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VIRTUAL POWER PLANTS' ROLES FOR DECENTRALIZED MANAGEMENT OF SMART GRIDS

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Smart Grids led by Virtual Power Plants (VPPs) improve their performance when are applied the Roles of Strategic Manager VPP and Data Analyst VPP based on demand response. The bidirectional flows that travel through the distribution networks and the battery units' storage capacity of Smart Grids, allow the VPPs according to their Roles, to decentrally manage consumers, smart consumers, producers and prosumers for power trading operations in power markets. For this reason, the Roles of Strategic Manager VPP and Data Analyst VPP guarantee the Stakeholders' requirements prioritization, as well as the process quality of data collection, processing and analysis, keys in the correct decision-making to power trading operations. This work analyzes how, through strategic management and data analysis Roles; VPPs can optimize the power distribution within Smart Grids, minimizing uncertainty in power production and consumption forecasts, achieving to compete with other traders when carrying out operations in the power market.

Keywords: Management`s roles; sustainability; smartgrids; renewable energy; virtual power plants

ROLES DE LAS PLANTAS VIRTUALES DE PRODUCCÍÓN ELÉCTRICA PARA LA GESTIÓN DESCENTRALIZADA DE LAS SMART GRIDS

Las Smart Grids lideradas por las Virtual Power Plants (VPPs) mejoran su desempeño al aplicarse los Roles de VPP Gestora Estratégica y VPP Analista de Datos en función de la respuesta a la demanda. Los flujos bidireccionales que viajan a través de las redes de distribución de energía eléctrica y la capacidad de almacenamiento de las unidades por baterías de las Smart Grids, le permiten a las VPPs de acuerdo a sus Roles, gestionar descentralizadamente a consumidores, consumidores inteligentes, productores y prosumidores para las operaciones de comercialización de electricidad en los mercados eléctricos. Por ello, los Roles de VPP Gestora Estratégica y VPP Analista de Datos garantizan la priorización de los requerimientos de los Stakeholders, así como la calidad de los procesos de recolección, procesamiento y análisis de datos, claves en la correcta toma de decisiones para las operaciones de comercialización de electricidad. Este trabajo analiza cómo, a través de Roles de gestión estratégica y análisis de datos, las VPPs pueden optimizar la distribución de la electricidad dentro de las Smart Grids, minimizando la incertidumbre en los pronósticos de producción y consumo de electricidad, pudiendo competir con otros traders al realizar operaciones en el mercado eléctrico.

Palabras clave: roles de gestión; sostenibilidad; smartgrids; energías renovables; plantas virtuales de producción eléctrica

1. Introduction

Virtual Power Plants (VPPs) play several important roles and functions within Smart Grids, having the ability to operate in systems connected to or disconnected from the utility grid (Wang et al. 2019). The leadership managed by VPPs towards Smart Grids, allows each of its systems to possess autonomy, independence and resilience for planning, metering, monitoring, control and effective communication with each of its elements (Li et al. 2014). Therefore, by playing their roles, VPPs act as an integrated management system that helps Smart Grids improve their performance by coordinating and optimizing energy generation, consumption, storage and trading in real time (Chakraborty et al. 2021).

Through the integration of renewable energy sources and energy storage systems, VPPs manage to reduce dependence on fossil energy sources, thus reducing operating costs and the generation of CO_2 or greenhouse gas emissions (Liu et al. 2018). In addition, VPPs acting as intermediaries and/or as representatives between the different participants of Smart Grids, manage to generate economic benefits to their Stakeholders by selling the surplus electricity produced within the system in the electricity market (Baringo et al. 2021). By coordinately applying the roles VPP Commercial, VPP Technical (Plancke et al. 2015), VPP Strategic Manager and VPP Data Analyst, according to the requirements of the Stakeholders and the characteristics of the Smart Grids systems, the VPPs facilitate the integration of the different energy elements and systems, allowing greater flexibility in decision making (Pereira et al. 2018).

The mission of VPPs is to guarantee an uninterrupted service in the generation and consumption of electricity for each Smart Grid user, so a key point is to allow users to adjust their energy production and consumption according to market conditions, system capacities and/or the requirements of their Stakeholders (Campaner et al. 2015). Thus, VPPs by managing Smart Grids with decentralized systems, through the performance of technical and commercial functions, based on decision making and operations by data analysis, allow Smart Grids to increase their flexibility and dynamism, improving their energy stability and reliability (Han et al. 2018) and (Jianchao Zhang, Seet, and Lie 2016).

2. Objectives

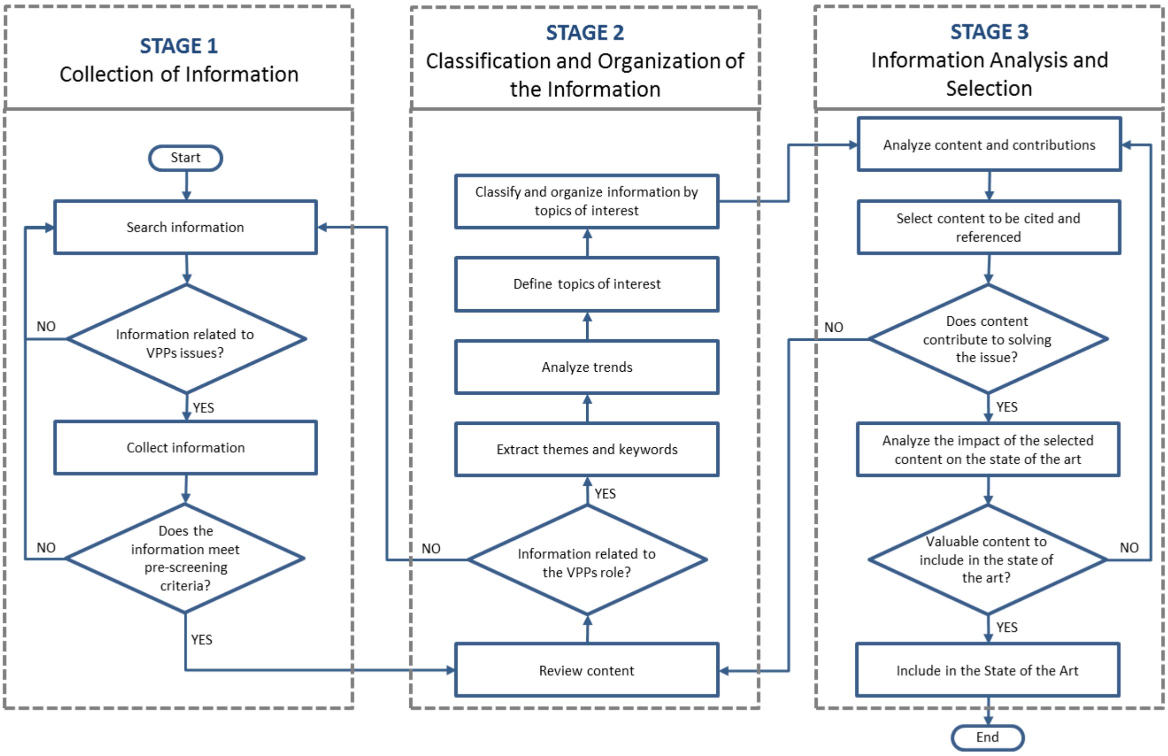
- To raise the new conceptual roles of the VPPs: VPP Strategic Manager and VPP Data Analyst, in order to contribute to the improvement of the energy performance of Smart Grids.
- Identify criteria associated with the roles of VPP Strategic Manager and VPP Data Analyst for the correct decision making in electricity production, consumption, storage, distribution and commercialization operations.
- Highlight the importance of VPPs when managing decentralized Smart Grids by mentioning aspects that involve the active participation of the elements, agents, operators and/or Stakeholders.

3. Methodology

The collection, analysis, organization and presentation of information are the key to expose useful concepts to the scientific community. Interpreting proposals of various models for the management of VPPs in Smart Grids requires research on the literature published by the authors of scientific articles, as well as a thorough and detailed study of each of the contributions provided by them.

Thus, considering what is indicated in (Saunders, Lewis, and Thornhill 2007), a sequence of stages was defined for the quantitative analysis of the literature, as shown in Figure 1 below, examining a large number of scientific articles (JCR journals) published in the last 15 years.

Figure 1: Stages for conducting the quantitative literature analysis



Stage 1: Collection of Information

As a pre-selection criterion or parameter, it was defined to choose the information from all those scientific articles that were related to PPV topics, and that were also within the impact levels or belonged to the quartiles: Q1, Q2 and Q3, and that their editions had been published no more than 15 years ago.

Stage 2: Classification and Organization of the Information

Once the scientific articles were pre-selected, the information contained in them was reviewed to highlight the information related to the role played by the VPPs in the Smart Grids, and thus, extract the key information, according to the number of visits of the scientific articles and their impact levels according to the journals to which they belonged.

Stage 3: Information Analysis and Selection

Finally, the information and contributions of each scientific article were analyzed in detail, selecting the content that provides support to the interpretation and description of the roles of VPPs, as well as their management to improve the performance of Smart Grids, optimizing the use of electricity in a sustainable manner.

4. Context and Main Roles of the VPPs

VPPs perform the functions of their roles in Smart Grids that operate with centralized systems (generally connected to the public power grid) and with decentralized systems (generally disconnected from the public power grid) (Dong et al. 2021). In centralized systems, information and operating power are concentrated in a single node, which means that decisions are made by an operator or by a small group of Stakeholders. Therefore, centralized systems work through a hierarchical structure in which there is a central node that directs operations, collects, stores, analyzes and distributes information, establishes communication protocols, and even controls the decision making of the entire system. Whereas in decentralized systems, information and decision making are distributed among several nodes. Under this concept, there is no single operator or small group of stakeholders that control and direct all system operations, i.e., the operating power works through a distributed structure, analyzing information for decision making according to defined communication protocols that seek the inclusion and participation of each of the elements of the system (Pasetti, Rinaldi, and Manerba 2018).

Therefore, by managing Smart Grids with decentralized systems, VPPs can take advantage of the potential of distributed generation to reduce load concentration and improve the resilience of the Smart Grid system to outages or failures; stimulating, in addition, the participation of Stakeholders, through the implementation of energy efficiency measures and the adoption of smart technologies for energy management (Maanavi et al. 2019).

Considering the above, and taking into account that the bidirectional flows that travel through the electric power distribution networks and the storage capacity of the Smart Grids' battery units, allow the VPPs, according to their Roles, to decentrally manage consumers, smart consumers, producers and prosumers for electricity trading operations in the electricity markets (Thomsen et al. 2017). The roles managed by VPPs in Smart Grids are described below, with which they develop greater autonomy, independence and resilience for decision making.

4.1. Role as Commercial VPP

VPPs focus on participating competitively in the wholesale and/or retail electricity market, establishing their operations based on electricity trading to optimize the cost-benefit ratio without considering the operational limitations of Smart Grids, either internally within their own systems or as an independent participant in the electricity market. In this way, VPPs integrate the capabilities of large producers and various Distributed Energy Resources (DERs) to form a flexible portfolio capable of making contracts in the electricity market and offering representation or intermediation services in electricity trading operations to Smart Grid operating agents (Mashhour and Moghaddas-Tafreshi 2010).

Therefore, under this position, VPPs lead and coordinate the execution of electricity sales and purchase operations, executing strategies defined with the combination of their other three roles to maximize profits by buying and selling electricity at the right times at the best prices, minimizing the costs of penalties for contractual breaches, and obtaining additional profits from the commercialization of green certificates (Liu et al. 2018).

4.2. Role as Technical VPP

VPPs consider each and every characteristic and operation of producers, consumers, smart consumers, prosumers, storage units, Distribution System Operators (DSOs) to maintain control within Smart Grids. VPPs focus on optimizing the generation and distribution of electricity flows, establishing a dynamic relationship for electricity distribution management with DSOs. In this way, VPPs monitor their systems continuously using sensors and connected devices to collect real-time data on generation, consumption and availability of energy in their networks, seeking information to determine at all times the status of Smart Grids and detect potential problems (Mashhour and Moghaddas-Tafreshi 2010).

Therefore, defining and executing quality control protocols over the entire Smart Grids infrastructure is one of the main objective functions within this role, as well as applying in a timely manner the technological tools for measuring the status and operation of the generation, consumption and storage assets connected to the Smart Grids, generating a greater amount of reliable information for decision making and system maintenance.

4.3. Role as VPP Strategic Manager

VPPs perform a set of responsibilities, functions and tasks to adequately and timely satisfy the requirements of their Stakeholders (El Bakari and Kling 2012). Under this scheme, VPPs organize the systems considering the capabilities and limitations of each of the interacting elements in the Smart Grids, acquiring the necessary information from the systems to plan the short, medium and long term business operations, monitor the infrastructural and technological performance of the systems, supporting the functions of each of the elements, agents and/or DERs, as well as controlling and ensuring good communication between the Stakeholders. In addition, in order to make the best use of intra-system and inter-system connections, in this role the VPPs perform their functions by designing, defining and using communication protocols to interact with the distribution systems of the grid, as well as with other systems, and even with other participants in the electricity market, maintaining timely actions based on demand response, and efficiently managing the balancing between production, consumption, storage and marketing of electricity. In this way, VPPs have the global vision of Smart Grids, allowing them to have enough information to choose when to activate, deactivate, eliminate or include elements, agents and/or various DERs to improve the performance of their systems.

4.4. Role as VPP Data Analyst

VPPs collect, process, analyze and interpret the large amounts of data generated in the short, medium and long term, continuously obtaining information related to Day-Ahead, Intraday, Ancillary/Reserve and Trade Carbon Emission (tCO_2e) electricity market prices, current or future contract penalties for electricity production and consumption, amounts of electricity produced, consumed, stored, transferred and wasted, historical and forecasted weather conditions, among others (Mahmud et al. 2020). But to achieve efficient data processing, VPPs use algorithms for data capture, monitoring and control of historical information, mathematical optimization, real-time communication, as well as algorithms to protocoled the priorities of stakeholder requirements (Ju et al. 2019).

In this way, with the support of Artificial Intelligence algorithms, the VPPs create mathematical models to generate patterns and predict trends within all the infrastructural, technological, commercial and economic characteristics in which the system performs, guaranteeing its Stakeholders the correct decision making based on reliable and verifiable information.

5. Management of VPPs Roles and Decentralized Smart Grid

As mentioned above, decentralized systems operate through a distributed structure, in which information and decision making are distributed among several nodes. Therefore, there is no small group of operators or Stakeholders that control and direct all the operations of the system.

Considering the decentralized management approach, the VPPs organize, monitor and control the Smart Grid systems, taking into account: i.) the infrastructural and technological types of these systems; ii.) the requirements of their stakeholders; iii.) the connections with the distribution networks; and iv.) the interaction with other electricity generation and distribution systems. Thus, in the management of VPPs over these systems, the information is stored in several nodes, which allows greater redundancy and security of the information since, if any of the nodes fails, the information will still be available in the others (Querini, Chiotti, and Fernádez 2020). Therefore, in a decentralized Smart Grid, the VPPs manage decision making through consensus among the nodes, making the system more resilient to failures and attacks, since by not depending on a single central node, problems in one node do not affect all the others.

Furthermore, in decentralized Smart Grids, demand response is handled by VPPs through distributed electricity generation and the active participation of elements, agents, operators and/or stakeholders in the management of operations. Distributed generation refers to the production of electricity on small scales, close to where it is used, rather than being generated in large centralized conventional power plants (Stepanescu et al. 2011) and (Yang et al. 2021). This may include the generation of renewable energy through solar panels, wind turbines or other means such as biomass, as well as the generation of energy from non-renewable sources, such as small thermal power plants.

In a decentralized system managed by a VPP, Stakeholders play an active role in demand management by implementing energy efficiency measures and adopting smart energy management technologies.

Thus, by including in the system by the VPP the use of smart metering devices to monitor energy consumption, the use of smart control devices to adjust energy demand, and the adoption of energy storage systems to store the generated energy in a decentralized manner, greater flexibility and adaptability in energy generation and distribution is generated (Shaukat et al. 2018).

The management of electricity purchase and sale operations by the VPP in this system is carried out through an Energy Management System (EMS) in which energy generation and consumption is controlled and optimized in real time (Nosratabadi, Hooshmand, and Gholipour 2017).

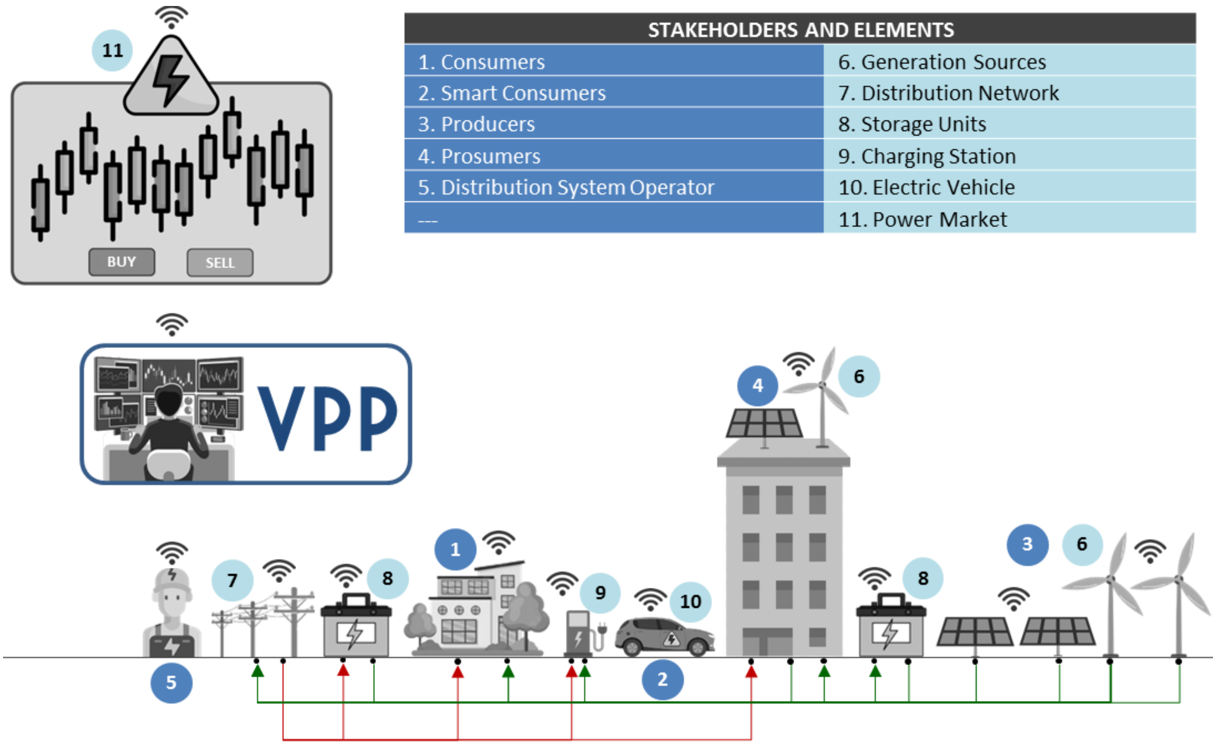
In addition, VPP uses information collected by sensors and energy measurement devices, as well as information from the electricity market to determine the best production and consumption strategies for its Stakeholders (Raab et al. 2011).

Within EMS-supported Smart Grids, Artificial Intelligence algorithms are used to analyze electricity consumption, production and storage patterns, thus making automated decisions as to when and how much electricity to generate to consume and sell, or how much electricity to buy in the electricity market, and even when and until when to store it in battery units (Gougheri et al. 2021).

In this way, in decentralized Smart Grids managed by VPPs, various electronic devices with sensors can be used to collect information in real time, allowing reliable energy measurements through Artificial Intelligence algorithms, and improving the efficiency, safety and resilience of Smart Grids (Jiahui Zhang et al. 2019).

Figure 2 presents the scheme of a decentralized Smart Grid, describing below the interaction of the roles and functions of the VPPs in higher and lower average according to the priority of the Stakeholders' requirements.

Figure 2: Scheme of a decentralized Smart Grid



STAKEHOLDERS AND ELEMENTS	
1. Consumers	6. Generation Sources
2. Smart Consumers	7. Distribution Network
3. Producers	8. Storage Units
4. Prosumers	9. Charging Station
5. Distribution System Operator	10. Electric Vehicle
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The main role of the VPP for this situation is performed according to the functions of "**Strategic Manager**", organizing and prioritizing the requirements of the Stakeholders, allowing the timely analysis and assessment of the capabilities and limitations of each of the interacting elements in the Smart Grid.

Since the management of electricity flows is bidirectional, it is also distributed, being a priority to maintain the balance between electricity produced, consumed and stored; since here, the VPP must: i.) guarantee the continuous supply of electricity, ensuring that the demands of consumers are met and that energy is well stored in the system's batteries; ii.) stimulate the participation of producers and prosumers for the generation of electricity used mainly by the system's consumers, and secondly, to seek profits from the sale of surplus or unused electricity in the electricity market; iii.) seek profits from the sale of surplus or unused electricity in the electricity market; iv.) stimulate the participation of producers and prosumers for the generation of electricity used primarily by system consumers, and secondarily, to seek benefits from the sale of surplus or unused electricity in the electricity market; iii.) to generate communication protocols with the operators of the distribution systems and final consumers so that the consumption made is the most adequate, thus minimizing electricity waste and making the distributed generation of electricity as efficient as possible; and iv.) to plan commercial operations in the short, medium and long term, monitor the infrastructural and technological performance of the system, to make negotiations in the electricity market to ensure the economic viability and technical sustainability of the system during its life cycle; all this, through the support of the role as "Commercial".

In this way, and as the second main role of the VPP in this type of decentralized system, it performs according to the functions of the "**Data Analyst**" role, considering that being a distributed system with bidirectional electricity production and storage, the amount of data to be analyzed is very large, since data must be captured for analysis and processing derived from weather conditions, The data to be captured for analysis and processing must be derived from weather conditions, the status of Smart Grid elements, battery storage capacities, consumption peaks and valleys, the behavior of purchase and sale prices in the electricity market, as well as risks related to penalties for non-compliance with production, and even data from the behavior of wireless signals and the geolocation of electric vehicles, among other variables; supported in the role of "Technical".

In other words, in a decentralized system, in order to properly manage an electricity generation and distribution network, the VPP must mainly apply two of its roles, the "Strategic Manager" and the "Data Analyst" role, with secondary support from the "Commercial" and "Technical" roles.

Thus, considering what is mentioned in the scientific literature, the proper management of each of the elements, agents, operators and/or Stakeholders of the system, allows the efficient generation and consumption of distributed electricity, giving the VPP priority to the good consumption and storage of electricity, before its commercialization, and promoting the analysis of data for reliable decision making for the Stakeholders.

6. Findings for the Application of VPP Roles in Decentralized Smart Grids

The correct performance of the systems managed by the VPPs depends on the correct decision making by them, so data analysis is essential to make decisions based on the quality and reliability of the information obtained from the elements and Stakeholders that interact in the Smart Grids.

Strategic management and data analysis require a minimum level of knowledge from producers, consumers and prosumers for the good management of Smart Grids led by VPPs. In decentralized systems where distributed participation to maintain sustainable production and consumption are fundamental, the application of prioritization, risk and impact strategies are the key for VPPs to guarantee through the role of "Strategic Manager" the prioritization of the requirements of their Stakeholders.

There has not yet been sufficient infrastructural and technological evolution to ensure that the electricity produced by small producers and prosumers can supply large systems, and even others of the same size, but located in very remote areas, since for the moment, the production and consumption of energy in distributed systems only takes place in places close to the source of production.

In addition, due to the quality of the training of some people in the respective subjects, technical training processes must be carried out for each producer, consumer or prosumer, which prevents for the moment to cover many geographical areas suitable for the generation of electricity through renewable energies, and the application of technological benefits that would make the implemented systems efficient.

Thus, the commercialization of electricity generated by Smart Grids represented by VPPs is still small compared to that generated by large conventional power plants, preventing Smart Grid Stakeholders from obtaining good profits or returns.

Although the costs for data processing by Cloud Computing are becoming cheaper and more accessible to the general population, the costs for the acquisition and maintenance of the electronic devices necessary for VPPs to manage Smart Grids technologically, still remain high. Along with this, the programming and maintenance of Artificial Intelligence algorithms requires specialized personnel and a large amount of data for the results presented to be reliable, which implies a considerable investment by the Stakeholders for the implementation of this.

7. Conclusions

- Associating the functions performed by VPPs into more roles allows Smart Grid researchers and operators to solve problems more efficiently by attacking situations with a more specialized approach. Although the "Commercial" and "Technical" roles are already considered for the generation of models by researchers, it is important to consider the new organizational and data analysis trends for decision making, so associating the respective functions to the "Strategic Manager" and "Data Analyst" roles gives the VPPs more and better possibilities to manage the Stakeholders' requirements.
- Establishing information generation protocols, as well as data processing and trend forecasting protocols for the execution of commercial operations in the electricity market or technical operations within the systems, allows the VPPs through the role of "Data Analyst" to execute actions in real time or program the execution of others in the short, medium and long term, minimizing uncertainties and guaranteeing a sustainable development of the systems throughout their life cycle.
- Artificial Intelligence algorithms are being programmed to achieve more accurate forecasting of electricity production from renewable energies, basically considering data related to weather conditions, the performance of DERs, the storage capacity and lifetime of energy in batteries, and the seasonal behaviors of consumers and smart consumers, as well as that of electric vehicles.

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According to: https://sdgs.un.org/goals

Communication aligned with the Sustainable Development Objectives