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Flexible Energy Contracts - FLECS

Smart contracts for Smart Grid 2.0

Universitat Oberta de Catalunya

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FLexible Energy ContractS – FLECS
Smart Cities

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January 8, 2023

Final Work specifications

document Title:	FLexible Energy ContractS
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Tutor name:	David Crespo García
Submittal:	PAC4
Delivery date:	01/2023
Programme:	Telecommunications Master's
Department:	Smart Cities
Language:	English
Keywords	Smart energy, flexible contract, blockchain, distribute ledger technology, machine learning, prosumers, secure energy transactions, scalable power market.

Resum del Treball

A l'actualitat, cada vegada hi ha un nombre creixent d'usuaris finals que passen de ser només consumidors d'electricitat a les seves llars per participar en un altre tipus de consum, com els vehicles elèctrics ("EV"), i per produir electricitat, per exemple, a les seves teulades. Fins i tot, els carregadors de vehicles elèctrics poden injectar electricitat a la xarxa.
Aquesta és l'evolució dels consumidors a prosumidors: producció + consum.
Aquest document només se centrarà en un tipus d'energia, l'electricitat. Tanmateix, la majoria de les aplicacions es podrien pensar per utilitzar a qualsevol altre tipus d'energia, adaptant-se a les necessitats i realitats.
Aquesta plataforma generaria transaccions en temps real que permetria fer transaccions individuals i agregades per part dels usuaris, generant noves oportunitats de negoci. Aquestes transaccions podrien ser entre els usuaris finals i la xarxa, en qualsevol direcció, generant així milions de transaccions en moltes direccions.
Per gestionar-ho, aquest document proposa una plataforma distribuïda que utilitza *Smarts Contracts* que poden ser fiables, escalables i flexibles per permetre als usuaris compartir energia amb altres i fer transaccions segures.
La plataforma es generaria de manera instantània i local sense necessitat

d'un servidor centralitzat, amb l'ús de la tecnologia *Blockchain*. A efectes de facturació, les transaccions es poden agrupar i agregar mensualment.
És un requisit, garantir la comunicació de tots els usuaris participants. En el mercat elèctric actual, els usuaris no realitzen cap operació en els seus equips de mesura, sinó que simplement llegeixen, registren i envien la informació. Caldrà garantir que puguin oferir aquesta capacitat amb la granularitat desitjada.
La inclusió de *Machine Learning* al sistema proporcionarà la capacitat d'analitzar l'enorme quantitat de dades que es generaran i s'intercanviaran cada minut.
Els *Smarts Contracts* i les tecnologies de registres distribuïts ofereixen una solució per a aquests reptes proporcionant seguretat a les transaccions a un cost més baix que un sistema centralitzat. En una plataforma distribuïda la inversió necessària és menor.

Abstract

There is an increasing number of end-users that are moving from just consumers of electricity in their households to participate in other type of consumption, such as Electrical Vehicles (“EV”), and to produce electricity, on their roofs for example, even the EV chargers can inject electricity to the grid. That is the evolution of the consumers to prosumers: production + consumption. This document will only focus on one type of energy, electricity. However, most of the applications should be thought for any other type of energy.
Such platform would generate transactions in real-time allowing individual and aggregate transactions to be made by users, generating new business opportunities. These transactions could be between end-users and the grid, in any direction, thus generating millions of transactions in many directions. To handle that, this document proposes a distributed platform that uses smart contracts that can be trustworthy, scalable, and flexible to allow the users to share energy with others and make secure transactions. The platform would generate instantly and locally without the need of a centralized server, with the use of the blockchain technology. For billing purposes, transactions can be grouped and aggregated on monthly basis.
It is a requirement to ensure communication of all participating users. In the

power market nowadays, these users do not perform any operations in their metering equipment, but simply read, record, and serve information. It will be necessary to ensure that they can offer that capacity in the desired granularity.
The inclusion of machine learning to the system will provide the capability of analyzing the enormous amount of data that will be generated and exchanges every minute.
Smart contracts and distributed ledgers technologies offer a solution for these challenges providing security to the transactions at a lower cost than a centralized system. In a distributed platform the necessary investment is smaller.

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1. Introduction

1.1. Background and reasons for this document

The power market has certain limitations regarding the capacity that exists to carry out transactions in real-time. Transactions are made at an hourly (or quarter of an hour) basis and a limited number of invoices are generated for these transactions. The regulation and control of this market is made by a central entity, similar to the old ways of banks in the financial system.

The inclusion of prosumers to the energy grid generates a much larger number of transactions in every direction, consumption, and production, thus opening the possibility for these users to participate in the market in a more profitable way than just consuming. Due to the millions for transactions, a central regulator would not be able to process them. With similar technologies than the ones used in the financial system, such as blockchain, and distributed ledgers, the power market could tend towards a distributed market for small users that would generate millions of economic opportunities. In addition, a distributed power market also offers improvements in the stability of the grid, reduced losses of energy transportation, and since the system would have a way to receive information in real-time, the users could be remotely controlled to provide such stability and to improve the quality of the grid electrically speaking.

1.2. Objectives

Nowadays, in a world where most of the populations inhabits in urban spaces, the need for a sustainable approach to urban problems has become a top priority to everyone. Specifically in the energy sector, it urges to incentivize the access to everyone to participate actively – producers and passively - consumers. To do so, this document identifies the already available tools and data that, in combination, can be used to develop a platform that creates new business opportunities, competitiveness in a sustainable manner.

The general objective of this document is to design, with a theoretical approach, a way to maximize the business opportunities in the Power Market using the available technology tools such as Blockchain, Distributed Ledgers, Smart Contracts, and Machine Learning. The following is a list of the specific objectives of this approach:

- Develop a data management tool that allows to develop new services and improve the existing ones.
- Generate economic transactions in real-time for prosumers (also called users) connected to the electrical grid.
- Allow any user to participate in this market.
- Create a distributed system that would also comply with any applicable law and regulation.
- Distribution and Commercialization companies will benefit from new revenues that will come from the services to be provided to the prosumers.

1.3. Impact in sustainability: ethic, social, and diversity

In the case this project becomes real, it will impact the society in many different ways:

- Access to anyone despite their origin, ethnic, and social situation.
- Opportunities to create small business to any participant.
- Guarantee of no bias towards anyone thanks to the automatized transactions.

1.4. Methodology

To reach the pretended objectives different technologies will be used. The following list in only indicative:

- Smart contracts: the contracts are the key part of the development, and they need to be smart in the sense that they will be flexible in their terms.
- Real-time transactions: there will be an enormous number of transactions occurring due to the mentioned smart contracts.
- Distributed Ledgers: To handle this number of transactions, the distributed ledger technology ("DLT") will be helpful. It will consist of a distributed trustworthy system that will register all the transactions without the need of a central regulator. All the parties will trust and gain trust to be part of the system.
- Blockchain: this technology, that gained popularity with the cryptocurrency, is also being used for many other applications, and among them, the DLT.
- Machine learning: the system will also generate an important amount of data related to the grid that can be used by the authorities and participants in the market to create new opportunities, modify regulations with the learnt experience, and improve the way the consumers and producers interact with the grid. With the machine learning technology will assist and complement the human capacity to produce these new applications.
- Real-time access: these new learnt features, mentioned on the previous point, may be used to control the consumption and production for grid stability purposes or any other useful application.

1.5. Schedule

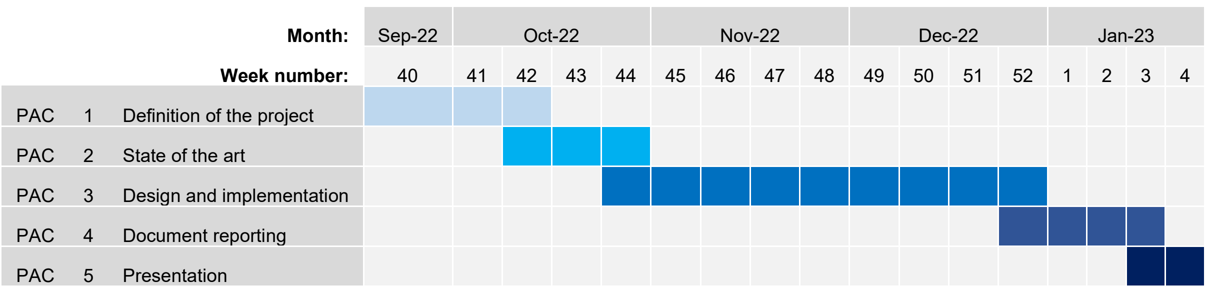

Table 1. Schedule of the works,

1.6. Summary of products

The main product result of this document is the proposal of a scenario for the Power Market towards a Smart Grid 2.0. This proposal will explore the use of solutions that already exist in some cases, such as blockchain for smart contracts, and machine learning for data analytics, and will also propose an approach for the structure of the market since it will become necessary to adapt the current structure into a more flexible one.

1.7. Brief description of the document chapters

This document is composed of the following Sections:

- **Section 2 State of the art**: of the technology, materials and methodology that is the basis of the development of the theoretical approach for new opportunities in the Power Market.
- **Section 3 Methodology and results**: theoretical design and development of the proposed solution or solutions.
- **Section 4 Conclusions and future development**: once the development has been proposed and compared to the current situation and baseline, a gap analysis will define the steps for the future development of the designed solution.
- **Section 5 Glossary**: definition of the terms used in the document.
- **Section 6 Bibliography**: list of references used in the document.
- **Section 7 Appendixes**: additional documentation.

2. State of the art

2.1. Smart Cities

In 2018, the UN reported [1] that 55% of the world population lives in urban areas, and that is expected that this number grows to 68% by 2050.To understand this growth, while in 1950, 751 million people lived in cities, that number grew to 4.200 million in 2018. At the same time, the world has seen a technology revolution that has changed how the people lives, their daily activities and all its surroundings.

With the world continuously growing, the need for a sustainable approach becomes crucial. The 2030 Agenda [2] aims to transform the world into a more habitable environment for everyone and created famous Sustainable Development Goals (SDG), 17 goals that seek to bring prosperity, peace and partnership to the planet and its inhabitants.

All 17 SDG are equally important and all of them are related to urban life and therefore, to Smart Cities.

Figure 1. SDG icons [2].

This document is focused in just one part of all the goals that a Smart City needs to handle: energy and it will have an impact into the SDG in the following way:

- **SDG5 Gender equality**: the project that this document is promoting should be develop in a way that give the same opportunities regardless of the gender.
- **SDG7 Affordable and clean energy**: the main goal of this document is to create a platform where energy can be traded and that can be accessed by everyone in compliance with the regulation. That method incentivizes competitivity and should drive to more affordable prices. Additionally, clean energy is more competitive than other no so clean sources of energy when considering its complete footprint, from the cradle to the grave [3] [4].

- **SDG8 Decent work and economic growth:** the main drive for the author to develop something is to find new ways of doing business and opening it to everyone with the will to do it while facilitating the way to get into the environment and produce a decent work while helping the economy to grow.
- **SDG9 Industry, Innovation, and Infrastructure:** the solution describes in the document is 100% based in innovation and industry (mainly technology and energy) and it will enhance the current capabilities of the electrical infrastructure.
- **SDG10 Reduced inequalities**: The proposed solution needs to allow access to big companies with their own interests but also small investors. Even group of smaller investors that unite to gain the necessary tools to participate in the market that otherwise, being alone, they could not have.
- **SDG11 Sustainable cities and communities:** the solution is addressed to the Smart Cities and to empower the communities in their energy management so they can become more than just consumers.
- **SDG12 Responsible consumption and production:** another feature to be developed by the proposal of this document is to register, organize, analyze the huge amount of data available in the daily trades of the power market within the Smart Cities. The result of this analysis would bring understanding of the behavior of the consumers, producers, and prosumers to help create new energy efficiency strategy to make the energy use more responsible.

There are several tendencies in the Market in regard to the shape that a Smart Grid should have. UN is one of the global entities that is working hard on this behalf and many countries in the world, are developing their own regulation in order to provide tools for the interested groups. In Spain, the set of Norms under **UNE 178101**, with the title Smart Cities, Infrastructure and Public Service Grids intends to provide such tools and is composed of several sectors. The electricity sector is defined in **UNE 178101-5.1**.

2.1.1. Smart City data

Smart Cities produce a continuous and huge amount of data, and such data is not currently used at its full extent. To show how the use of this data can be enhanced, it is necessary first to understand how the data flow process works:

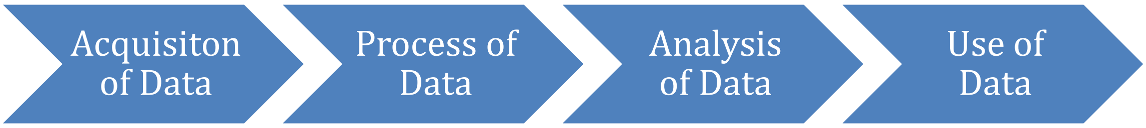

Figure 2. Data flow – management.

Computational Intelligence [5] (CI) is all-in-one theory, design, application, and implementation of biologically and linguistically motivated computational paradigms, based on three techniques: Neuronal Networks (NN), Fuzzy Systems, and Evolutionary

Computation. Machine learning (ML) is part of the family of CI and it aims to provide the computers the ability to learn without being explicitly programmed to do it.
In any given system, in this case a power market system, there are multiple devices of different kind, each one of them generating a considerable amount of data every unit of time. Part of this data is processed and send, while the rest of the data is either not recorded or recorded during a limited amount of space on the storage unit of the device.
There are multiple strategies to introduce ML to the Power Market and to be successful, the chosen one needs to be less intrusive and require lower infrastructure expansion. Otherwise, if the investment is too high, it can make the proposal not feasible financially speaking.
In the following section, there will be a more detailed explanation of the involved devices, which type data the produce and how this data can be used to develop new services.

2.2. Power Market

Before the 80s [7], Electricity Market, also known as Power Markets, all consisted of Public Companies that held all the control of the different segments: Generation, Transmission, Distribution and Commercialization; these companies are also called Fully Integrated Utilities. In UK and Norway, we can find the first cases of Market opening to private companies. There were different motives depending on the country, but many other countries followed the example and currently, most of the Power Markets in the world are open to private companies, in different ways.
To be able to open the Market, the regulation had to be adapted and so, it was created a new scheme of regulation considering the technology available at that time. Following the latest advancements in the industry, both energy and technology-wise, the regulators has proved to not be ready to catch up with the advancements.
Consequently, we currently have a complicated situation with several phenomena occurring at the same time:

- **Integration of more renewable** generation to the grid that increases the technology challenges. Since the renewable generation tends to be unpredictable, it is widely considered a non-dispatchable resource, meaning that to serve the demand, which is the top priority of any market, requires new strategies, policies and obviously, a huge investment.
- **Digital Transformation of the sector** has become a top priority also in the energy industry as well as in any other industry. On top of that, the energy is a strategic sector for any country and holds a big chunk of the Gross Domestic Product of any and every country. The impact of digital transformation is huge and positive, but it also requires investment and planification.
- **Top to down and down top down concurrently approach** means that the traditional top to down scheme is no longer the base case. In this approach, the energy flow from the produce to the consumer. In the new approach, consumer can also become a procedure, changing dramatically the management and planification of the market.

- **Electrification of everything** is the new trend in every industry being the best example the Mobility industry, where Electrical Vehicles (EV) have become a priority within the sustainable policies everywhere.

2.2.1. Structure

Each Power Market is different and so is the reason. In every country we can find a different culture and approach to solve things. For example, Latin America countries tend to have preference to keep more public control to certain sector while in western Europe we normally have lower interference of the government.
Below, a Figure of a representative of a Power Market is shown:

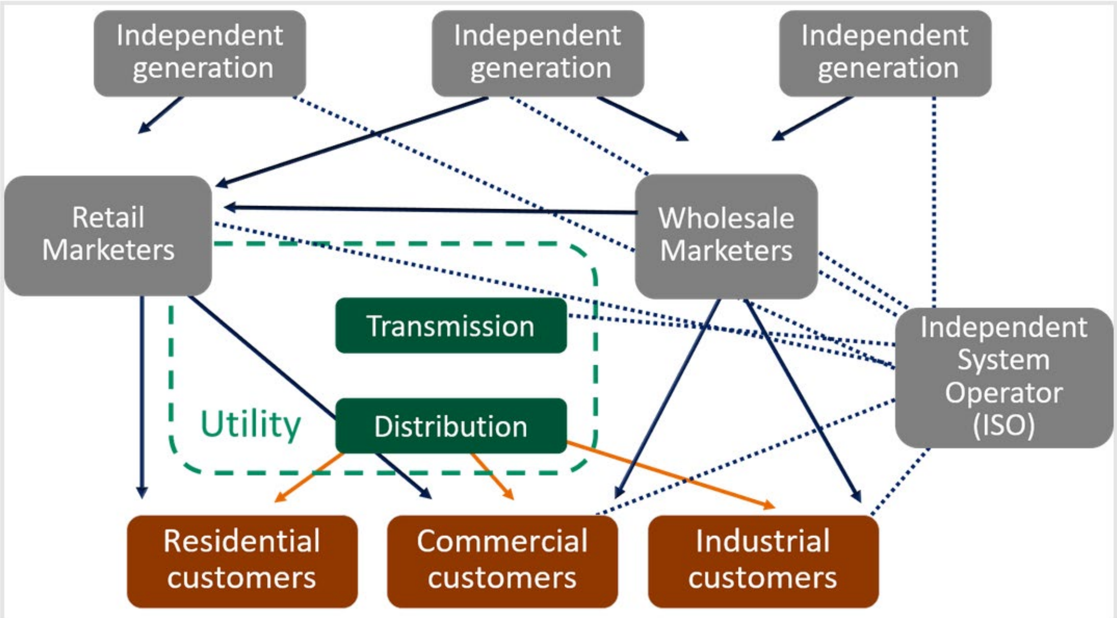

Figure 3. Power Market Structure, source: [7].

Figure 3 shows the structure of a traditional Power Market. Even if the structure is just one case, it perfectly exemplifies the top to down approach where the energy flows to the consumer. It is also important to point out the centralized management, in this case done by the Independent System Operator (ISO) who is in control of many critical tasks.
Using that approach, seems unlikely continue with the natural evolution of the sector. Why? Because it does not consider all the new available features, some of which, have already been mentioned: Machine Learning, Prosumers, Smart Cities and as it will be introduced later, Blockchain and some others.
This document might not be the first to announce this truth and for sure not the last. Hopefully it will be another “cox in the machinery”.

2.2.2. Smart Grid

In the traditional, since the 80s, Power Market structure, is hard to imagine how the Smart Cities can be fully developed. For one, the ISO is a management entity that has no entitlement nor natural knowledge in the urban management. If we imagined that the ISO would also be the Operator of let's call it Power Market 2.0, how could they manage the needs and realities of a city? Would they have a Control Room connected to all the sensors and devices in a city? The answer is no and impossible.

The management of a Power Market is complicated and complex, and it requires a lot of effort, planification and it keeps improving even after 20 to 30 years depending on the country. Equally, the management of a city is also hard and requires planification too. Both systems have different needs.

The energy management of a city is not currently controlled under on single entity. On one side, the Power Market intervenes in any city, whether the distribution companies have their own facilities to supply to end-users, the trading companies (in open markets) might have many customers, in the given city or even the City Council could be an active participant in the Power Market. On the other side, the City Council needs to manage many other activities happening in any city: public services requiring energy such as traffic lights, public lightning among others, public transportation like the subway that normally is electrically powered, Electrical Vehicles infrastructure which is growing rapidly and demanding more every day, City planning for growth and expansion within the limits or the limits themselves; each and every one of them have a different management but they generally share either ownership, control or even management.

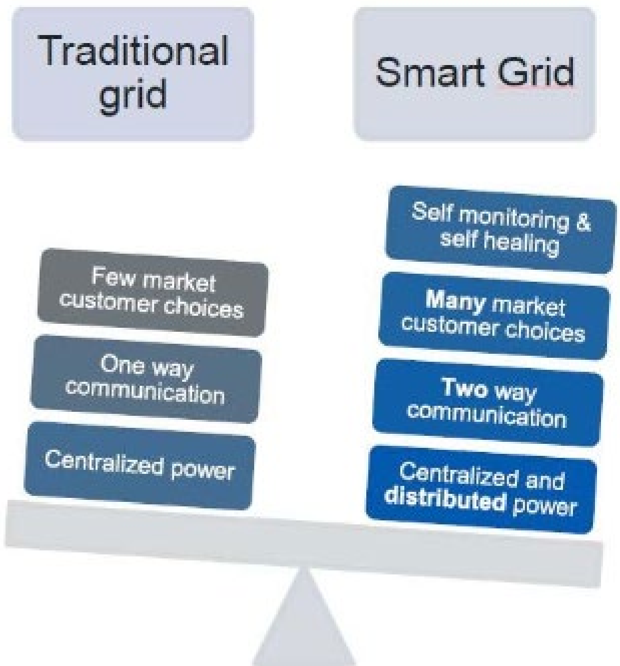

Figure 4. Traditional Grid vs Smart Grid, source: [8].

2.2.3. Internet of Energy

In the Traditional Grid, there was a limited flow of information between the nodes, generally constrained by the limited resources of communication. With the rapid evolution of the

Internet, the energy meters were enabled with communication, normally for revenues purposes [8], AMI 1.0.
The first version of the Smart Grid used this abovementioned feature to start using the additional data generated by the meters and other devices, to analyze it an provide other related services such as energy efficiency, grid stability analysis and so many others.
The current Smart Grid 2.0 goes beyond with the introduction of a both ways communication, where the devices and interoperate, distributed intelligence is used at different levels of the network and grid, where customers become active players, Smart Home is in full development, and with new players such as Demand Response Providers /Aggregators.
The following **Figure 5** shows the evolution of the Grid to Smart Grid 2.0:

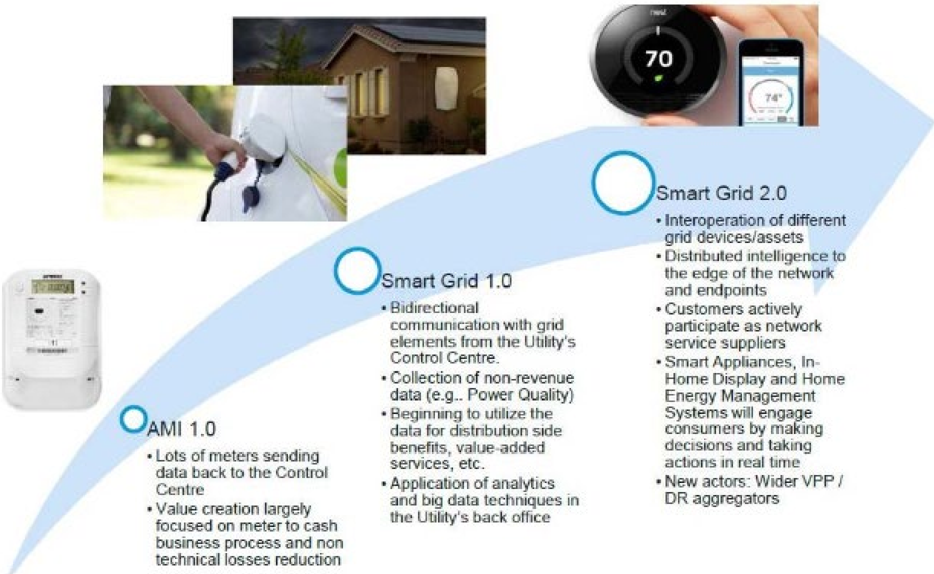

Figure 5. Evolution to Smart Grid source: [8].

2.2.4. Current Situation

The Power Market has always been a complex Market, as it depends of several factors some of them that can be controlled and some others that are out of the control of the parties involved. In the present date of this document, there is a conflict ongoing in eastern Europe, specifically in Ukraine, a country in war with Russia over the dispute of geopolitical control of the area. Other countries have interest in this war, especially those in the European Union, United States, and China, among the biggest ones.
In consequence to this conflict, we have witnessed a huge increase on the energy prices of electricity. Following section 2.2 we can determine that the Power Market in Europe has been quite stable for the last decade or even more. This stability has caused that the players have trusted the system to continue stable. Due to the marginalist pricing strategy [12] present in almost all power markets, the increase of the electricity price of those plants fueled by Liquid Natural Gas (LNG) has caused the increase of price of electricity of all other plants with any source, including renewable. This situation, which is hard to

understand for the public, has caused some countries to intervene in the regulation with pricing exemptions such the one implemented by Spain and Portugal [13]. Without the intention of sounding too obvious, it seems that the solution for this particular problem is easier than it seems, and it is being used in many countries in the world, including many countries in Latin America. This solution is nothing more that securing Power Purchase Agreements (PPA) between Buyers and Sellers of energy instead of trading it in the daily market also known as Sport or Merchant Market [14]. That would avoid the non-LNG plants to sell at LNG prices, and it would cap LNG prices to the agreed formula on the mentioned PPA.

This document intends to take the existing PPA as a basis to propose flexible and smart contracts that would, additional to the current benefits of such contracts, enable many new tools for new services and new business opportunities.

2.3. Smart Contracts [9]

An **energy contract** is an agreement between two parties where they trade energy at an established price. There are other service that can be traded such as firm power, ancillary services as frequency regulation or reactive power, availability, and some others. In general, the management of the main conditions are done by the ISO.

Analogously, **Smart Contracts** are applications that are stored on a blockchain that run when predetermined conditions are met. They typically are used to automate the execution of the energy agreement so that all players can be certain of the result at the same moment, without any the intervention of the ISO or any other centralized authority and without any loss of time, so it becomes a distributed system.

2.3.1. Blockchain

Blockchain technology is a shared, immutable ledger for recording transactions, tracking assets, and building trust.

As each transaction occurs, it is recorded as a “block” of data. Those transactions show the movement of an asset, in this case a tangible one such as energy, as in a kilowatt per hour. The data block records the desired information: player identification, energy, timestamp, connection point, how much energy and the condition of occurrence.

Each block is connected to the ones before and after it. These blocks form a chain of data as the asset, energy, moves from the buyer to the seller. The blocks confirm the exact time and sequence of transactions, and the blocks link securely together to prevent any block from being altered or a block being inserted between two existing blocks.

Transactions are blocked together in an irreversible chain: a blockchain.

Each additional block strengthens the verification of the previous block and hence the entire blockchain. This renders the blockchain tamper-evident, delivering the key strength of immutability. This removes the possibility of tampering by a malicious actor — and builds a ledger of transactions you and other network members can trust.

2.3.2. Distributed Ledger Technology (DLT)

In a Traditional Grid, the ISO is a centralized entity that analyzes all the transactions, keep records of them and sends a statement at the end of the period for tax and accounting purposes.

With the DLT, the Smart Grid 2.0 becomes a reality as a complete distributed, reliable, and secure system where the transactions occur in a safe way without any external intervention and highly scalable, since the number of transactions does not impact its usability. All grid players have access to the distributed ledger and its immutable record of transactions. With this shared ledger, transactions are recorded only once, hence eliminating the duplication of effort.

2.4. Machine learning

A Smart Grid is a complex environment with million devices all interconnected that constantly generate huge amounts of data. Such generated data requires collection, storage, management, and analysis. The Internet of Things (IoT) could provide a robust solution to fully employ the power of the smart system.

As mentioned in 2.2.3, the data comes from various sources including smart meters, field measurement devices, remote terminal units, circuit breakers, switchgears relays and many others. A human operator would not be able to analyze all this data so big data analytics becomes crucial not only for the efficient operation of the Smart Grid but also for the development of new business opportunities.

Even though electric utilities have realized that deployment of big data analytics is a must and not a choice, implementation of big data analytics in utility framework is lagging.

Machine learning is a data analysis technique in which computers are taught to make decisions based on experience. With the increase in the amount of big data, machine learning has become a crucial technique to solve problems.

Machine learning techniques provide an efficient way to analyze, and then make appropriate decisions to manage the Smart Grid; hence enabling it to work as it is intended to. Machine learning functionalities include:

- Predictions of consumption price.
- Power generation.
- Future optimum scheduling.
- Fault detection.
- Detection of network intruders.

2.5. Summary

In the following Section, it will be described how it is intended to develop the implementation of a solution. It will be proposed in a theoretical way to provide the tools for a potential real implementation in the future.

In the final Section, it will be proposed a budget and schedule with the wish of raising funds in the future to enable the creation of a team to develop this initiative.

3. Methodology and results

Before explaining the results, it is necessary to further explain the methodology. The previous chapter gave a high-level view of the state of the art, and now it will be complemented with an extended description of the planned methodology, considering more than one option in some cases.

The chapter 3 will also narrow down the selection and propose a potential solution:

- **Section 3.1** proposes a **Decentralization solution** in terms of moving to a distributed system. The traditional Power Market, renamed as **Main Power Market (“MPM”)**, will maintain its centralized structure but introducing a new interface with the **Segmented Power Market (“SPM”)**. The latter will be a completely decentralized system. Together they are part of the Dualization solution to be implemented to develop the new activities and features of the Smart Grid 2.0.
- The structure of the proposed system is detailed in **Section 3.2** divided by players in the MPM and in the SPM, and offers possible solutions for the **energy metering, the processing and management of the SC**. ML will be processed out of the SC to reduce energy consumption.
- Section 3.3 explains how the blockchain technology might be used with the **Power of Authority** consensus (“POA”), then it describes the Smart Contract composition and technology already in use.
- In the final **Section 3.4**, it is explained the several approaches to use **Machine Learning** to generate useful features for the system.

3.1. Smart Grid 2.0 and Power Market

The old and still operating Power Market is a centralized system that works well. It is far from being a perfect system, however, it allows the electricity to flow from the producer to the consumer while being a competitive market with opportunities to return the investment of the investors.

There are three things that should be considered when moving the Power Market to the Smart Grid 2.0:

- The decentralization of the system.
- The introduction of a huge number of nodes.
- Changing one-way paradigm to two ways.

These topics can evolve into a much longer discussion so to find a way to solve them it is mandatory to understand them well.

3.1.1. Marginalist theory and decentralization of the system

Before proposing a solution, it is crucial to understand how the system works currently, where the Power Market is a centralized system with one (or two, in some systems there is a different one for each regulation) regulators that control it. There are two sides of it: system and market, so there is a System Operator and Market Operator. It is a very important distinction since the System is the part that guarantees that the demand of the consumers is met by the production of electricity. It is the first layer of the system. The second layer is the Market, the demand is met following the commercial agreements between the different players.

Each Power Market in the world are based in a similar theory with differences. First, it is important to note that different goods are traded in a Power Market: a) energy, b) power, and c) ancillary services. To simplify the explanation, the focus will be in the energy trading. The energy is generally traded in a 15-minute o 1-hour granularity. This choice is related to the capability of the old energy meters. This granularity will be an important feature in the new Smart Grid 2.0, and it will be explained later.

As mentioned, the first obligation of any Power Market is that all demand is met by production. In any Market, there are several types of technology to produce energy and any of them has different strategies to return their investment, here is a brief explanation:

- **Thermal-based plants**: regardless the used fuel (coal, LNG, fuel, biofuel, etc.), they are all based in a similar strategy to have return on their investment. In general, a Power Market is willing to pay this type plants for being available. Why is that? Because this technology is dispatchable, meaning that they are ready or almost ready at any given time. They can be turned on and off at will, considering certain limitations, and can also offer most the necessary ancillary services.
- **Traditional renewables plants**: mostly hydroelectric power plants, they are critical to the system specially if they have reservoirs. A reservoir is nothing more than a "battery" that can help the system to maintain its stability, like a thermal-based plant but without the dependency on the fuel and its price. Therefore, several markets use a term named "price of water", meaning that give water an artificial price to help regulate the market. This price is generally based in an average thermal plant.
- **Non-traditional renewable plants**: to promote the investment in these technologies, most of the markets have implemented different strategies to allow them to be dispatched first in the merit order. Sometimes, they fall in second place if nuclear is present in the market.
- **Nuclear plants**: this technology has a separate treatment, since I cannot be switched on and off at will and in case of failure, it can have catastrophic consequences. Therefore, its treatment is sometimes similar to the one of the renewable plants.

Additional to the nature of the technology, there is another important consideration. There are two ways of meeting demand and production: a) variable cost assignation and b) price offer.

Variable cost assignation means that each technology is tagged with its variable cost. And **price offer** means that both demand and production, put a price to the energy they want to sell/purchase.

<u>How is that related to the Power Market?</u>

During the creation of the Power Market as we know them today, most countries chose a methodology called marginalist theory in order to assign price to electricity.

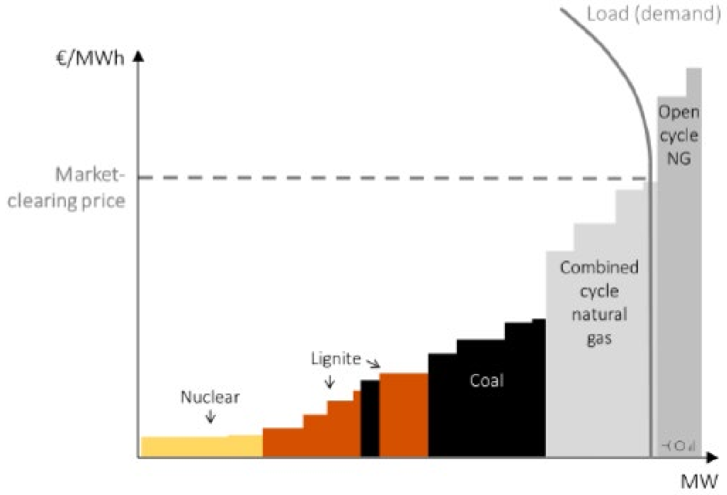

Figure 6. Marginal Price and Merit Order [12]

Figure 6 shows a given hour dispatch result of the marginal price and merit order based in a variable cost assignation. Nuclear energy, with the lowest marginal price, is dispatched first. The rest of technologies follow it in order of merit (variable cost) until the last kWh of energy is met with the demand in that hour. When that happens, we reach the market clearing price. This price is the uniform price for all the technologies in that period. There are several questions that come up to mind: Is that fair to the consumer? Is that fair to the producer? Fairness is a difficult quality to be reached, but in general terms and given the historical behavior of the market, the answer to both questions would be yes.

If the answer is yes, why is not being fair in Europe in the current war-driven gas price increase? Well, that brings us to the next component of the Market Operation. One thing is how the energy is allocated to meet the demand; the other thing is how the energy is traded in parallel to its allocation. What options are available? Mainly two: Power Purchase Agreement (PPA) and Spot Market.

A PPA is an agreement between two parties to sell and purchase energy. In some countries, there is some conditions to be met in this type of agreements and in others, they are mainly open to the parties' agreement.

The Spot Market also known as Merchant or Occasional, is basically a market for surplus and shortage. This is in theory, in reality any player of the market can use any of the forms of getting their needs. In some markets, the Trading Company is mandated to cover a minimum of their needs for the coming years, meaning they that must sign PPA and only use the Spot Market for surplus and shortage. This strategy is useful also for planning, since it is easier to plan a market knowing its coverage and needs. The other strategy, followed by most of the European countries for the last few years is to get all the energy, or most of it, from the Spot Market. This strategy has proven successful during several years, until a war exploded in Ukraine and the LNG has produced an increase of the electricity price.

The impact of this increase in the countries with the first strategy is minimum. The impact in the countries based mostly in the Spot Market has been catastrophic. Extreme high power (and low) prices make both buyers and sellers become more cautious about entering PPA deals, which usually have a long-term nature.

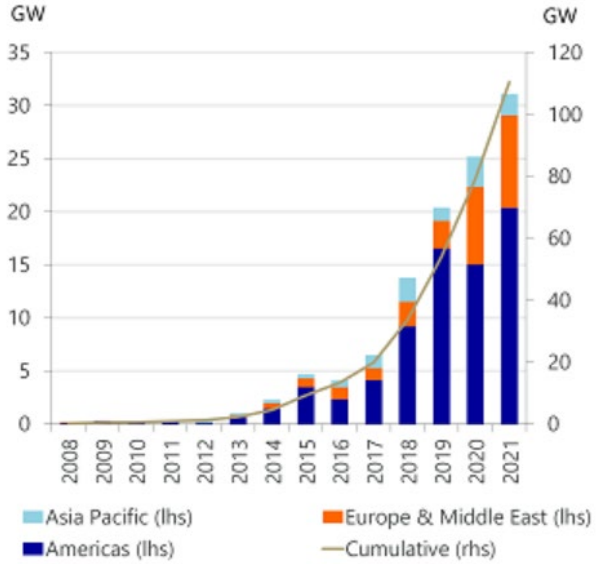

Figure 7. Bloomberg NEF, 2022

In **Figure 7** it is interesting to see how each region has used a different strategy to handle the Power Market trading.

In the last couple of years, the European markets have seen an increasing number of PPA:

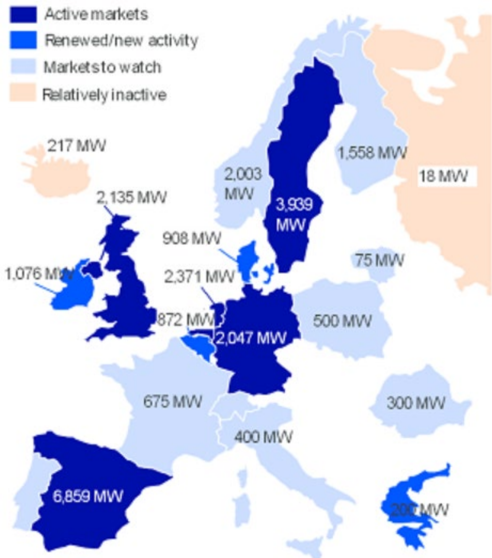

Figure 8. Bloomberg NEF, 2022

This has proven to arrive late and short, seeing the consequences of the gas crisis to the electricity prices. Obviously, this is a simplification of the problem. In a complex market such as the Power Market, there are many factors that impact in its development. In the end, all companies seek the same: the best return on their investment.

The main questions that point to potential solutions are:

- How is that important to the Smart Grids 2.0 and how will impact?
- What strategy can be more successful?
- If the market chooses to regulate a minimum of PPA coverage, how can that be handled with the huge number of players that will be part of the new system?
- Have the traditional PPA the flexibility to adapt to the always evolving blockchain-based contracts?
- Can the management be done by one (or two) entities?

3.1.2. Decentralization and dualization

The traditional players in the market will continue its operations and their purpose will be the same, to produce profits. The traditional players are:

- The **Generation Company (GenCo)**, its purpose is to produce electricity and sell it in form of availability, electricity, or ancillary services such as reactive power, or frequency regulation. The return of investment is a long-term strategy, and they are privately owned in most of the markets
- The **Transmission Company (TransCo)**, its purpose is to transport energy from the GenCo to the DistCo in high voltage to reduce losses, being paid by the consumer through the tariff. The return of investment is a long-term strategy, in some markets they are owned by the government and managed by a private company. It is a highly sensitive part of the system.
- **Interconnection**: almost all countries are electrically interconnected to others and trade energy with them. It is not a player by itself, but it is an important way to trade energy and to balance surpluses and shortages.
- The **Distribution Company (DistCo)**: its purpose is to distribute energy from the TransCo to the Consuer in medium voltage, being paid by the consumer through the tariff. The return of investment is a long-term strategy and can be either public or private through a concession.
- The **Trading Company (TradCo)**: its purpose is to trade energy and they do their business with the ability of sell at a higher price than the cost. They must offer financial reliability to provide stability to the Power Market. In some markets, the DistCo and the TradCo are the same company.
- **The System Operator (SO)**: is the company, public or private, that manages the system in the real-time execution (also known as Dispatch) to make sure that the energy that the demand needs is served.
- **The Market Operator (MO)**: is the company, public or private, that manages the system in the post-dispatch to make sure that the trading has been served correctly, both agreements and spot market. In some markets, the SO and the MO are the same company.
- **Authority bodies**: there are several government entities that actively participate in the Power Market. The Regulator is normally the **Energy Ministry or Secretariat**, that manages the planning of the Sector, it can also act as an arbitrator.

The players on the **SPM** side are more heterogeneous per nature and have different objectives:

- **Prosumer**: it can take different shapes, a residential user that consumes and produces, or a company offering District Heating services, either one of them with completely different objectives or horizon.
- **Aggregated Company (AggCo)**: one or several players that share common interests and participate together in the market.
- **Demand-response provider**: it can be either a user with the capability of adjusting their demand and make profit of it or a company that installs stand-alone batteries to provide this service.

They are not new players in general terms, as they already exist. This document proposes some new features that can be applied to these players.
The first proposal made in this document for Smart Grid 2.0 is to separate the Market in two interconnected parts that I named **Dualization**:

- **Main Power Market ("MPM")**: The MPM will have a similar structure and regulation as it has now with the introduction of a mechanism to interact with the new players.
- **Segmented Power Market ("SPM")**: The SPM will need to be structured from scratch.

3.1.3. Segmented Power Market structure

In the previous section, it has been described the different players of the SPM. These new players bring new features into the system, that the system was not used to handle. The main newly introduced features, need to be addressed and they will generate a different structure comparing to the current one since it seems impossible to handle with existing structure and management of data. That does not mean that the MPM will not communicate with the SPM; quite the opposite, the new structure needs to ensure full duplex communication between the two parts of the dual market.
Currently, a Power Market is divided into three stages that determine its structure:

- **Planning:** in this initial stage, all participants must plan their future, both in short and long-term. This stage is crucial to ensure the financial feasibility of the system and it serves to reach a balance of cost of the energy and profit for the investors.
    - **Long-term:** one or many of the players are generally the manager of the planning of the growth of the system. On one side, there is the demand. On the other side, there is the generation, and in the middle, the transmission and distribution lines. The more the demand grows, the more the rest need to accompany this growth. The Power Market must avoid, "at all costs", that the demand is not met by available generation and/or transportation of this energy. "At all costs" is not the best practice and in many practical cases, this "must", is not met too often.
    - **Short-term**: this planning is related to the operation of the system, so is the nexus to the next stage. In this case, all participants must inform of their availability to the SO/MO, so this entity can forecast the next time slot.

Generally, the Power Market has a general week-ahead planning that can be corrected with the day-ahead planning, in the case of any change with the previous informed week-ahead plan.

- **Real-time execution:** with the week-ahead planning information and the reality of the situation with the players (even if it is obvious, it is important to remark that the planning can be completely changed by many reasons, such a failure, weather conditions, and any other contingency), the SO is responsible to ensure that every customer is served with energy. The Power Market used a time period of 1-hour or 15-minutes.
- This is its **priority** and to do so, the stability of the grid is an obligation that involves the use of other ancillary services. In electrical terms, it is known as **Primary Frequency Regulation ("PFR").** This regulation has the shortest granularity, between a few seconds and not more than 30. There are another two regulations: **Secondary Frequency Regulation ("SFR")**, with the purpose of maintaining the stability of the grid, it acts right after the PFR for a period of until 15 minutes, and the **Tertiary Frequency Regulation ("TFR")** that is basically to maintain the stability of the grid and not only ensures the stability of the grid but also the balance with the optimal cost to do it.

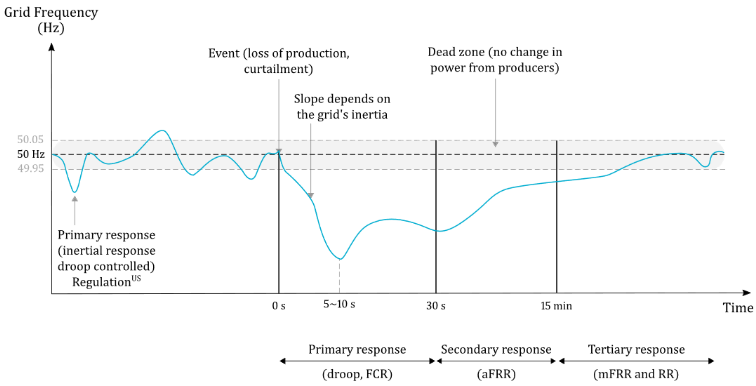

Figure 9. Grid regulation, PFR, SFR, and TFR [15]

- In parallel to the Physical Dispatch explained above, it occurs the Financial Dispatch. Therefore, everything is dispatched considering the different agreement between the players and with the use of the Sport Market as a tool to allow players to buy or sell energy in the case they need it. At this point is where the Power Market becomes more complex. Since the purpose of this Document is not to enter into details of the Power Market, but to offer a general view that can be used to show a potential solution for the Smart Grid 2.0. In section 3.1.1 it is described the Spot Market that is both a physical and financial management of the energy. The Power Purchase Agreements ("PPA") are only a financial management of the energy. The main PPA that are used in any Power Market are:
    - **Financial (or Virtual) PPA**: regardless of whether the energy is physically served, the Seller must ensure that the Buyer is served. So, the Buyer will pay the Seller for all the energy in the agreement and the Seller will back it up with own or third-party energy.

   - **Physical (or Sleeved) PPA**: in this case, the Seller will only serve its own energy and the Buyer will pay for it.
   - **Take and pay:** in this type of agreement, the Buyer only pays for the consumed energy. This a traditional renewable sourced PPA agreement.
   - **Take or pay**: in this type of agreement, the Buyer pays for the agreed energy, whether it is consumed or not. This a traditional fuel based PPA agreement.
   - **On-site and Off-site**: with the distributed generation, it is possible for the Seller to install a generation plan in the Buyer facilities, making it an On-site PPA. The rest of the PPA are off-site, where the Buyer and Seller are located in different spots.
   - **Green Certificates**: it has become more popular in the last few years, to trade green certificates additionally to the traditional PPA. In this case, a megawatt-hour (“MWh”) of green energy also generates a certificate that can be traded. Most companies use this certificate to fulfill their commitment of reducing their emissions, worldwide, the customers need to measure their emissions, thus generating Emissions certificates. There are other types of certificates such as Offset certificates, for example a forest can generate this type of certificates with the effect of absorbing emissions.
- **Supervision (post-dispatch):** once everything in the execution stage has passed, the MO is responsible of validating all the trades and transactions. In some markets, the MO also has access to an account of the players to manage the financial transactions of the Spot Market in order to maintain the flows of funds and avoid frauds. The PPA are generally managed between the parties involved in each agreement, but it is responsibility of the MO to manage the transactions and inform of them to all players. Basically, the MO has access and management power to all transactions of the market.

In the SPM, seems reasonable to maintain the main structure of the MPM: planning, execution, and post-dispatch. At the same time, it does not seem possible to do it the same way, since the number of transactions will be huge, the time period will be shorter, and the number of players will be much bigger. With these conditions, there is no MO capable of handling this quantity of data in real-time.

The following **Table 2**, **Table 3**, **Table 4**, **Table 5**, and **Table 6**, are proposals of this document for the new Power Market scheme in this potential solution for Smart Grid 2.0. **Table 7** is an already existing solution that is considered in the proposed scheme.

The current MPM structure as the baseline can be used to create one or more solutions for the SPM:

	Existing PM	MPM	SPM
Planning	One entity is responsible	One entity is responsible of the MPM, and all players must have an interface to deal with the distributed SPM in case they want to be part of the activities	Decentralized system, with a supervising entity to be created. Following the current regulation, all players will need to keep updated certain information in a database. There will be certain levels, enabling the players to engage in further activities according to the level of information they share. The players will need to send information and have the appropriate infrastructure. In a similar way, the Supervising Authority ("SA") will require a distributed and powerful data management system to collect, filter, analyze and process the amount of information generated by all the players. Any player that wants to interact with the MPM, need to adapt to the centralized system and its regulation
Long-term	All players share information every 3, 6 and 12 months. This information is used for the responsible entity to develop an Expansion Plan of the Grid. It considers all the new producers and consumers, and with that, it establishes the required expansion of the grid (transmission	All players will maintain the current methodology and they will adhere to the SPM level-oriented system.	In the level-oriented system, the players may choose to share the amount of information appropriate to their activities. For instance, a residential household with just a self-consumption solar plant will need to share much less information than an Aggregator that plans to manage the

	and distribution lines and substations) while maintaining a reliable and stable grid. Each market will use the tools they have to allow competitiveness		equivalent to several hundreds of residential units. Therefore, the planning can be determined by applying a weighted value to the players and their planning
Short-term	All players share weekly and daily information. This information is used to plan the weekly dispatch. The daily information is only used to correct the weekly plan with any change that occurs after the weekly information was submitted. Again, the purpose is to maintain a reliable grid, and with the tools available, to move towards a competitive energy price	All players will maintain the current methodology and they will adhere to the SPM level-oriented system.	Following the level-oriented system and the weighted valuation, a label of criticality must be applied to distinguish among players. The ones with the most critical label, will require to disclose full information. The labeling of the players will not be fixed but it will adapt to the moving circumstances and the conclusions extracted from the data analytics, meaning that a player that has generated a situation at a certain moment, might be required to supply additional data. This is currently done "manually" in the PM, the proposal is move to an automated solution. The SA will use Machine learning for the data analytics as described later in **Section 3.4**
Execution	One (or two) entities manage the execution	The entities managing the execution will have to communicate to the SA and integrate its methodology to the automated system. There will be an interface between the MPM and the SPM, because	The SA will work in an automated way. The only way to do that with the huge number of operations is to implement ML procedures as described in **Section 3.4** like optimal scheduling based on price, dynamic pricing and short-term forecast, load

		there will be transactions between MPM and SPM players. A MPM player can trade with other MPM players, then it will follow the same rules that apply today. In case they want to trade with SPM players, they must follow the new rules that apply also to SPM players	forecasting with ANN DR optimization, load clustering and forecasting, customer power curve profiling, EV load forecasting, or weather and demand forecasting
System	One entity is responsible, and each player must work under certain specifications	The entities managing the execution will have to communicate to the SA and integrate its methodology to the automated system. The priority is the same as today, to maintain the grid stability, power quality and cost-balance. The current entities that manage the MPM will have to upgrade their system so they can also automate their actions and work with the SPM	The SA will need a powerful system and team to be able to create, maintain, and introduce new feature of self-control to supervise the execution of the system. Additionally, it will require common efforts with the entity responsible of managing the System of the MPM
Market	One entity is responsible, there are two main ways of managing the energy trading: Spot Market and PPAs	In a similar fashion that the Operation of the System, the Market will be managed with the current managing entities when the trading is between MPM players. If MPM players trade with SPM players, then it will be under SPM smart contracts systems and supervised by the SA	The responsibility of the SA on the supervision of the Market will have a different paradigm. The new Smart Contracts will be analyzed in their code structure and execution triggers, so they follow the regulation and there is no fraud, abuse of power, or any other misuse. In the PoA system, the Authority can and will enforce their power of authorizing of unauthorizing any player who does not follow the rules

Supervision (post-dispatch)	One entity is responsible and manages the supervision of the transactions/trades once they have been executed, also called post-dispatch. In the Spot Market, the bank account is sometimes managed by this entity to ease the flow of funds. In trades under PPA agreements, the parties involved will supervise their own commercial relationship following post-dispatch reports by the managing entity	The managing entity will maintain its post-dispatch obligations for all the trades that occur within the MPM. The new trades occurring between MPM, and SPM players will require a common post-dispatch analysis with the participation of this managing entity and the SA. The SA will have a grid-level view	The SA will have a planning methodology that will change the current paradigm. Instead of working on the fixed post-dispatch analysis, this new post-dispatch will be oriented as a correction. For example, if the SA detects that a flow of energy between two aggregators in a certain city is causing electrical disturbs, it will generate a "patch" that will be applied to that precise activity. In order to avoid subjectivity, the regulation will need to establish, in a clear and technical manner, the priorities of the Smart Grid so the "patches" follow those rules and all players accept the proposed solutions

Table 2. Power Market towards Smart Grid 2.0 in a dual system

3.2. Physical structure

It is necessary to define the physical layer of the system because there will be a need to invest in new equipment capable of processing the new features. There is different type of players with different requirements each, with their own specifications as shown in **Table 3**:

Market	Type of player	Energy metering	SCADA system[1]	Comments
MPM	GenCo	Full capabilities Physically in place	Own system	Easiness in case of any upgrade or modification
	DistCo	Full capabilities In place, several locations	Own system Processing of customer data	Ownership of customers energy meter in the MP, **new paradigm in the MPM/SPM**
	TransCo	Full capabilities In place, several locations	Own system	Easiness in case of any upgrade or modification
	TradCo (See **Table 4**)	Virtual metering of customers	Own system	**Need to invest in the SCADA system for the MPM/SPM**
	MO/SO	Virtual metering of players	Own system Processing of players data	**Need to invest in the SCADA system for the MPM/SPM**
SPM	Prosumer (See **Table 4**)	**May need to upgrade** Physically in place	**Need to invest in a SCADA system**	Frequently the meter is not owned by the customer
	Aggregator (See **Table 5**)	Virtual metering of customers	Own system	**Need to invest in the existing SCADA system**
	Demand-responsive (See **Table 4**)	**May need to upgrade** Physically in place	Own system	New type of player
	SA (See **Table 6**)	Virtual metering of players	Distributed SCADA system	New type of player

Table 3. General characteristics of metering/SCADA of players

[1] SCADA stands for “Supervisory Control and Data Acquisition”, in this context it means the processing system of each player whether it has sensors or not.

The following **Table 4** shows the specifications for the prosumers and demand-responsive players:

	Metering/Generation	Data processing	Data flow	Data storage
Energy	• **Metering:** 0.2S Class accuracy certification for energy measurements and high accuracy frequency measurements for frequency control applications • **Power Quality Monitoring**: record waveforms at up to n samples per cycle, up to m events stored before rollover • **Communication**: Modbus ASCII/RTU/TCP, DNP3, and IEC 61850 protocols • **Ports**: Ethernet, IEC61850, IrDA and RS485 Different brands with solutions such as **Electro Industries, Carlo Gavazzi, SEL, Circutor, Bender, Janitza, GMW, Entes, Hioki**	By the energy meter	• **Active player**: handles itself the access to the system, communicates to the DistCo, other players and SA. • **Passive player**: handles through the TradCo the access to the system, communicates to the DistCo, and TradCo/Aggr (this one communicates with the SA).	The meter should be able to: • Independently programmable historical trending logs • Record n parameters per log • I/O log, System Events anti-tampering log, Limit Alarm log
Smart contracts and DLT	Preinstalled code executed once predetermined rules are adhered to (if/when/then) **Proof of Work** ("PoW") protocol for blockchain has a	Required to install a system capable of processing the blockchain-based contracts. As a single user, it might generate a maximum of 60	• **Active player**: constant flow of smart contracts with other players	Process of verification and granting access, information is stored and written in each player on a distributed ledger

	high energy demand, and high safety. **Proof of Stake** (“PoS”) reduces energy consumption but increases safety risks. **Proof of Authority** (“PoA”) increases safety, reduces energy consumption but becomes a centralized system (in terms of smart contracts), it seems the best option, being a permissioned blockchain where all the players are known and trusted	(minutes) x 24 (hours) x 30 (days) = 43,200 periods a month, more than one contract per minute (energy, power, ancillary services, etc.) Probably, it will generate much less contracts Required to install a system with computing capabilities such as **Rapsberry Pi, Onion Omega2+, Banana PI M3+ or similar** for lower computing need such a single residential unit. It will need and additional storage unit of at least 128GB and a UPS system for 8 hours of backup. The new processing system will process the DLT with information of all the blockchain contracts	• **Passive players**: will be handled by the TradCo/AggrCo	• **Active player**: the processing system will keep a record of all the activities accessible to the SA • **Passive players**: will be handled by the Tradco
Machine learning	The computation for ML should not be done inside the smart contract and executed “on the blockchain", computations such as complex learning and optimization are best performed “off-chain", to	Processing will be done out of this type of player. The only processing done locally will be to process the patches generated by the SA and received from the SA (Active players) or the TradCo/AggrCo (Passive players).	• **Active player**: to be sent to the SA for processing. To be able to receive patches and execute them • **Passive players**: to be sent to the TradCo/AggrCo and then to the SA for processing.	This type of player does not require to store a record for a long time. If recorded, the purpose is to have a record of the patches and the system configuration before applying the patch so the changes can be undone in case of need. If the patch

	reduce energy consumption caused by the blockchain	The processing system will be able to process it	To be able to receive patches and execute them	change is undone at this player level, SA shall be informed

Table 4. Specifications for the Prosumers and demand-responsive

The following **Table 5** shows the specifications for the TradCo and AggCo players:

	Metering/Generation	Data processing	Data flow	Data storage
Energy	Virtual metering of their (passive) customers (prosumers, demand responsive, other TradCo or AggCo)	Powerful and scalable (up to n customers) processing system It will process 1-minute data of several measurements of n customers	Receive through the internet from (passive) prosumers, demand responsive, other TradCo or AggCo There are different proprietary solutions such as **MV90 of Itron** [16]	By the processing system
Smart contracts	Preinstalled code executed once predetermined rules are adhered to (if/when/then) and PoA	It will generate n times the number of contracts that their customers will require, sometimes among themselves and sometimes with external customers The requirements are much higher than the ones of a single residential unit and it will scale as the company grows in customers. Processing, storage and UPS capabilities will be according to each company	The TradCo/AggCo will have pre-established conditions agreed with their customers, so they will be able to execute the smart contracts following those conditions. There will be modifications either requested by the customer or the SA that will require to adapt the conditions. At the end of the invoicing period, the TradCo&AggCo will share the DLT related to each customer	Large amount of data will be generated and stored. It will need to be accessible by the customers and SA at any time. The TradCo&AggCo will need an accessible and secure platform. **Data protection** will be crucial in this environment
Machine learning	ML is done out of the smart contract	There are different types of ML to be processed in the SA facilities: **Supervised learning, Unsupervised learning, and Reinforcement learning.** There are other techniques such as **ANN, Natured**	The real-time information gathered by all the players and its equipment will be sent to the SA, this will include technical and commercial data	By the processing system

		Inspired Intelligence and Multi-Agent Systems		

Table 5. Specifications for the TradCo and AggCo

The following **Table 6** shows the specifications for the SA:

	Metering/Generation	Data processing	Data flow	Data storage
Energy	The SA may count as a prosumer itself, but as another single player. As SA, it will not participate on that.	The SA will participate on processing energy measurements, and its derivatives, but it will be treated in the ML subsection.	Similar to the Data processing.	Similar to the Data processing.
Smart contracts	Smart Contract supervision: to employ the SA to verify and certify the code of smart contracts regularly, as is standard practice.	The SA will manage and supervise many of the operations of the SPM. It will need a distributed nodal system with powerful Data Centers to handle the amount of processing	Huge amounts of data to be communicated in several ways during the normal operation of the system.	Huge amounts of data to be stored and accessed to during the normal operation of the system.
Machine learning	AI techniques such as machine learning include a set of methods that can learn and identify patterns in the data in an automatic way, and then use these patterns to predict, cluster and assist in decision making under uncertain environment	The SA will manage and supervise many of the operations of the SPM. It will need a distributed nodal system with powerful Data Centers to handle the amount of processing	Huge amounts of data to be communicated in several ways during the normal operation of the system.	Huge amounts of data to be stored and accessed to during the normal operation of the system.

Table 6. Specifications for the SA

3.3. Blockchain

It is necessary to describe briefly the blockchain technology before moving to the SC. A blockchain is a chain of information blocks, in this case, information about the smart contract specifications. These chains are interlinked through cryptographic methods. It is also a Distributed Ledger, thus the acronym DLT. A key feature of blockchains is that it is tamper proof: information written in previously accepted blocks cannot be changed, a property assured through cryptographic hashing.

3.3.1. POA consensus

The main issue in the blockchain methodology is how to reach consensus among the nodes about the information blocks stores and shares in the ecosystem. There are three main protocols, and one of them seems the most appropriate for Smart Contracts:

- **Proof of Work ("POW")**: the most extended system in blockchain for cryptocurrencies, such as Bitcoin. In POW consensus, the node that has the right to add the next block to the chain is determined by solving a cryptographic puzzle, also known as mining. This mining methodology has become very common lately, where large number of users have invested a lot of money in mining new blocks. To do the mining, they required specialized hardware called ASICs ("Application-Specific Integrated Circuits"). Until a year ago, this caused a shortage on the procurement of these devices, since everyone wanted to take profit on the increasing price of the Bitcoin and other POW cryptocurrencies, also causing a shortage in semiconductor [23] that are needed for other devices, being in fact, part of any almost any technology related product (from cars to electronics, to house appliances, computers, and many others). Countries like the US [24] saw this as a problem, since they depend on other countries, especially China, to produce semiconductors. They launched a program to be able to be independent on semiconductor production. Also, the European Union launched a similar program [25]. The issue is more complex than it seems because the production of the semiconductors also depends on its components and securing the full production line is a very complex issue. Therefore, mining requires large amounts of energy being that the main problematic feature of this methodology. Since the purpose of this project is the energy efficiency and sustainability, this methodology does not seem appropriate.
- **Proof of Stake ("POS")**: the POS methodology gives more weight and more chance to mine the next block to nodes that have a greater 'stake in the system. This reduces the energy consumption of the POW methodology and can make generating blocks faster. Ethereum network is the main representative of this type of blockchain consensus. This methodology can lead to monopoly, assuming that there are large stakeholders in the energy business, they could ally to become the majority stakeholder and take possession of the system. This makes the POS consensus not viable for the Smart Grid.

- **Proof of Authority ("POA")**: the POA methodology is as a variant of POS, where the stake is the identity of the validator. POA relies on a small number of preapproved validator accounts or ''authorities'', that have the right to validate transactions and add new blocks. This methodology seems just right the system implemented in a Power Market, where all the players are known and need to be trusted by the others. That can be seen as a reduction of the decentralized principle, but trustworthiness is very important for the Power Market and there might not be any reason for a player to do a trading without reporting its identity, it would be even suspicious and would lack of trust for the other party.

3.3.2. Smart Contract composition

As mentioned in **Table 2**, the Smart Contract is, in fact, a preinstalled code that is executed once predetermined rules are adhered to. The main steps will be, 1) establish an agreement between more than one player and 2) convert it into a SC, 3) if and when happens the established conditions and 4) then, execute an order. See **Figure 10** explaining the 4 steps:

Figure 10. The four steps for execution of Value Transfer on a Smart Contract [22]

There are several definitions of a Smart Contract like the one by Szabo [26] that defines it as ''a set of promises, specified in digital form, including protocols within which the parties perform on these promises", or the Ricardian contracts [27], who states that a SC aim to capture the defining elements of a legal agreement in a format that can be expressed and executed in software code. Even the Barclays Bank has published several SC templates [28].

Taking into account the proposal in [22] of the 6 layers of a SC, it can be matched to the idea of this document, see **Figure 11**:

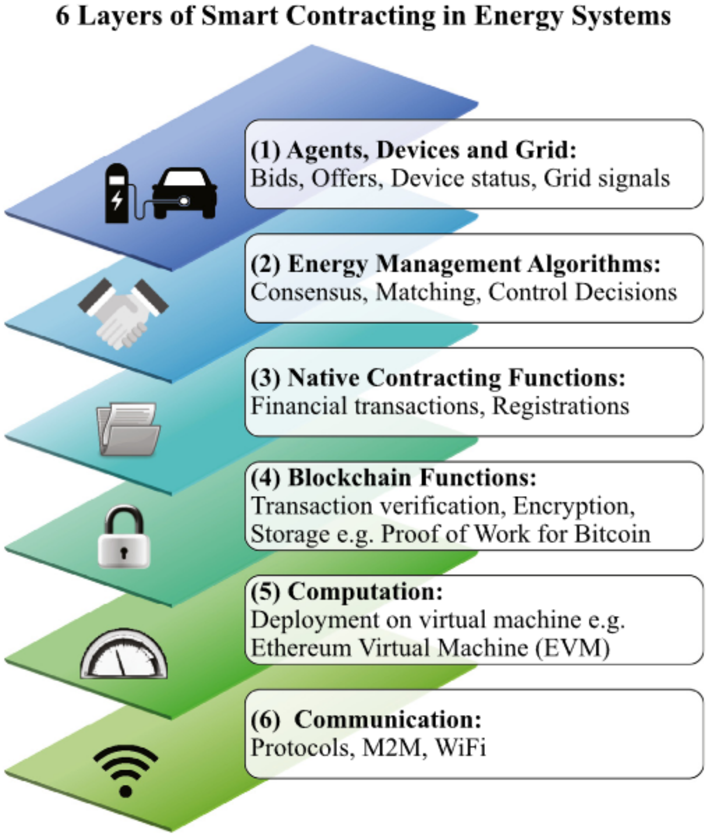

Figure 11. The 6 layers of Smart Contracts [22]

In the following **Table 7** there is an description of the 6 layers:

Layer	Description
Layer 1	The necessary data is picked up from the energy meter or any other sensor or equipment of any player.
Layer 2	At this stage, the ML participates. Initially, the algorithms will be based in known situations and scenarios. Once the ML produces new results, those could be introduced into the SC. Any decision-making such as control algorithms, negotiations, etc. would be performed on this layer and it would be automatic. ML is processed out of the SC to reduce energy and processing consumption at the player level.
Layer 3	The third layer involves programming of the contract, which is often in a standalone smart contract language, for example, Solidity. The output is a digital contract composed of code
Layer 4	This layer involves the integration of the smart contract on a block in the blockchain. This brings the aspects of verification, encryption, and authorization made by the SA (using POA).
Layer 5	Implementation and computation take place involving interaction with virtual machines.
Layer 6	The information is transferred any communication protocol available, and as a result, the SC may trigger the smart meter to send information validate the operation.

Table 7. The 6 layers of Smart Contracts in the proposed system

There will be two main types of SC, Peer-to-Peer ("P2P") between players, and Peer-to-Grid ("P2G") contracts, between a player and the grid. P2P and P2G will be important in the new system. Spot or Retail market can used P2G-based smart contracts.
P2P will represent the majority of the trades but they might not cover all the needs, then, the P2G will cover the rest. There are applications [29] that use a SC-based ancillary service P2P energy exchange platform which acts as a ''virtual decentralized market authority'', without the need for the presence of the Authorization entity.

3.3.3. Smart Contract technology

In section 3.3 it was established that the POA consensus seems the most appropriate for Smart Contracts. That makes it a permissioned blockchains (also known as ''private" or ''enterprise" blockchains) where not any party can join, there is a central authority granting access according to pre-agreed rules. The central authority being the SA.
There are several developments in the market already available:

- **Energy Web Foundation ("EWF")** [30]: this foundation has launched a decentralized technology solution, a blockchain-based software infrastructure: the Energy Web Chai, a publicly accessible network with permissioned validators hosted by EWF Affiliate organizations. It relies on a Proof-of-Authority consensus mechanism with capacity for a 30x performance improvement and 2–3 orders of magnitude lower energy consumption compared to Ethereum [37].
- **Grid Singularity** [31]: A German Start-up, co-founder of EWF, focused on a decentralized energy exchange platform for local communities. In 2018 presents the decentralized Autonomous Area Agent (D3 A) Market Model [38], an open energy exchange engine to model, simulate and operate energy trading markets in local communities.
- **Power Ledger** [32]: Australian company founded in 2016, focused on peer-to-peer energy trading. Power Ledger deploys a dual-token ecosystem with a POA consensus mechanism.
- **LO3 Energy** [33]: founded in 2012, they developed an energy exchange platform called Exergy as a permissioned data platform for peer-to-peer trades, and the Pando platform that can be used by the SO to pool local resources and establish an energy marketplace, based on bidding auctions between business and prosumers
- **Prosume.io** [34]: founded in 2016, proposes a platform based on smart contracts, IoT devices and the prosumer token with multiple applications, including peer-to-peer energy trading, smart billing, grid balancing and trading processes optimization for electricity and gas, according to local laws in each country.
- **Hyperledger Foundation** [35]: In October 2016, IBM launched Hyperledger Fabric, an opensource, modular and permissioned blockchain focused on business. Hyperledger includes modular consensus protocols, whereas Chaincode is the equivalent of Ethereum smart contracts.
- **Octopus Energy** [36]: a UK-based trading company that focuses on providing data analytics to their customers.

Of the previous list, all are existing developments. In a future stage of development, it would necessary to analyze and test them thoroughly in a real scenario in order to validate which could bring a feasible solution for the system.

3.3.4. Supervision

Two levels can be considered for supervision, one at the DistCo/AggrCo/TradCo level, where these companies have control and manage several of their user. In this case, the SC can be used for monitoring purposes, to gather measurement data from smart meters, and to ensure that the data is generated by a certain player. These measurements can then be used in the settlement and billing processes.
On the second level, the SO/MO or the SA, can also use smart contracts to synchronize monitoring systems such as Phasor Measurement Units (PMU) in order to store and facilitate access to the state of the network when a fault arises. They can also use these tools to supervise the compliance with the regulation, both al physical level (compliance with grid code requirements), at regulation level, and at commercial and legal level.

3.4. Machine Learning and other techniques

Machine Learning is a multi-disciplinary sector that requires experts in various domains and makes it the best choice for the increasing amount of data to be dealt with in Distributed Energy Resources ("DER") applications.
All the techniques mentioned in this Section 3.4 already exist and are under research, this document concludes that they would be useful for the proposed solution.

3.4.1. Techniques

There are different techniques that are summarized below:

- **ML techniques**:
  - **Supervised learning**: the objective is to learn a mapping between the inputs and the outputs, being both inputs and outputs known values. The pair input-output is a set of data called training set. The inputs can be either simple or complex structures, while the output can be of any type, if it is a categorical value, then we have a **classification,** and if we have a real-valued scalar variable then we have a **regression problem.** There is a set test to prove if the found mapping works with any set of input data, and this set test should not contain any data of the training data.
    - **Kernel-based**: create representations of the input data to a new feature space, and subsequently find an appropriate hypothesis in this feature space. There are several techniques: Support Vector Machines ("SVM"), Gaussian Processes ("GPs"), Support Vector Regression ("SVR") used for forecasting. Since GP is a probabilistic approach, it can lead to better forecasts.

  - **Tree-based**: widely used in price and load forecasting.
  - **Linear regression**: very simple tool that has been used to forecast the flexibility of a Virtual Power Plant ("VPP") in [39], to determine the aggregated power of price-sensitive loads at each hour of the day [40], to forecast the aggregated power for heating, as a function of the temperature, the time of the day, the type of day and the price [41], in PV power forecasting [42][43], in short-term wind power forecasting [44], and in the forecasting of inflexible loads [43].
- **Unsupervised learning**: In this case of unsupervised learning methods only the inputs are, and the system attempts to detect patterns in the data that could be of interest. It is a less well-defined problem as the supervised learning. The usual examples of unsupervised learning are clustering the data into groups, dimensionality reduction by discovering latent factors, learning graph structure, and matrix completion. In **Clustering** groups of objects are created in a way that objects within the same cluster are similar to one another, and dissimilar to the objects in other clusters. The various clustering algorithms have been applied to segment the consumers and find typical shapes of load profiles.
- **Reinforced Learning** ("RL"): is an approach that considers the problem of a player focused on goal-oriented learning while interacting with an uncertain environment. Trial-and-error type of search as well as delayed reward are the two most characteristic aspects of this approach. For example, RL has been used for scheduling and control of the various units of domestic appliances or EVs, interacting with the consumers to consider their preferences. It has also been used to modelling the controllers of the Energy Management System ("EMS") at consumer and service provide level.

- **Nature-inspired algorithmics:** inspired by natural and biological systems, this AI technique mimics these systems for searching and planning purposes, they have been used to schedule loads or appliances at the consumer level (algorithm embedded in HEMS), to assist AggCos and TradCos to optimize the pricing of their customers who offer DR services. Since meta-heuristics are able to find solutions in a reasonable timeframe, they have been heavily utilized under the DR context, where the scheduling task can be computationally expensive. **Evolutionary algorithms and Swarm AI:** is a heuristic-based approach that uses three steps: 1) initialization, 2) fitness evaluation and selection and 3) population reproduction and variation. Used for multi-objective scheduling of loads [45], for the multi-objective management of lithium-ion battery storage in a datacenter [46] and a bi-level evolutionary algorithm (EA) to determine a TradCo's optimal power pricing in the face of DR strategies of consumers trying to minimize their electricity expenses [47].

3.4.2. Results

The research found in [15] related to AI and ML show that various groups of AI techniques have been used for numerous DER applications. **Figure 12** is a heatmap chart displaying the number of documents that have utilized a specific category of AI methods for a particular DER application area.

Figure 12. Heatmap displaying the intensity of AI research methods in different DR application areas, source [15]

That brings to the conclusion that several techniques can and will be used in Smart Grid 2.0. And considering that the research is still ongoing, more techniques will be used for different applications that the ones presented in this document, and also new techniques will be discovered to complement or substitute the existing ones. In the following **Table 8** it can be found a summary of recommended techniques depending on the application:

Application	Recommended	Not recommended
Forecasting	**ANNs:** both for load and price prediction. Using a single hidden layer, and multi-layer architecture. **Supervised ML:** less flexible, higher bias, and rely heavily on feature selection and feature engineering; regression trees and gradient boosting can handle missing data better than ANNs. Use of probabilistic models for load forecasting	Time-series models such as autoregressive (“AR”), auto-regressive integrated moving average (“ARIMA”), and exponential smoothing
Segmenting Electricity Customers	Clustering (unsupervised) models is the only viable approach	The rest
AI Dynamic Control	Reinforcement learning methods	

Table 8. Relation of ML technology and its application

4. Conclusions and future development

This document has provided a general review of a potential scenario for Smart Grid 2.0, which will inevitably happen in one way or another. Currently, the Power Market for electricity is already in transition from the old scenario to a new one, where the main difference will be: a) energy flows in both ways instead of one, b) electrification of everything, c) digitalization of all devices and systems and d) higher integration of renewables and energy efficiency. With all these new ingredients, it seems crucial to produce a solid structure that can handle all the new scenarios, some known and many others unknown. Exactly because there are still many uncertainties, it is important to continue the development of this structure and to invest in time and resources, to create a real-life and workable environment.

This document has explored several tools and applications that already exist and that are being tested in real systems. The **Blockchain** technology can bring **Smart Contracts** into the Power Market allowing to increase the flexibility of the energy trading as it is done in the current market. Thanks to the **PoA** consensus, the system would maintain security in the transactions, and it would have the means to supervise all the transactions to ensure the compliance of all players, something essential in a critical sector such as the electrical one. Within the Power Market, it will be necessary to make profound changes and this document has proposed a scenario where the Market would become a Dual Market, and in the new side (the **SPM**) the players such as **Prosumers** and **Aggregators**, would be able to extend their trading and activities. This will help to democratize the Power Market, which has been accused of monopolistic on several occasions.

Since a huge amount of data will be created, **data analytics** will become a critical part of the system and, thanks to **Machine Learning** and other AI solutions, it will be more a solution than a problem. In the current Power Market, there are most the decisions still made based on human analysis, lately with more assistance from data analytics but with a high human analysis component. It is expected that ML will take the leadership, specially since the amount of data will not be possible analyzed by a human mind.

Another good consequence that will introduce this Smart Grid 2.0 is to allow the management of the growing **renewables energy resources**. The more renewable resource portion, the more difficult to manage the system, specially in smaller grids or not interconnected grids. It will also help into the introduction of other technologies such as Electrical Vehicles related devices and other solutions that might not exist today. In an analogy with the development of the **Internet of Things**, where the market has witnessed and increasing creation of new solutions to any home appliance, unthinkable a few years ago, it is the belief of the author of this document, that the **Internet of Energy** will have a similar evolution.

Future development and challenges

There are several factors that affect the development of the Smart Grid 2.0 and the **regulatory** might be one of the most significant. In the investment rationale, there needs to be a return, which it can be short or long-term. Current regulation allows for a few of the features of the SG 2.0 to be developed, and in fact, some companies are already making profit out of it, see [48]. There are also examples of companies investing in the market of

EV with, most probably, looking to position themselves in the market more than in short-term return, see [49]. Another factor is the **establishment resistance**. It is well-known and very common in any market, that the established companies are resistant to changes that could compromise their position, see [50]. In a conditional scenario, if these companies saw changes coming, they might resist to them and that would slow down the process, for example, by pushing back the regulatory changes thanks to their natural good relationship with the government.

5. Glossary

Blockhain: It is a label that through a data structure whose information is grouped into sets (blocks) to which meta-information related to another block of the previous chain in a timeline is added to make a secure follow-up through large cryptographic calculations.
DER: Distributed Energy Resources, refers to often smaller generation units that are located on the consumer's side of the energy meter.
DLT: Distributed Ledger Technology, is a shared and unchangeable ledger that facilitates the process of recording transactions and tracking assets in a business network.
DistCo: Distribution Company, company that is responsible of transporting the electric energy, generally from the Transmission Grid to the end-customers and is a natural and regulated geographic monopoly.
GenCo: Generation Company, company that is responsible of generating electric energy and inject to the grid.
IoT: Internet of Things, involves all devices with sensors and capability to send information to the Internet.
LNG: Liquefied Natural Gas, natural gas that has been cooled down to liquid form for ease and safety of non-pressurized storage or transport
MO: Market Operator, entity that is responsible of certain roles in the electricity market, like balance scheme management, recording of closed contracts and operational forecast, balancing the market, among others.
MPM: Main Power Market, it is the name of the market given in this document to the existing electricity market in the new dualized scheme.
PM: Power Market, basically is a system that facilitates the exchange of electricity-related goods and services.
PoA: Proof of Authority, is an algorithm used with blockchains that delivers comparatively fast transactions through a consensus mechanism based on identity as a stake, where there is an entity acting as a validator,
PoS: Proof of Stake, is a consensus mechanism used in blockchains where the validator is the quantity of holding of each participant, Ethereum is based on PoS.
PoW: Proof of Work, is a consensus mechanism where one participant proves to the others that a certain amount of a specific computational effort has been expended, Bitcoin is based on PoW.
PFR: Primary Frequency Regulation, is an automatic function for frequency regulation and it is the fastest among the three levels, as its response period is a few seconds.
SFR: Secondary Frequency Regulation, its purpose is to restore the nominal value of the frequency, the reserve of each generator previously used, and the power exchange among the power systems.
SPM: Segmented Power Market, it is the name of the market given in this document to the new segment in the electricity market in the new dualized scheme, on the side of prosumers.
SC: Smart City, is a technologically modern urban area that uses different types of electronic methods and sensors to collect specific data.

SG: Smart Grid, is a technologically modern electric grid that includes advanced metering infrastructure, renewable and energy efficiency resources, distribution and transmission automation and control, and sufficient communication capabilities to connect all the devices and sensors necessary.
SA: Supervising Authority, it is the name of the validator in the Proof of Authority mechanism given in this document in the new dualized scheme
SO: System Operator,
TFR: Tertiary Frequency Regulation, its purpose is to replace the reserve used in the primary and secondary frequency regulation.
TransCo: Transmission Company, company that is responsible of transporting the electric energy, generally from the Generators to the Distribution Company and is a natural and regulated geographic monopoly.

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7. Appendixes

This document does not contain any Appendix.