Technologies and Concepts for the Next-generation Integrated Energy Services

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Abstract. In recent years, as part of the European Union initiatives to help combat climate change and reduce greenhouse gas emissions, Citizen Energy Communities (CEC) concept was promoted with a primary objective to enhance self-consumption of locally produced renewable energy. The integration of distributed energy resources (DERs) requires orchestration of tools and services on edge and cloud level. This paper describes an approach to establish and validate a SGAM compliant software platform with deployed data-driven services for holistic control and energy dispatch optimization. The developed by and deployed at the Institute Mihajlo Pupin (IMP) platform has been tested for a CEC from Spain in the NEON project framework. 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.

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

1 Introduction

In the last few years, particularly in Europe, a significant number of measures has been taken to develop and validate future scenarios that target the “Net Zero CO_2 Emissions by 2050” goals. According to the International Energy Agency, the energy sector is responsible for around three-quarters of global greenhouse gas (GHG) emissions [1] and hence the uptake of all the available technologies and emissions reduction options is crucial for implementation of the foreseen decarbonization scenarios.

The focus of this paper is the electricity value chain. In the centralized system (as it used to be in 20th century), electricity is produced through the generation system (see Figure 1, part 1), transported through the transmission system (see Figure 1, part 2) and is distributed to the end users through the distribution system (see Figure 1, part 3). Nowadays, with solar and wind power on the rise and integrated with consumption devices, there is a need for new equipment and monitoring and control systems to make the whole power system operate flexibly. Smart Energy Management (SEM) refers to a variety of novel concepts and technologies, serving at both energy generation and consumption side, such as energy efficiency, demand management, Smart

Grid, micro-grids, renewable energy sources, and other emerging solutions. SEM tools are build upon advanced edge-cloud computing frameworks, Big Data Analytics techniques, AI-driven methodologies, novel integration approaches based on semantic technologies and others. SEM solutions are deployed on the consumers' side (buildings, districts) in order to achieve holistic optimization of the use of local distributed energy resources (wind, solar, EV charging stations, batteries), improve the self-consumption and lower the costs of the electricity used from the grid. European Union legislation refers to these initiatives as Energy Communities or Citizen Energy Communities (CEC). CECs vary in size, configuration, and capacities in terms of the renewable energy sources involved, 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.

This paper discusses the approach of building and deploying a software platform that will enable and enhance monitoring and control of smart communities. It is organized as follows. Section 2 explains the topic of smart communities; Section 3 presents the process of design and deployment of a SGAM compliant platform at the Institute Mihajlo Pupin and Section 4 discusses the approach for platform and services validation.

2 Motivation: Smart Community

In the last years, in Europe, there have 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. Grid operators (distribution and transmission) grid stand to gain advantages from the rise of citizen-led energy initiatives, for instance, e.g. 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. However, in order to establish a smart community, substantial involvement of end users and citizens is needed. Service providers, which may include ICT companies specializing in integrating various energy services, can also 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. These initiatives often generate local jobs, ranging from installation and maintenance of renewable energy systems to the development of innovative technologies and services [5]. Moreover, they encourage entrepreneurship and foster a supportive ecosystem for local businesses, such as renewable energy equipment suppliers, energy consultants, and energy efficiency specialists.

Figure 1 illustrates an example of a control center established to integrate the energy services, supervise the self-consumption, dispatch the electricity in the smart community and control the export to the main grid. Examples of services that have to be deployed in such center is given in Table 1.

Fig. 1. Integration of RES in electricity value chain.

Table 1. Examples of Smart Energy Management Services and Applications.

Actors	Services / Applications	Reference
Generation	RES Production forecast RES effects calculation	[6]
Transmission	Electricity balancing	[7]
	AI algorithms for optimized grid planning	[8]
Distribution	Reactive power distribution optimization	[9]
Prosumer	Non-Intrusive Load Monitoring	[10]
	Energy Efficient Buildings System	[11]
	Residential Demand Response	[12]
	Prosumer Energy System Planning	[13]

3 Designing a SGAM Compliant Platform

The Smart energy Grid Architecture Model (SGAM) is a three-dimensional architectural framework that can be used to model interactions (mostly exchange of information) between different entities located within the smart energy arena [14]. The model does not specify which components to be applied in order to build a software platform for CEC monitoring and control, however structure the knowledge related to implementation of services in energy sector.

Hence, the Institute Mihajlo Pupin team leveraged the SGAM model to implement approaches for seamless connectivity between the physical energy assets and integration with diverse data-driven services 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 design of the platform architecture is a result of analysis and consideration of various standard-enabling technologies 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.

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.

In Figure 2, we present the platform architecture. Business Layer encompasses the applications and dashboards that facilitate the management and visualization of data. This layer focuses on providing user-friendly interfaces and tools, on one side for RES Production sizing and planning, and on the other, for CEC monitoring and control of electricity and financial data. The financial data is related to the business arrangements and contracting mechanisms.

Function Layer constitutes a crucial aspect of the platform architecture, as it plays a vital role in enabling the desired energy management capabilities and services within CECs. Example services that are part of this layer are

- Self-consumption management tool
- RES Production forecasting
- Flexibility forecasting
- Non-intrusive load monitoring
- User energy efficiency benchmarker
- Holistic energy dispatch optimization
- Flexible assets consumption dispatcher

Information Layer is responsible for managing the information used and exchanged between different functions, services. It serves as a crucial communication hub, ensuring the seamless flow of data across various aspects of the project. For instance, based on the analysis of existing semantic models already in use, such as CIM [14], SAREF [15], SEAS [16] and DCAT [17] a knowledge graph has been created, please check the authors' previous work [18].

Communication Layer focuses on defining the protocols and mechanisms necessary for the interoperable exchange of information between the different components. 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 CEC project's goals in a tangible and practical manner.

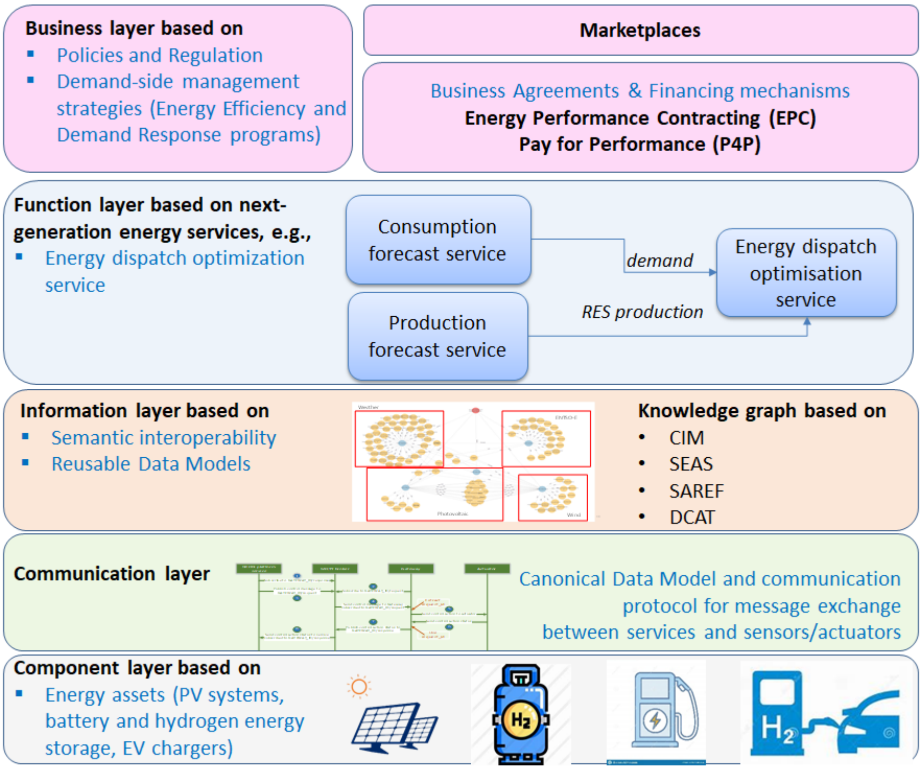

Fig. 2. Platform architecture (SGAM interoperability layers)

4 Platform Validation

The SGAM compliant platform was validated within the EU project NEON (Next-Generation Integrated Energy Services fOr Citizen Energy CommuNities) for the POLÍGONO INDUSTRIAL LAS CABEZAS CEC – Spain) and will be validated in OMEGA-X (Orchestrating an interoperable sovereign federated Multi-vector Energy data space built on open standards and ready for GAia-X) project for the Institute Mihajlo Pupin (IMP) R&D Campus.

To assess and measure the performance of the pilot sites during operation, it is crucial to evaluate how the goals and objectives of the pilot sites are achieved. This evaluation is 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 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 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 energy efficiency services.
- User Engagement KPIs are designed to describe the behaviour and interaction of users with the CEC services and the 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 energy services/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.

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.

5 Discussion

The platform was designed, installed and tested at the Institute Mihajlo Pupin premises in the NEON project framework, has been adopted for the forthcoming activities in SINERGY [19] and OMEGA-X projects [20].

Example from Spain: In the NEON framework, 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 premises and the subsequent testing using data from Spain, represents a significant milestone in the development and evaluation of the NEON project.

Example from Serbia: Activities in SINERGY and OMEGA-X frameworks 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. The IMP team is looking for strategies to (1) reduce emissions and optimize costs, by focusing on installation of on-site renewable electricity and storage solutions, as well as (2) methods for integration of EV chargers. Thermal and electric storage solutions will complement the existing installation to maximize use of locally produced electricity. In the scenario, a combined district modelling with a prospective scenario of the Serbian electricity mix and hourly electricity prices has been used.

6 Conclusion

In this paper, we have discussed the proposed solution for a SGAM compliant platform for integrating data-driven services and connecting physical energy assets within CECs. The design of the platform architecture was elaborated, considering standard-enabling technologies, interoperability solutions, and ethical and legal compliance.

The success of an Energy Communities or Citizen Energy Communities project depends on many factors. Besides the technical aspects discussed in this paper, the outcome relies on the legal and regulatory frameworks in place, as well as the specific structure and goals of each community energy project (including the citizens engagement). Energy communities may partner with external entities, such as local governments or private companies, to facilitate the development and operation of renewable energy projects.

As part of the future work in the case study from Serbia, additional short, mid- and long-term planning services will be integrated and tested with the platform using data from the IMP campus.

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