Platform for Efficient Building Operation and Demand Response Flexibility Provision

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Abstract. This paper describes a SGAM (Smart Grid Architecture Model) compliant collaborative platform including its logical components in terms of functionalities and interfaces and their relationships. It aims at facilitating the service deployments, establishment and management of a Citizen Energy Community (CEC) by stakeholders along the energy value chain (consumers, energy managers, grid operators, service providers). Its foundation is based on standard-enabling technologies and practices and recommendations from EU projects (NEON and SINERGY). Unified Modeling Language (UML) is used for illustrating potential scenarios of using the services by NEON piloting partners. The energy dispatch optimization service developed by Institute Mihajlo Pupin (IMP) has been tested for a CEC from Spain.

Keywords: SGAM Architecture, Interoperability, Services, API, KPIs, Standards.

1 Motivation

In the last few years, particularly in Europe, there has been a notable increase in the number of citizen-led energy initiatives focused on producing, distributing, and consuming energy from renewable energy sources (RES) at a local level. This growth is evident when considering the *Inventory of citizen-led energy action*, which includes data from 29 countries and highlights over 10,000 such initiatives [1].

These initiatives, commonly referred to as Citizen Energy Communities (CEC), vary in size, configuration, and capacities in terms of the renewable energy sources involved, such as photovoltaic or wind plants, as well as other devices deployed, including energy storage batteries, energy consumption devices, and green hydrogen production devices, among others. The primary objective shared by these initiatives is to enhance self-consumption of locally produced renewable energy.

Service providers, which may include ICT companies specializing in integrating various energy services, can derive benefits from these initiatives. They may earn service fees based on the contracted share of energy savings and receive payments for providing unlocked flexibility and automated demand response (DR) mechanisms [2] under

Energy Performance Contracting (EPC) [3] and Pay-for-Performance (P4P) arrangements [4] established with utilities.

Simultaneously, stakeholders involved in the power grid stand to gain advantages from the rise of citizen-led energy initiatives. These advantages encompass reduced maintenance and operation costs resulting from improved grid stability and lower transmission losses, courtesy of the increased hosting capacity for local renewable energy sources.

Furthermore, the proliferation of citizen-led energy initiatives is not only beneficial in terms of renewable energy production but also contributes to the overall sustainability goals of communities. By promoting the use of clean energy sources and reducing reliance on traditional fossil fuel-based power generation, these initiatives help combat climate change and reduce greenhouse gas emissions. They also foster a sense of local empowerment and engagement, as citizens actively participate in the transition towards a more sustainable energy future. In addition to the environmental and community benefits, citizen-led energy initiatives also have the potential to create new economic opportunities. These initiatives often generate local jobs, ranging from installation and maintenance of renewable energy systems to the development of innovative technologies and services. Moreover, they encourage entrepreneurship and foster a supportive ecosystem for local businesses, such as renewable energy equipment suppliers, energy consultants, and energy efficiency specialists.

To ensure the long-term success and scalability of citizen-led energy initiatives, collaboration and coordination among various stakeholders are crucial. This includes close cooperation between the community members, local authorities, energy service providers, and utility companies. By working together, these stakeholders can develop effective regulatory frameworks, streamline administrative processes, and establish clear guidelines for the integration of citizen-led energy initiatives into the existing energy infrastructure. The increasing number of citizen-led energy initiatives in Europe reflects a growing momentum towards decentralized, renewable energy systems. These initiatives not only contribute to the transition to a cleaner and more sustainable energy sector but also bring about economic opportunities, community engagement, and local empowerment. With continued support and collaboration, citizen-led energy initiatives have the potential to revolutionize the energy landscape, leading to a more resilient, environmentally friendly, and inclusive energy future.

2 Research questions

In this paper, we present a novel software platform that serves as a solution for integrating diverse data-driven services within Citizen Energy Communities (CEC). The platform not only facilitates seamless connectivity between the physical energy assets but also enables efficient data exchange and processing among different actors and software systems involved in the CEC ecosystem.

By leveraging advanced technologies and data analytics capabilities, the proposed software platform empowers CECs to optimize their energy management strategies and enhance the overall performance of renewable energy assets. It enables real-time monitoring and control of energy generation, consumption, and storage systems, allowing for efficient allocation and utilization of resources. The platform also supports the integration of emerging technologies such as demand response mechanisms, energy forecasting algorithms, and grid optimization tools, enabling CECs to actively participate in grid balancing and provide valuable flexibility services.

The research conducted in this paper is closely aligned with the objectives of the NEON (Next-Generation Integrated Energy Services for Citizen Energy Communities) and SINERGY (Capacity building in Smart and Innovative eNERGY management) projects. The NEON project aims to develop innovative solutions for integrating renewable energy resources, enhancing energy efficiency, and fostering sustainable practices within CECs. In NEON, the platform provides a robust and scalable solution for data-driven energy management in CECs from Italy, France and Spain, while in SINERGY, the platform is adopted for testing services relevant for the IMP campus in Serbia

Furthermore, we acknowledge the significance of adoption of interoperability standards for future data spaces, tested in the EU project OMEGA-X (Orchestrating an interoperable sovereign federated Multi-vector Energy data space built on open standards and ready for GAia-X) as a relevant initiative in this context. The aim of OMEGA-X is to implement a data space (based on European common standards), including federated infrastructure, data marketplace and service marketplace, involving data sharing between different stakeholders and demonstrating its value for real and concrete Energy use cases and needs, while guaranteeing scalability and interoperability with other data space initiatives, not just for energy but also cross-sector. By aligning with the principles and objectives of the OMEGA-X project, the proposed software platform for CECs aims to promote interoperability and integration between different energy systems, devices, and software applications, fostering a more interconnected and efficient energy ecosystem.

Furthermore, this paper introduces a software platform that addresses the integration challenges within CECs, enabling seamless connectivity, data exchange, and processing among diverse actors and software systems. The platform aligns with the goals of the NEON project and emphasizes the importance of interoperability solutions exemplified by initiatives like OMEGA-X. Through the adoption of this software platform, CECs can unlock the full potential of data-driven energy management, leading to improved energy efficiency, increased renewable energy utilization, and enhanced grid integration capabilities.

3 Methodology

The design of the platform architecture is a result of analysis and consideration of various standard-enabling technologies [5] and practices. These include cloud-based infrastructures, service-oriented architectures, blockchain technology, flexibility and loosely coupled design principles, interoperability, security and privacy by design, and configuration management. By incorporating these elements, the platform architecture aims to create a robust and scalable foundation for the integration of diverse CEC energy services.

One key aspect considered during the design process is the COSMAG (COntextualisation of the Smart Grid Architecture) and SGAM (Smart Grid Architecture Model) specifications. These specifications provide a comprehensive framework for structuring and organizing the various components and functions within smart grid systems. By aligning with COSMAG and SGAM, the platform architecture ensures compatibility and harmonization with existing smart grid infrastructures, enabling seamless integration and interoperability between CECs and the broader energy grid ecosystem.
Moreover, an "ethics by design" approach is followed to guarantee compliance with the European ethical and legal framework. This approach encompasses adherence to regulations such as the NIS (Network and Information Security) Directive, eIDAS (electronic Identification, Authentication, and Trust Services), and GDPR (General Data Protection Regulation). By integrating ethical considerations from the early stages of design, the platform architecture prioritizes data protection, security, and privacy. This approach ensures that the platform safeguards the personal and sensitive information of individuals while promoting transparency and accountability in data handling processes.

In addition to legal and ethical compliance, the platform architecture emphasizes the importance of configuration management. This aspect involves effectively managing and controlling the various configurations and settings of the platform to ensure optimal performance and adaptability. Through robust configuration management practices, the architecture enables efficient customization and adaptation of the platform to suit the specific needs and requirements of different CECs, while maintaining stability, reliability, and consistency.

By incorporating standard-enabling technologies, following ethical design principles, considering COSMAG and SGAM specifications, and implementing effective configuration management, the platform architecture is designed to empower CECs with a secure, interoperable, and customizable framework for integrated energy services. It sets the stage for the deployment of advanced energy management solutions within CECs, promoting sustainable practices, and enabling the seamless integration of renewable energy resources into the broader energy ecosystem.

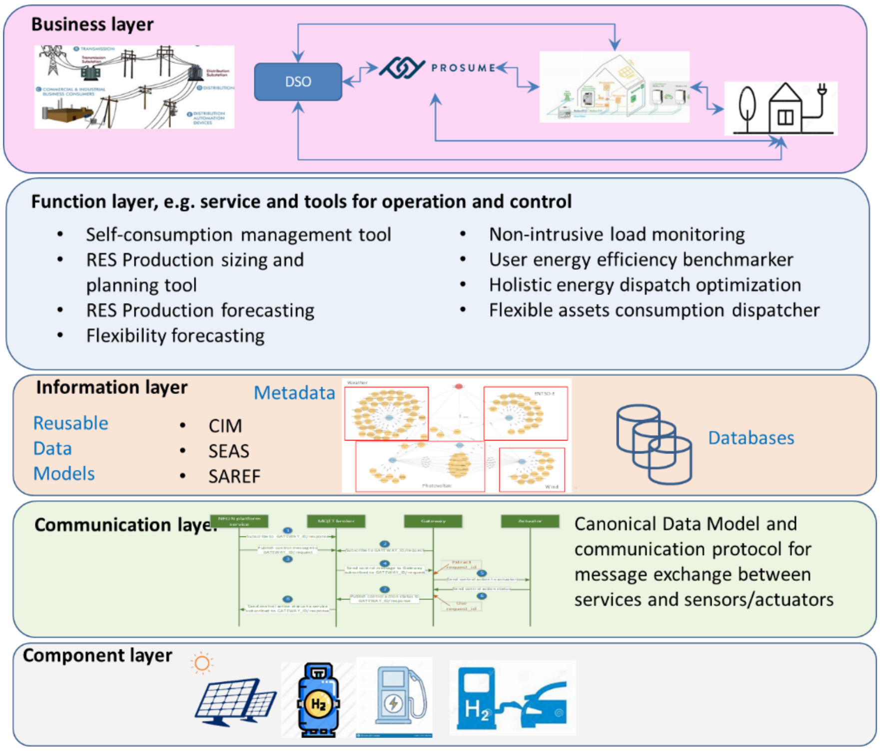

Fig. 1. NEON platform architecture

In **Fig. 1**, we present the platform architecture. During the initial year of the NEON project (in 2021 and 2022), the Institute Mihajlo Pupin team dedicated significant effort to conducting a comprehensive analysis of the available components and services that could be utilized within the project. These components and services were carefully examined and subsequently mapped to the interoperability layers specified in the SGAM:

- Business Layer encompasses the applications and dashboards that facilitate the management and visualization of data within the NEON project. This layer focuses on providing user-friendly interfaces and tools for CECs to monitor and control their energy systems effectively.
- Function Layer constitutes a crucial aspect of the NEON project architecture, as it consists of various components and services that perform specific functions. This layer plays a vital role in enabling the desired energy management capabilities and services within CECs.
- Information Layer is responsible for managing the information used and exchanged between different functions, services, and components within the NEON project. It serves as a crucial communication hub, ensuring the seamless flow of data across various aspects of the project.

- Communication Layer focuses on defining the protocols and mechanisms necessary for the interoperable exchange of information between the different components within the NEON project. This layer ensures that the various systems and devices involved can communicate and share data effectively, promoting interoperability and seamless integration.
- Component Layer pertains to the physical distribution of all the participating components within the smart grid context. This layer encompasses the deployment of hardware and software components across the CECs, enabling the realization of the NEON project's goals in a tangible and practical manner.

By organizing the NEON project's components and services into these interoperability layers, the consortium established a structured and comprehensive framework for the development and implementation of the project. This approach ensured that all necessary aspects, from business applications to physical components, were considered and integrated harmoniously, fostering the successful deployment and operation of the NEON platform within Citizen Energy Communities.

The UML (Unified Modeling Language) modelling language was utilized to elaborate on all aspects of the self-consumption process within the NEON project. This required analysis of the specific requirements and needs of four different Citizen Energy Communities (CECs) - BERCHIDDA in Spain, DOMAINE DE LA SOURCE in France, POLÍGONO INDUSTRIAL LAS CABEZAS in Spain, and STAINS CITY in France. The UML modelling language provides a standardized and comprehensive framework for describing the various elements and interactions within the self-consumption process, ensuring clear communication and understanding among project stakeholders.

To assess and measure the performance of the pilot sites during operation, it was crucial to evaluate how the goals and objectives of the pilot sites were achieved. This evaluation was carried out using scientific methodologies to provide accurate and reliable results. Key Performance Indicators (KPIs) provided means to quantify different metrics and gain insights into the specific and overall performance of the CECs. The use of KPIs allowed for a standardized and systematic approach to measuring and evaluating the effectiveness of the NEON solutions. The identified KPIs were categorized into several key areas:

- Energy Efficiency KPIs accounts for the optimization of users' energy usage through the exploitation of demand flexibility and energy efficiency of multi-carrier opportunities. It focuses on the benefits derived from the holistic cooperative Demand Response (DR) strategy implemented within the CECs.
- The Economic KPIs evaluates the economic savings resulting from changes in user behaviour as a result of their engagement and energy usage following the recommendations and services provided for the CECs and the NEON platform.
- The Comfort KPIs assesses the benefits experienced by end users in terms of their indoor environment. It aims to measure the improvements in comfort levels resulting from the implementation of NEON solutions.

- User Engagement KPIs are designed to describe the behaviour and interaction of users with the CEC services and the NEON platform. These KPIs provide insights into the level of engagement and participation of users within the CEC ecosystem.
- The Social KPIs explores how the required levels of flexibility intersect with social norms and everyday practices, such as routines and family life. It also considers the effects of CECs on health and well-being, emphasizing the social impact of NEON solutions.
- Environmental KPIs evaluate the impact of NEON solutions on the local environment, focusing on aspects such as carbon footprint reduction, greenhouse gas emissions, and other environmental indicators.
- Technical category encompasses KPIs that evaluate different technical characteristics of the CEC services and systems. These KPIs provide insights into the performance, reliability, and functionality of the technical infrastructure supporting the NEON platform.

By defining and measuring these diverse categories of KPIs, one can comprehensively evaluate the performance and impact of the proposed solutions. This allows for evidence-based decision-making, continuous improvement, and the refinement of the platform and services to ensure optimal outcomes within the CECs.

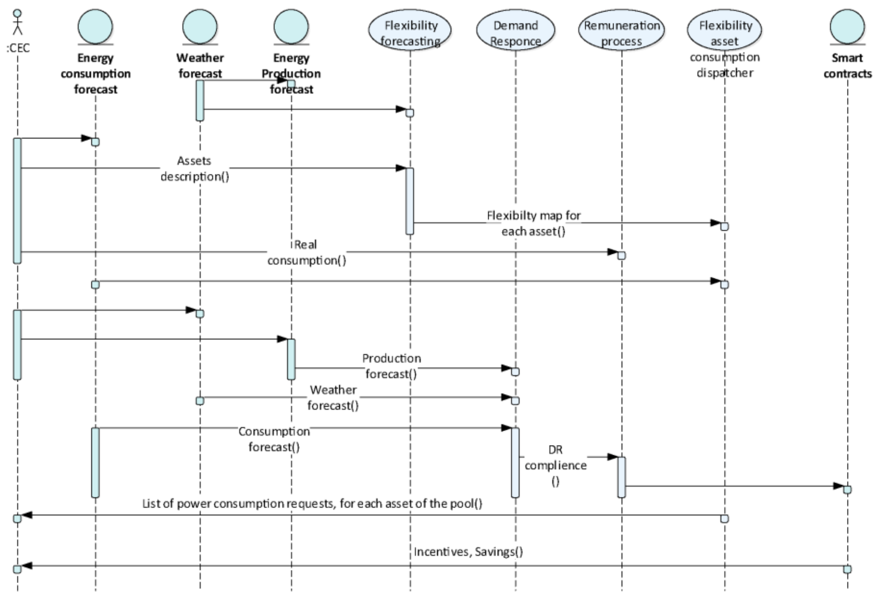

Fig. 2. CEC - Demand Response, Flexibility services and Remuneration Process

4 Solution/Discussion

The platform designed, installed and tested at the Institute Pupin premises in the NEON project framework, has been adopted for the forthcoming activities in SINERGY [6] and OMEGA-X projects [7]. This installation serves as a crucial step in the development and validation of the platform's capabilities. During the testing phase, services for energy dispatch optimization, demand and production forecasting have been put to the test. These services focus on optimizing the dispatch and distribution of energy resources within the platform. By analysing the available data and utilizing advanced algorithms for production and demand forecasting and optimization, the energy dispatch optimization service aims to maximize the efficiency and effectiveness of energy distribution.

The data utilized in the testing process is sourced from Spanish CEC, providing a real-world context for evaluating the performance and functionality of the platform. Overall, the installation of the platform at the Institute Pupin premises and the subsequent testing using data from Spain, along with the components provided by the Institute Pupin, represents a significant milestone in the development and evaluation of the NEON project. These activities contribute to the refinement and enhancement of the platform's capabilities, ensuring its suitability for deployment within Citizen Energy Communities (CECs) and promoting the efficient management and utilization of renewable energy resources.

In **Fig. 3**, we show Grafana web interface for visualization of results provided by services. The top graph represents the PV production forecasts. In essence, it provides predictions regarding the amount of electricity that will be generated by solar panels over a specific timeframe. The middle one shows the demand forecast. This graph presents projected energy consumption levels during the same period. It effectively communicates when energy usage is expected to peak or decline based on predictive analytics. The graph at the bottom presents the optimal demand which signifies the recommended approach for energy consumption. This recommendation is based on an alignment of energy consumption with the availability of renewable energy generated by the PV plant and other system parameters such as battery capacity, maximum allowed power from/into grid, etc. As it can be seen, the optimization recommends to shift the energy consumption towards the period where renewable energy from the PV plant is available, while also respecting the system constraints.

Fig. 3. Grafana visualization of forecasting and optimization services

5 Conclusion

In this paper we have highlighted the diverse scales and configurations of these initiatives, emphasizing the goal of increasing self-consumption and the potential benefits for service providers and grid stakeholders.

In this paper, we have discussed the proposed solution of the NEON platform, which serves as a software platform for integrating data-driven services and connecting physical energy assets within CECs. The design of the NEON platform architecture was elaborated, considering standard-enabling technologies, interoperability solutions, and ethical and legal compliance. The NEON project's progress and accomplishments were presented, including the detailed analysis of components and services mapped to SGAM interoperability layers, as well as the measurement of performance through key performance indicators (KPIs). Finally, we have provided more details on implementation of platform with the focus on forecasting and optimization service which were applied on the data obtained from Spain CEC. As part of the future work, additional short, mid- and long-term planning services will be integrated and tested using data from the IMP campus.

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