European exchange, covering Belgium, France, Ireland, The Netherlands, Norway, Portugal and the UK; it operates regulated and transparent equity and derivatives markets and is the largest centre for debt and funds listings in the world (EuroNext, 2020).

From the total volume traded of 524 TWh, 8.3 TWh corresponds to the Nordic, Baltic and German intraday markets. Currently 360 companies from 20 countries exchange energy in the Nord Pool market. With a high penetration of renewables and relative stability in market prices and due to the traded volume, Nord Pool is the leading electricity market in Europe. Following the recent acquisition, Nord Pool’s ownership is divided between Euronext holding a 66% share and a joint holding company owning the other 34% share, which represents the Nordic TSOs (Nord Pool, 2019).

![Figure 92 Nord Pool regions (Nord Pool, 2020)](image)

![Figure 93 Intraday turnover in the Noord Pool (Nord Pool, 2019)](image)
The Nord Pool market, as most electricity markets in developed countries, operates by auctioning a day ahead and an intraday market. In the day ahead auction, which takes place at every day at midday, the price for each hour of the following day is set. The price is set following marginalism logic, by matching the buy and sell offers.

The intraday auction is called every day and products of 15, 30, 60 minutes and blocks are traded. The intraday market opens at 14:00 and closes one hour before the time of dispatch and consists of 24 blocks of one hour.

The TSO is responsible of fixing any imbalance that may occur after the intraday and wholesale markets are closed. For serving this purpose, the different ancillary services are called. If the load at any given time is lower than the generated electricity, the power used for regulation is negative (need to reduce generated power to match demand); on the other hand, if the generated power is lower than the energy demand, the generated power is positive (need to increase generation to match demand). Generators overproducing or consumers reducing their load in a balancing up scenario are paid; generators reducing their output or consumers increasing their load are paid in the balancing down scenario. One of the prices is the same as the hourly price of the day ahead price (AlfiyaKulmukhanova, T.Al-Awami, M.El-Amin, & S.Shamma, 2019).

When in the balancing up scenario, the agents that cannot meet the generation level that they agreed in the spot market must buy their deficit in the ancillary services market, where the price is higher than the day ahead price, as the system operator penalizes this behavior. Producers can choose to strategically present lower offers in the market in order for them to not to take the risk of incurring in balancing costs. On the other hand, the generators with overproducing capacity can sell the excess energy at the same price than the day ahead price for that same hour. The difference in price helps the TSO to balance the system by incentivizing overproduction in the balancing up scenario while at the same time penalizing underproduction.

When in the balancing down scenario, generation deficit can be solved by buying the needed energy in the balancing market at a price equal to the day ahead price. These agents are not penalized by their lack of production, as it helps to balance the system. Overproducing generators, on the opposite, can sell the excess energy in the balancing market at a price that is lower than the day ahead price, as a penalty for their contribution to the system total imbalance.

It also can occur a scenario in which, regardless of the individual deviations of each producer or consumer, the system is balanced. In this scenario the exchange of energy that happens in the balancing market has the exact same price that the day ahead price for that particular hour, as there is no need to penalize no agent (Pinson, 2018).
VPP model

Generally, distributed energy resources give priority to serving their individual demand and thus only the excess generated energy would be sold back to the grid (You, Traeholt, & Poulsen, 2009). However, this will depend on each individual DER owner and the agreement reached between the parties. In order to simplify the analysis, the generators and loads evaluated will act as if serving the VPP was their first priority.

VPP modeling has been mildly discussed in literature such as: (You, Traeholt, & Poulsen, 2009) where a centralized market-based VPP model is proposed and various bidding scenarios are explored; in (Guerra Sánchez & Martínez Velasco, 2017) the aggregation of renewables and storage are modeled and simulated using OpenDSS; (Duan, Wang, Gao, & Yang, 2018) shows a multi-objective Virtual Power Plant algorithm model; (Pandzic, Morales, Conejo, & Kuzle, 2013) explores a stochastic programing based offering model for a VPP; (AlfiyaKulmukhanova, T.Al-Awami, M.El-Amin, & S.Shamma, 2019) defines a VPP model using centralized and decentralized dispatch and game theory; (Condesso, 2015) creates a simulation tool to simulate the output of aggregated distributed energy resources and (Tan, y otros, 2017) shows a stochastic scheduling optimization model for a VPP. This literature has been reviewed and some of the learnings are shown herein. In any case, this work’s aim is to show a simplified view of some of the implications of market participation of aggregated distributed energy resources.

Assumptions

Assets aggregated in a VPP can be very diverse; for simplifying purposes, the VPP that will be modeled herein will account for one thermal generator, one passive load and one renewable generator. A real VPP would have plenty of those, but for the purpose of this work it is considered that the operation of the VPP is clearly envisioned by simplifying it to just one unit of each asset type.

It has also been stated in some sections of this work that VPP will mostly participate in the ancillary services markets. The reason for modelling its participation in the spot market responds to various reasons: first, the information and modelling of the VPP is easier this way; the available data is also substantially larger for wholesale markets and lastly because the goal of this model is to show how a VPP could mimic a conventional power plant in the market. Is for this reason also that the VPP operator will be considered to be also the market agent that trades the generated (or consumed) energy in the market.

The VPP modeled herein does not own any assets; it aggregates assets from third parties and takes their output to the market. As a result of the individual output of each asset, the VPP can go to the market with buy or sell offers, as the overall result might be energy production or consumption. The generators are modeled different: the renewable generator has zero marginal cost and its production is dependent on the previous forecast and the accuracy of such forecast; the thermal generator has a marginal cost that is different from zero (due to the fuel cost) and can decide its production level, with some limits due to the physical limitations of the power plant. The day-ahead price is considered to be equal to the prevision previously made (no inaccuracy). Also, congestions in transmission lines do not occur. Lastly, it is considered that the aggregated capacity of the VPP is irrelevant for the size of the market, and therefore it has no influence in the market prices, acting as a price taker.
Market events

As it can be seen from the figure above, the VPP first receives all the information about the forecasted demand of its aggregated load, the estimated price from the day ahead market, the renewable production forecast and any other relevant information. Then, the thermal generator sends its agreed production to the VPP who submits the aggregated bid to the market. On a second step, once the real demand and the renewable output for the hour at issue are confirmed, the VPP will use the balancing markets to solve the difference between its agreed market bid and the actual output. Lastly, the VPP remunerates its aggregated DERs accordingly.

During the time since the information is gathered to the moment the VPP remunerates the DER owners, the following occurs:

i. The price for the hour ahead is known in advance and the forecasted renewable generation, load consumption and balancing prices.

ii. Generators send their offers, based in the info gathered in the previous step. Thermal generators bid strategically, as they might be thinking on the penalties that they might face if imbalances are caused.

iii. The VPP gathers all the information about production and consumption bids and sends a bundled offer to the market.

iv. The market accepts the buy or sell offer sent by the VPP, as it is a price taker.

v. The actual values of the load demand, renewable production and the balancing up and down prices are published.

vi. The VPP balances its output by curtailing the passive load or modifying the output of the thermal generator.

vii. DERs owners are remunerated as agreed.

(AlfiyaKulmukhanova, T.Al-Awami, M.El-Amin, & S.Shamma, 2019)

DER behavior

As it has been stated, for the model of the VPP it is considered a passive load, representing the consumption part of the scheme and two generators, representing the energy generation part of the scheme.

Renewable generators are characterized for virtually zero marginal costs. The generated energy cannot exactly be known in advance and will be considered to vary randomly. The VPP operator receives the expected production output of the renewable generator, which is set based on their forecasting and predictive technology. The renewable generator has physical restrictions that are known in advance, represented by a maximum production output that cannot be exceeded. The output cannot be negative as the generator cannot consume energy. After all market events conclude, the VPP will remunerate this agent based on the actual generated electricity and the
potential deviation that might occur. For this reason, the accuracy in the prediction as well as the bidding strategy are fundamental for the renewable generator to obtain optimal revenues. Overbidding might result in high deviation costs while underbidding might result in loss of potential revenues.

The thermal generator does have operational costs, as opposed to the renewable agent. The operational costs are mainly related to cost of the fuel. The thermal generator can know in advance exactly its production output, and can also bid strategically considering that it might want to participate not only in the intraday market but also in the balancing market. Same as the renewable generator, there are some physical restrictions that limit the production output of the renewable generator and are represented by a maximum output and a minimum load under which the thermal generator cannot operate. Once the thermal generator is running it can choose to ramp up or down its output to participate in the balancing markets. This is also limited by a maximum ramping parameter. Lastly, this agent can freely decide to participate in the generation mix or remain off. The VPP operator will remunerate the thermal generator based on the provided energy and balancing.

The passive load will submit to the VPP its predicted consumption, which will vary randomly. The consumption forecast and the actual demand are not necessarily the same. For this model, regarding the passive load, the VPP is considered to play the role of an energy retailer, charging a fixed rate for the consumed energy while holding responsible for the generated imbalances due to the difference between forecasted and actual consumption.

**DER formulas**
The formulas that represent the restrictions, incomes and costs for the different agents are shown below.

The different hourly prices of energy are:

- $\Phi_{t}^{HA}$: hour-ahead market Price at hour ‘t’
- $\Phi_{t}^{DN}$: price for overproducing or reducing consumption at hour ‘h’
- $\Phi_{t}^{UP}$: price for increasing demand or under-producing at hour ‘h’

According to that, the three scenarios that might take place are:

- **Balanced scenario**: $\Phi_{t}^{HA} = \Phi_{t}^{DN} = \Phi_{t}^{UP}$
- **Balancing down scenario**: $\Phi_{t}^{HA} = \Phi_{t}^{UP}$; $\Phi_{t}^{HA} > \Phi_{t}^{DN}$
- **Balancing up scenario**: $\Phi_{t}^{HA} < \Phi_{t}^{UP}$; $\Phi_{t}^{HA} = \Phi_{t}^{DN}$

Note how in the balanced scenario the prices for balancing up and down are equal as the system is balanced and there is no need to incentivize one behavior as opposed to the other. In the balancing down scenario, someone has overproduced or under-consumed and thus there is excess generation in the system resulting in a need for reducing the production output; therefore generators that under-produced are not penalized as they buy their energy needs in the balancing market at price ($\Phi_{t}^{HA} = \Phi_{t}^{UP}$) and generators that have overproduced are paid less for their overproduced energy than in the hourly price ($\Phi_{t}^{HA} > \Phi_{t}^{DN}$) and are therefore penalized, thus overproducing is discouraged. Following the same reasoning, in the balancing up scenario someone has under-produced or overconsumed, resulting in lack of generation and therefore the system needs to incentivize generators to increase their output. This is achieved by establishing a premium in the balancing market for the energy that under-producers need to buy to keep their balance ($\Phi_{t}^{HA} < \Phi_{t}^{UP}$); at the same time, overproducers sell their excess energy in the balancing market without penalization ($\Phi_{t}^{HA} = \Phi_{t}^{DN}$) as its overproduction contributes to balance the system.
Renewable generator

The behavior of the renewable generator is described by the following formulas:

- Hour ahead price in the intraday market: \( \Phi_t^{HA} \)
- Production forecast for the Renewable Generator: \( P_t^r \)
- Energy bid by the Renewable Generator: \( E_t^r \)
- Actual Production by the Renewable Generator: \( P_t^r \)
- Income for the Renewable Generator, if under-produces: \( i_t^R(E_t^r) = \Phi_t^{HA} P_t^r + \Phi_t^{UP}(P_t^r - E_t^r) \)
- Income for the Renewable Generator, if over-produces: \( i_t^R(E_t^r) = \Phi_t^{HA} P_t^r + \Phi_t^{DN}(P_t^r - E_t^r) \)

Before the session of the intraday market closes, the price \( \Phi_t^{HA} \) for the hour ahead is published. According to the production forecast \( P_t^r \), the generator submits a bid \( E_t^r \) to the VPP; in real time, the actual production \( P_t^r \) is known. Knowing the real production, the generator goes to the balancing market to fix the error between the forecast and the actual production. As a result of this process, the incomes generated for the renewable generator are defined by the produced energy multiplied by the price for the hour ahead plus the sale of the excess energy or minus the buyout of the lack of produced energy in the balancing market (Alfiya Kulmukhanova, T. Al-Awami, M. El-Amin, & S. Shamma, 2019).

For a better understanding, this will be illustrated with a simple example:

**Considering a renewable generator of 100 MW capacity, according to its forecasting technology estimates that it will generate 70 MWh in the hour ahead. In order for him to not end up under-producing, decides to strategically submit a bid to the VPP of 60 MWh. The price for the hour ahead is realized, resulting in 22.51 €/MWh. The actual production of the generator ends up being 75 MWh. In this scenario, the generator has produced more energy than his bid and therefore needs to sell the excess energy in the balancing market; the system is in the balancing up scenario, for this reason the price for electricity is the same as in the day ahead, which is 23.56 €/MWh. The renewable generator is then paid for the production in that hour:**

\[
75 \text{ MWh} \times 22.51 \text{ €/MWh} + 23.56 \text{ €/MWh} \times (75 \text{ MWh} - 60 \text{ MWh}) = 2,041.65 \text{ €}
\]

Thermal generator

The behavior of the thermal generator is described by the following formulas:

- Hour ahead price in the intraday market: \( \Phi_t^{HA} \)
- Thermal generator on/off: \( z_t \in [0,1] \)
- Energy bid by the Thermal Generator: \( E_t^T \)
- Energy bid by the Thermal Generator in the balancing market: \( E_t^{T,\text{bal}} \)
- Production by the Thermal Generator: \( P_t^T \)
- Maximum ramping-up capacity in a given hour: \( R_{\text{UP}} \)
- Maximum ramping-down capacity in a given hour: \( R_{\text{DN}} \)
- Income for the Thermal Generator, if balances down (sells excess energy for balancing): \( i_t^T(z_t, E_t^T, E_t^{T,\text{bal}}) = \Phi_t^{HA} E_t^T + \Phi_t^{DN}(E_t^{T,\text{bal}} - f(E_t^T + E_t^{T,\text{bal}})) \)
- Income for the Thermal Generator, if balances up (buys lack of energy for balancing): \( i_t^T(z_t, E_t^T, E_t^{T,\text{bal}}) = \Phi_t^{HA} E_t^T + \Phi_t^{UP}(E_t^T - f(E_t^T + E_t^{T,\text{bal}})) \)

Where the cost of fuel is modeled as \( f(E_t^T + E_t^{T,\text{bal}}) = c \cdot (E_t^T + E_t^{T,\text{bal}}) \); \( c \): €/MWh of fuel
Before the session of the intraday market closes, the price $\Phi^\text{HA}_t$ for the hour ahead is published. The thermal generator decides to participate or not to participate in the intraday market for the hour ahead, which is represented by the parameter $z_t$ being either 1 (on) or 0 (off). There is no inaccuracy for the production of the thermal generator and therefore the sum of the bid in the intraday market $E^\text{T}_t$ and the bid in the balancing market $E'^\text{T}_t$ equals the production of the generator $P^\text{T}_t$. The generator can only ramp up $R^\text{UP}$ or down $R^\text{DN}$ a certain amount of energy in a given hour. If the generator chooses to balance down, this is, generate more and sell the excess production in the balancing market, the income will be the price for the hour ahead $\Phi^\text{HA}_t$ multiplied by the bid in the intraday market $E^\text{T}_t$ plus the bid in the balancing market multiplied by the balancing down price $\Phi^\text{DN}_t$ minus the marginal cost, which is herein simply represented by the cost of the fuel $c$. If the generator chooses to balance up, this is, curtail their production and buy the curtailed energy in the balancing market, the income will be the price for the hour ahead $\Phi^\text{HA}_t$ multiplied by the bid in the intraday market $E^\text{T}_t$ minus the curtailed energy multiplied by the balancing up price $\Phi^\text{UP}_t$ minus the fuel cost.

The thermal unit will overproduce when the balancing up scenario is called, and therefore the excess energy can be sold at a price $\Phi^\text{HA}_t = \Phi^\text{DN}_t$. If the balancing down scenario is called, the thermal generator will curtail the production and buy the curtailed energy in the balancing market at a price $\Phi^\text{HA}_t = \Phi^\text{UP}_t$. Doing the opposite results into losses. For this reason, as the balancing market price for the thermal generator will always be $\Phi^\text{HA}_t = \Phi^\text{DN}_t = \Phi^\text{UP}_t$. Therefore:

Income for the Thermal Generator: $I^\text{T}(z_t, E^\text{T}_t, E'^\text{T}_t) = \Phi^\text{HA}_t E^\text{T}_t + \Phi^\text{DN}_t E'^\text{T}_t - f[E^\text{T}_t + E'^\text{T}_t]$  

For a better understanding, this will be illustrated with a simple example:

Considering a thermal generator of 50 MW fueled by grape vines biomass that costs 57.5 €/t with a heating value of 18.29 MJ/kg (Bioraise) (Phyllis2), resulting in a cost of 11.32 €/MWh. The price for the hour ahead is realized, resulting in 22.51 €/MWh. With a ramping limitation of 10 MW/h, decides to bid in the hour ahead 40 MWh. In real time, the balancing up scenario is announced and therefore the generator decides to increase their output to up to 50 MWh, selling the excess 10 MWh in the balancing market at a price 23.56 €/MWh. The thermal generator is then paid for the production in that hour:

$$22.51 \text{ €/MWh} \times 40 \text{ MWh} + 22.51 \text{ €/MWh} \times 10 \text{ MWh} - 11.31 \text{ €/MWh} \times (40 \text{ MWh} + 10 \text{ MWh}) = 570.5 \text{ €}$$

Passive load
The behavior of the passive load is described by the following formulas:

Load demand forecast: $D^\text{f}_t$
Load actual demand: $D^\text{a}_t$
Load fixed tariff: $\theta^\text{VPP}$
Expenses for the Passive Load: $e^\text{T}(D^\text{f}_t) = D^\text{f}_t \theta$

The passive load establishes a bilateral contract with the VPP, in which the VPP charges a fixed tariff $\theta^\text{VPP}$ to the load owner and pays in the market for the demand at the market price. The VPP bids in the market the forecasted demand $D^\text{f}_t$ and will pay in the market for the energy consumed and the deviation caused by the difference between the forecast and the actual demand $D^\text{a}_t$. 
VPP Operation

Now that the operation of each of the DERs has been described, the market participation of all them together through a centrally controlled VPP will be evaluated. By participating as one unified market entity they can benefit from the synergies created, reducing balancing costs and increasing overall revenues. Also, by being aggregated their bundled capacity is larger and therefore are not as limited by minimum bid sizes as they were by participating individually. According to article 8 of Regulation 2019/943 of the European Parliament on the internal market for electricity, which came into force the 1st of January of 2020, member states are committed to include in wholesale and intraday markets products of reduced bid sizes of ≤ 500 kW “to allow for the effective participation of demand-side response, energy storage and small-scale renewables” (European Commission, 2019). Considering that most residential rooftop solar installations are usually below 10 kW (ANPIER, 2019) and commercially available energy storage systems are at around 5-8 kW, it seems reasonable that a VPP infrastructure will be needed to access the market.

Regarding intraday participation, the VPP will first bid strategically based on the demand prediction of the passive load, the forecasted output production of the renewable and the hour ahead price. It is reasonable to think that the VPP will have better forecasting and predictive modeling technology than a small renewable generator or an individual consumer and would therefore make more accurate market bids. In a first step, based on the published hour ahead market price $\Phi_{t}^{HA}$, the production forecast of the renewable generator $P_{t}^{R}$ and the estimations of the balancing down and up prices $\Phi_{t}^{DN}$, $\Phi_{t}^{UP}$ for the hour ahead the VPP makes a bid. As said before, the VPP might decide to bid strategically and try to minimize the imbalance costs due to bid inaccuracy. The estimates of the balancing down and up prices are obtained by introducing historical data of how much time was the system in each of the balancing scenarios and applying statistical models to the historical prices.

**Hour ahead price in the intraday market:** $\Phi_{t}^{HA}$  
**Production forecast for the Renewable Generator:** $P_{t}^{R}$  
**Load demand forecast:** $D_{t}^{L}$  
$\Phi_{t}^{DN}$: estimated price for overproducing or reducing consumption at hour ‘h’  
$\Phi_{t}^{UP}$: estimated price for increasing demand or under-producing at hour ‘h’  
$\omega_{h}$: probability of the system being in each of the balancing scenarios  
**VPP market bid:** $V_{VPP} = f(\Phi_{t}^{HA}, P_{t}^{R}, D_{t}^{L}, \Phi_{t}^{DN}, \Phi_{t}^{UP}, \omega_{h})$

At this point, having an advanced predictive models and forecasting technology is a key differentiation aspect as it affects to the later balancing costs and has direct implications in the VPP overall profitability. Once the real values of renewable output $P_{t}^{R}$, load demand $D_{t}^{L}$ and balancing prices $\Phi_{t}^{DN}$, $\Phi_{t}^{UP}$ are realized, the VPP needs to go to the balancing market to settle its deviations. The VPP will do this by ramping up or down the thermal generator. Alternatively, this could also be done by curtailing the load. For enable this mechanism, the load would need to be flexible and some short of demand elasticity would need to have been agreed between the VPP and the load owner in the signed bilateral contract.

**Renewable imbalance:** $I_{t}^{R} = (E_{t}^{R} - P_{t}^{R})$  
**Load imbalance:** $I_{t}^{L} = (E_{t}^{L} - D_{t}^{L})$

If $I_{t}^{R} > 0$ renewable under-production; If $I_{t}^{R} < 0$ renewable over-production  
If $I_{t}^{L} > 0$ load under-consumption; If $I_{t}^{L} < 0$ load over consumption
Both the renewable generator and the load can cause imbalances if their ultimate output is different from the bid that the VPP made based on predictions. These imbalances can mitigate or aggravate each other.

When \( l^R > 0 \) and \( l^L > 0 \):
- If \( l^R = l^L \) imbalance cost = 0
- If \( l^R \neq l^L \) and \( l^R > l^L \) imbalance cost = \( (l^R - l^L) \Phi^UP \)
- If \( l^R \neq l^L \) and \( l^R < l^L \) imbalance cost = \( (l^L - l^R) \Phi^DN \)

When the renewable generator under-produces and the load under-consumes, the caused imbalances are compensated to some extent. If the lack of renewable generation is larger than the lack of load consumption, the VPP will overall have a lack of generation and will need to buy the lack of generation at the \( \Phi^UP \) price. If, differently, the lack of load consumption is larger than the lack of renewable output, the VPP will overall have excess generation and will need to sell the excess generation in the balancing market at the price \( \Phi^DN \).

When \( l^R < 0 \) and \( l^L > 0 \):
Imbalance cost = \( (|l^R| - |l^L|) \Phi^DN \)

When the renewable generator overproduces and the load still under-consumes, the excess generation of the generator is increased by the lack of consumption and therefore the VPP needs to sell the combined excess energy in the balancing market at a price \( \Phi^DN \).

When \( l^R > 0 \) and \( l^L < 0 \):
Imbalance cost = \( (|l^R| - |l^L|) \Phi^UP \)

When the renewable under-produces and the load over-consumes, the VPP will need to go to the balancing market to buy the lack of generation caused by both imbalances at a price \( \Phi^UP \).

When \( l^R < 0 \) and \( l^L < 0 \):
- If \( l^R = l^L \) imbalance cost = 0
- If \( l^R \neq l^L \) and \( l^R < l^L \) imbalance cost = \( (l^R - l^L) \Phi^UP \)
- If \( l^R \neq l^L \) and \( l^R > l^L \) imbalance cost = \( (l^L - l^R) \Phi^DN \)

Lastly, if the renewable over-produces while the load also over-produces, the imbalances are also mitigated. If the overproduced energy is larger than the over-consumed load, the excess energy will need to be sold in the balancing market at a price \( \Phi^DN \). If the over-consumed load is larger than the excess of generation, the VPP will need to go to the balancing market and buy the lack of energy at a price \( \Phi^UP \).

At any time, if the cost of fuel of the thermal generator \( c \) is lower than the price \( \Phi^UP \) and if the thermal generator physical and ramp up requirements allow it, the thermal generator can increase production to mitigate the imbalance at a lower cost than the balancing price. Also, when there is excess generation and the system operator calls for the balancing down scenario the thermal generator can decrease production instead of selling the excess renewable generation at a lower price, as in this scenario \( \Phi^HA = \Phi^UP ; \Phi^HA > \Phi^DN \).

In short, the scenarios in which the load imbalance and the renewable generation imbalance go in the same direction, the imbalance is mitigated. In those scenarios in which imbalances go in different direction, those are aggravated. In the aggravated case, these imbalances would have had the same costs if participating individually instead of aggregated. Besides, imbalance costs
can be mitigated by strategically utilizing available ramping requirements of the thermal generators. In a more technologically advanced VPP with load flexibility capabilities, imbalance costs could be reduced even further by curtailing the loads when necessary.

From the above, the income generated by the VPP for participating in the intraday market are as follows:

\[
\text{VPP income: } I_{\text{VPP}} = D_t \cdot \theta + \Phi_t^{\text{MA}} E_t + \Phi_t^{\text{RA}} E_t + \Phi_t^{\text{DME}} E_t - \Phi_t^{\text{MA}} E_t - c(P_t + E_t) - \text{"Imbalance costs"}
\]

And more precisely:

Lastly, the VPP makes payments to each of the agents participating in the terms agreed in each of the bilateral contracts.

Of course, there are still taxes and other regulated costs that will ultimately impact the revenues the VPP gets, but those are considered out of the scope of this work.

In conclusion for DERs to participate in the market through a VPP is beneficial because they can access the market that otherwise would be unreachable due to limited individual technical specifications; synergies are created between the different assets taking part in the VPP and overall costs are reduced; the VPP will have better forecasting technology and predictive models so as to incur in fewer imbalances than each of the assets individually and the team members of the VPP are likely to have wider expertise and market know-how than each of the DERs owners.

The aim of this model was to show how a VPP can operate in a market and somehow mimic a conventional power plant. For serving this purpose, a high-level simplified VPP model has been evaluated. Nevertheless, the operation of a VPP in the real world is much more complex. Many other issues need to be considered like the market in which it participates, the different remuneration systems of each mechanism, load and generation availability of each DER, congestion constraints, locational issues, dispatch priorities, bidding optimization strategies, load disaggregation in different markets and mechanisms and many others. In order to optimally orchestrate the aggregated DERs and effectively participate in the market, powerful computer engines, advanced intelligent algorithms, state-of-the-art predictive models and experienced team members with deep market and power system know how are required. For the scope of this work, the goal of demonstrating how a simple aggregation of energy assets would participate in the market and its implications is considered to be effectively satisfied with the herein shown simplified model.
4 Planning and economic approach

As it has been described before, the implementation of the proposed business model sees three differentiated phases. Phase 1 consists on defining the value chain, exploring the market, evaluating the competitive landscape and defining the business model to address the market. Once the business model is defined, partners need to be identified and reached, pilots defined and implemented and the minimum viable product (MVP) created. Lastly, in phase 3, the definitive business model is implemented in the market and actions focused on gaining market traction are taken, in order to achieve market consolidation.

Phase 1: Define & Explore

Phase 1 of the process corresponds with the current thesis work. For this reason, the planning and budget of all the activities included in the elaboration of this work are here included.

Planning

This work emerge as a proposal of one of my fellows in i-deals to develop a document that evaluates the markets and state of the art of demand-side flexibility through VPPs and analyzes and proposes a business model to capitalize this flexibility. As it has been stated several times throughout this document, flexibility is increasingly important for the power system as the energy transition materializes and demand-side flexibility stands out as the most disruptive and less capital intensive source of flexibility. For this reason, building solid knowledge around this technology and business model was identified as a good opportunity to develop a valuable professional profile within the energy sector.

As a first step, mi i-deals tutor shared his knowledge in the subject with me and provided me with guidelines, reports, sources and papers to get a solid foundation on the matter. After that, we developed a structure for the TFM and started selecting the most relevant information. Most relevant markets and use cases were studied, and the strategic positioning of some of the most relevant players in the energy industry was evaluated. Most of the incumbents and emerging start-ups providing solutions in this field were benchmarked, as part of an i-deals project with

![Figure 96 Venture implementation roadmap, own elaboration](image-url)
one of the major Oil & Gas players in Europe. Incipient regulation regarding this matter was briefly explored and a high level market participation model was described.

This work has been the result of continuous work starting in late November 2019, when I started my internship in i-deals. Since then, and complementary to my everyday work in i-deals and my studies for the M.Sc. a I’ve been constantly working in creating a document that could show the potential of VPPs in providing some of the needed flexibility.

Lastly, the work related with preparing the defense of this TFM is also considered in advance for the elaboration of the below shown Gantt diagram.

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Figure 97 Planning, own elaboration
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**Proyecto: TFMplanning**
Fecha: 23/05/20 13:55

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<th>Informe de resumen manual</th>
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<td>Tareas externas</td>
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Página 1
Budget

The cost structure related to the elaboration of this work is shown below. The price per hour for each of the resources are estimated. Other costs refers to software licenses, equipment used, printing, registration costs of TFM’s ECTS and any other costs related.

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<th>Price (€/h)</th>
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<td>Tax (21%)</td>
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<tr>
<td>Total</td>
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</table>

Figure 98 Budget, own elaboration

In short, the final cost of elaborating this work, which corresponds to the phase 1 of the venture creation process, is 14,580.50€.

Phase 2: Test & Build

Once the business model is defined and validated by the firm, the next phase of the project consist on materializing the defined model into a viable solution ready to address the mass market. Partners need to be explored and reached, business plan needs to be refined and pilots need to be implemented, once pilot project are successfully carried out, the minimum viable product is created and the solution fit in the target market is evaluated.

It is proposed the execution of a benchmark focused on EMS solutions and developers. The objective is to determine the best-in-class features and capabilities available in the market. This will allow the understanding of the minimum level of sophistication that must incorporate an
EMS. The EMS is the enabling technology that supports the value inherent to the proposed business model. During the first stages of deployment, growth will be based on being able to demonstrate potential energy savings with the deployed assets, the operational optimization of those assets and the system as a whole is key to maximize return on investment made by the client. Such relevance of the EMS forces the necessity to incorporate the best available EMS technology, which can be internally development and/ or provided by an external partner. Also, EMS development requires having a relevant dataset gathered from historic data of real usage to optimize algorithms and these are only available by utilities or EMS partners. It must be considered whether relevant data can be obtained from pilots to be conducted or they must be provided by an external partner. The relevance of having a leading technological positioning in this segment obliges to quickly deploy the best available technology. In order prevent any delay on EMS development partnering or taking a position on an EMS developer is highly recommendable. Some examples of EMS providers are:

![Figure 99 EMS relevant players, own elaboration](image)

Also, in order to develop pilots and MVPs the firm needs to select a demonstration infrastructure with a meaningful scale and the adequate equipment to validate technology and business case prior to commercial testing. A representative test site in which the technology is deployed at a large set of real customers is mandatory to understand and validate technology performance and the business case built around it. Operational data at customer level and their aggregated impact at grid level shall be available to feed both EMS and VPP development. The actions to be executed are (i) the definition of requisites, (ii) screening of potential sites, (iii) due diligence, negotiation and closure, (iv) objectives definition, testing plan design, and budget, (v) project management and coordination. This step is crucial and needs to be carefully planned so as to being able to access the right infrastructure and engineering expertise to obtain meaningful results. Some RTOs that might have infrastructure for testing and could be potential partners for this process are TECNALIA (Bilbao), CIRCE (Zaragoza) or IREC (Barcelona) in Spain; and EnergyVille (Belgium), EURAC (Italy) or the DTU (Denmark).
As important as accomplishing the objective of building a competitive EMS, it is to develop/acquire a VPP tool that is able to integrate the fleet of EMS distributed in residential and C&I customers building a comprehensive tools to aggregate and operate them. For addressing this, it is proposed the execution of an in-depth benchmark focused on VPP products, developers and vendors. The objective would be to determine the best-in-class features and capabilities available in the market, allowing the understanding of the minimum level of sophistication that must incorporate future VPP own developments. It is recommended to incorporate existing technology by means of an investment. Some of the best positioned VPP players have already been defined; in any case, some of the most relevant for this purpose are:

Phase 3: Grow & Improve
Lastly, once the venture has been pilot tested and is ready for operating in the market, efforts need to be focused on growing the customer base and improving the product offering. As the firm is a utility, reaching customers through the firm’s core business customer base can be an adequate way of achieving the needed critical mass to get the VPP running.

The last step of the commercial deployment is the launch and commercial operation of VPP tools in C&I and residential segments. The opportunity of this strategy relies on deploying assets and operating those providing services to the grid operator. Having achieved (i) the successful deployment of a significant fleet of EMS in residential and C&I sectors, (ii) the creation of a control center for the distributed assets and (iii) the development of advanced VPP tools, the next step is to integrate the technologies and knowledge that makes possible to start operating in the market as an aggregator. For doing so, it is important to identify the most suitable areas/group of controlled EMS fleets to start the commercial operation of the VPP. Once the EMS and VPP are in commercial operation, the market needs to be constantly scouted in order
to understand how regulation evolves, which new assets are being deployed and how customer preferences change, in order to identify potential threats and opportunities that might emerge.

It is hard to estimate how much time would take to reach market consolidation and achieve the breakeven point of the venture, as there are many external and internal factors affecting the outcome of the venture. In any case, it is considered that it would take anywhere from 10 years on.
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Electricity is a fundamental input in developed countries and is directly related to economic growth and quality of life. Since the late 20th century, power systems have been continuously evolving. In order to ensure security of supply in an economically optimal manner, free competition has been gradually introduced in those parts that are not considered to be natural monopolies, namely generation and retail. Other important changes are taking place in the energy industry driven by the urgent need of reducing carbon footprint of the sector, in order to mitigate the impact of the undeniable climate change.

Climate change has forced economies to commit to reduce their greenhouse gas emissions in order to keep the global warming below 2ºC by the end of the century. The Paris Agreement, signed in 2012, obliges signing countries to send 10 year climate plans in order to fulfill their climate targets. Countries also need to submit a plan for adapting to the changes that the climate change will bring.

The climate change is driving the energy transition, a unprecedented transformation in the energy sector. The main directions in which the energy sector is changing are decarbonization, as the system is switching from fossil fuels to renewables; electrification, as end-use sectors like heating and mobility are transitioning from burning fuels to consuming electricity; and decentralization, as electricity generation is being atomized and changing from centralized large power plants to decentralized distributed energy resources. Due to this transition new needs are raising to allow for the integration of large shares of variable renewable energy resources.

As opposed to conventional fossil fuel fired power plants, variable renewable energy sources operate at zero opportunity costs and cannot control when they produce. The variability and uncertainty of the resource raises previously dismissed concerns about load following. As the weight of these sources raises in the energy mix, the power system needs more flexibility to match load and demand at any time and maintain the system balanced.

Historically flexibility was provided only from the supply side, by adapting the output of thermal generators to match the variable demand. Nuclear and coal base load generators where complemented with gas and fuel-oil generators with better ramping capacity (and lower CAPEX with higher marginal costs). These peaking plants only entered the mix at moments of high demand. These pollutant and expensive sources are being substituted from new disruptive sources of flexibility, like different types of energy storage and flexible demand behavior.

As the system transitions to a decentralized power system, distributed energy resources can participate in markets and provide TSO services when aggregated. Aggregation consists on bundling the capacity of decentralized small and mid-sized assets to benefit from economies of scale and scope and participate in energy markets by imitating the output of a conventional power plants. Aggregated assets can be supply, demand and storage type.

In this context, a Virtual Power Plant is defined as a system-of-systems comprising distributed energy resources of different kinds that are managed in a coordinated manner by an operator that might (or might not) use installed hardware gateways to control the energy assets and leverages in an aggregation platform based on advanced market modeling algorithms and intelligent predictive models to optimally dispatch and trade in different energy markets the aggregated capacity.

Depending on the type of resources aggregated and the bundled capacity of the portfolio, these can participate in different markets. Supply side VPPs can seamlessly participate in wholesale electricity markets while demand-side VPPs are more suitable for the ancillary services markets.
as these do not affect end users comfort that much. Mixed asset VPPs can participate in any of the available markets.

In order to enable the participation of these new agents, regulation is evolving both at a national and European level to adapt to the new paradigm. EU Network Codes foster the participation of aggregated capacity in ancillary services whereas the Clean Energy Package goes one step further to demand non-discriminatory market participation for aggregators. The regulatory framework for DSO-operated local flexibility markets is gradually being developed and will probably be operating before the end of the decade.

In order to effectively exploit these newly enabled sources of flexibility, sustainable business model need to be built around this opportunity. Different approaches coexist in an evolving flexibility value chain, and each market segment requires a different approach. While residential flexibility can be addressed by scalable solutions, the more lucrative C&I flexibility requires a tailored approach.

The creation of a business model also needs to consider the target market, as different geographies have different customer segmentation, DERs penetration and energy mix. Europe, with mixed assets VPPs and the US, with demand response aggregators being widespread implemented are the most relevant market and show dramatic growth rate predictions. Asia-Pacific with Australia and Japan and in the near future with the hard to predict role of China are also markets to be considered. The Spanish market is the one selected for the creation of a new venture, as it is unexploited, there are ambitious goals of renewable penetration in the midterm and markets are being opened to aggregator participation in the second half of 2020.

Some of the main energy players are positioning themselves in the VPP business. This is the case of some of the Oil & Gas giants that are diversifying their businesses out of oil and into electricity like Shell, Total, BP, Equinor and Repsol. Also, some of the most important utilities like Centrica, Enel, E.on, Engie, Eneco, Statkraft and others are broadening their service offering by taking strong positions in this business. In both cases, the most prevalent strategy is to follow a open innovation approach and invest, acquire or partner with emerging start-ups that are already showing some short of market traction.

In order to evaluate how to effectively exploit this opportunity, the creation of a venture to capitalize flexibility though VPPs is proposed. This venture is proposed for a utility, but it can be adapted to different players in the energy sector. In this context, once the market has been evaluated and the different existing strategic positions have been analyzed, a business model is proposed for the Spanish market. As a VPP needs to be able to control and optimize many distributed assets, it is considered that a joint EMS-VPP solution can be an appropriate approach to be able to develop a sustainable source of competitive advantage.

In sum, for a utility, creating a disruptive product such as the one proposed and integrating it into the core business might sound as a risky strategy. However, it is a great opportunity for switching from competing in crowded competitive markets to creating new industries through fundamental differentiation. This can be done by increasing value for customers by offering them new products and services while at the same time reducing costs, in this case both for customers (energy optimization) and for the core business (optimized market participation). Utilities can take advantageous positions in the new energy paradigm by creating new, uncontested market space through value innovation rather than outdoing competitors in terms of traditional performance metrics.
In conclusion, VPPs seems to be a legit solution to provide some of the needed flexibility in the new energy paradigm. Despite the business case for flexibility is weak, as margins are kept low and do not justify the investment in new assets, it seems that aggregation of DERs might be a secondary business model for many energy players, as it can be considered an added value service for retailers and suppliers, can improve return on investment on existing assets and fosters a more efficient use of energy and resources. Cross industry players like the retail industry, telecom, automakers, waste management and many others will probably also benefit from VPPs as a recurring revenue stream from their available energy assets, but always as a secondary cash flow and probably hardly ever as a core business activity. Even if some key players show that operating a VPP can be a profitable business model today, this is only feasible by avoiding new assets’ CAPEX by operating DERs owned by others. However, as VPPs transition from disruption to mainstream, fierce competition might weaken the business case for VPP-only companies.

In any case, an efficient use of energy is crucial in order for us to be able to reach the 2ºC scenario. In this context, Virtual Power Plants create value all throughout the value chain: for asset owners, by creating additional revenue streams; for the system, by allowing for the integration of VRE; and for the environment, by contributing to a renewable powered system and by more efficiently using existing resources. Therefore, Virtual Power Plants stand as a win-win solution to address some of the challenges that emerge in the energy transition.
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