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ENABLING REAL-TIME DATA-DRIVEN ENERGY COMMUNITIES THROUGH OPEN AND INTEROPERABLE TECHNOLOGIES

Summary

Energy Communities, and their integration into the energy networks are gaining momentum in the European Energy Transition roadmap. This work addresses open-source solutions for the acquisition and processing of real-time data from meters and sensors, as well as interoperability with generation and consumption platforms, according to the diverse Energy Communities requirements. The work integrates scalable, secure, and microservices-oriented architectures, facilitating monitoring, advanced analytics, and energy optimization. The results presented are derived from practical experience in real-world environments, with versions currently in production and under continuous development.

Keywords: Energy communities, real-time data acquisition, open-source technologies, microservices architecture, interoperability, energy monitoring, energy data analytics, smart energy systems

Field of application for the findings: Energy Communities, Distributed Energy Resources Integration, Real-Time Energy Monitoring Systems, Smart Energy Management Platforms, Interoperable Energy Data Platforms, Energy Data Analytics and Optimization.

Addressed audience: Scientific community

1. Introduction

Citizen Energy Communities (CECs) are community-driven initiatives that seek to decentralize and democratize the energy system, prioritizing social and environmental benefits rather than focusing solely on economic profit (Moroni et al., 2019; Roby & Dibb, 2019). Their growing importance in Europe is closely linked to the overall energy transition, as they support the shift from centralized energy systems to more decentralized structures, aligned with the European goal of achieving a carbon-neutral society (Hainsch et al., 2022). A key aspect of these communities is fostering active consumer participation by transforming homes and buildings from passive consumers into prosumers capable of managing their own energy demand, generation, and storage. Their distinguishing feature is that they promote sustainability by increasing the use of renewable energy sources, which contributes to reducing CO_2 emissions and improving air quality and living standards (Hainsch et al., 2022). On the other hand, CECs strengthen economic resilience by introducing new business models that promote energy savings, allowing communities to reduce costs by optimizing local energy consumption, and help prevent energy poverty (Hansen et al., 2020).

Energy communities rely on the deployment of distributed renewable energy generation infrastructure, such as photovoltaic panels, wind turbines, or small-scale hydroelectric systems, to provide local and sustainable energy. On the other hand, Energy Communities must comply with local and regional regulations and maintain interoperability between heterogeneous devices. With specific services, demand response mechanisms that dynamically adjust consumption, increase efficiency and reduce operating costs can be implemented. To a lesser extent, although increasingly important, the integration of energy storage systems is relevant for balancing generation with consumption patterns, thus providing a better balance between generated and consumed energy (Namjoo et al., 2022).

Current networks allow for bidirectional energy flow and participation in ancillary services or local energy markets (Jin et al., 2020). In this sense, scalable service architectures enable community expansion, while mobile applications engage members in energy monitoring and management. Open service infrastructures for Energy Communities facilitate long-term data logging, trend analysis, benchmarking, and continuous improvement.

2. Approach

A modular microservices platform, designed to provide advanced and competitive services through a cloud-based, scalable, and interoperable architecture is being developed to suit the diverse requirements of the Energy Communities (Cinque et al., 2022). The platform is part of a European collaborative effort aimed at designing and implementing innovative technological solutions for the energy sector (Oprea & Bâra, 2021a), supporting the transition towards more sustainable and decentralized energy systems. The platform's modular design enables flexible deployment and integration of services across multiple providers, facilitating real-time monitoring, adaptive visualization, and infrastructures simulation. By leveraging containerization technologies such as Docker and orchestration tools, the platform ensures robustness, scalability, and seamless interoperability between different components and service providers (Cinque et al., 2022). In addition, the platform incorporates Internet of Things (IoT) connectivity and artificial intelligence algorithms for predictive analytics, operational optimization, and data-driven decision-making (Oprea & Bâra, 2021a; Qin et al., 2022). It is built upon open-source principles, promoting a collaborative ecosystem that encourages innovation, knowledge sharing, and the development of new business models within the community energy sector (Oprea & Bâra, 2021b; Kirli et al., 2022).

Among the requirements for Energy Communities are real-time monitoring capabilities, including continuous visualization of energy generation, consumption patterns, and energy allocation among community members. For this reason, a centralized energy management platform is required to collect, analyze, and visualize generation and consumption data (Aboushady & Gowaid, 2019). On these platforms, advanced analytics services allow for profiling energy flows, predicting demand, and optimizing resource allocation (Qin et al., 2022). To cover these necessities, accurate, high-frequency data acquisition from distributed assets and smart meters, enabling transparent tracking of self-consumption rates, shared energy distribution, and grid exchanges are required. These capabilities are essential when operational decisions must be taken immediately, such as battery charging management or the activation of heat pumps. For scenarios where real-time decision-making is not required and cost optimization is a priority, there exists platforms that collect consumption data from smart meters through the energy distribution companies, providing access to validated metering information. Although this approach involves a delay of several days in data availability, it eliminates the need to install and maintain parallel metering equipment, significantly reducing infrastructure and operational costs.

3. Preliminary results

A modular microservice for Energy Communities monitoring in real time has been built using a selected set of open-source software components, each of which has been proven for stability, reliability, and efficiency in demanding environments. Ensuring resource efficiency is a primary consideration, enabling the system to operate effectively without unnecessary computational or energy overhead. The solution is designed to collect and integrate data from multiple sources, supporting a wide variety of communication protocols, with MQTT as the central integration backbone, facilitating seamless communication between all parts of the microservice and ensuring real-time data availability. Data collection and flexible visualization capabilities are a core feature of the designed microservice, by taking into account the Energy Communities profiles and user-bases, with a layered approach aimed to ensure that both operational oversight and end-user engagement are fully supported. Fig. 1 shows the real-time solution scheme and the open-source software modules that comprise it.

By combining modularity, open-source technologies, and protocol versatility, this solution lays the groundwork for subsequent development phases. It ensures interoperability among heterogeneous devices, scalability for expanding communities, and adaptability to evolving energy management requirements.

This microservice is being tested by different, real energy communities. The usability, data accuracy, data visualization, end-user engagement and user feedback will be assessed, in order to cover not only the technical but also the social requirements of Energy Communities.

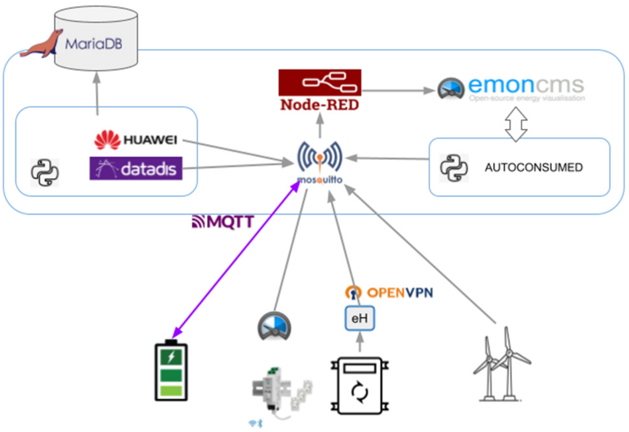

Fig. 1: Real-time solution scheme

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