Article European Countries

European Energy Communities: Sector Coupling, Flexibility, and Operational Perspectives

24 October 2023

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This article explores the growth of European Energy Communities and emphasizes their role in reducing grid dependency and promoting renewable energy. It also discusses sector coupling for increased renewable energy utilization and introduces the FEDECOM project, which is developing an ecosystem to demonstrate the advantages of energy sector coupling across European energy communities.

An **energy community (EC)** is a collective formed by citizens, small businesses, and local authorities with the overarching aim of producing, managing, and consuming their own energy [1]. ECs primarily seek to achieve social and environmental benefits alongside financial benefits. The benefits span the community members and seep into the overall energy system. The governing of such a collective covers production, distribution, supply, consumption, storage, energy trading, efficiency services and aggregation parts in the energy supply chain. ECs can be diverse, depending on location, involved actors or stakeholders, and provided energy services.

Setting up ECs can assist in reducing costly grid investments and instead drive the production and consumption of electricity generated locally and from **renewable sources**. High utilization of renewable energy systems has the potential to reduce **greenhouse gas (GHG) emissions** and transform the individual user from consumers into prosumers. ECs with a high share of locally produced renewable electricity are less dependent on the grid and save energy costs for the users.

The European Commission reported that in 2021, there were more than 7,700 ECs across the EU. These ECs involved at least 2 million people and housed an installed renewable capacity of 6.3 GW [2]. 705 ECs were reported in The Netherlands in 2022, with installed capacities of 272 MWp of solar power and 315.6 MWp of wind power [3]. Around 20 projects were identified in Italy, with many investment commitments in ECs. The region of Lombardy aims to build up to 6,000 ECs with a total installed capacity of 1.3 GW [4]. In 2021, Germany reported a total of 914 renewable ECs involving over 220,000 people and avoided 3 million tons of CO_2 emissions [5].

Sector Coupling and Flexibility Aspects

Electricity production from renewable sources is subject to intermittency, and its availability can fluctuate within a day and throughout different seasons. The intermittency problem's effects on energy systems can be reduced through the introduction of sector coupling. Sector coupling is the concept of integrating multiple energy networks into one energy system, enabling higher efficiencies and higher utilisation of renewable energy, promoting decarbonisation, and introducing flexibility in meeting the **energy demand** [6]. One application of sector coupling is the direct electrification of different processes. For example, renewable electricity can be used in district heating networks, also known as power-to-heat, with technologies such as heat pumps and electric boilers. Electricity can also be used to produce hydrogen or other synthetic gas. This is known as power-to-heat, and the produced gas can be stored for hydrogen vehicles or as an electricity or heat source. Power-to-mobility looks to electrify the transport sector with electric cars and a widespread charging infrastructure. Sector coupling is vital for the successful establishment and functioning of renewable-based ECs.

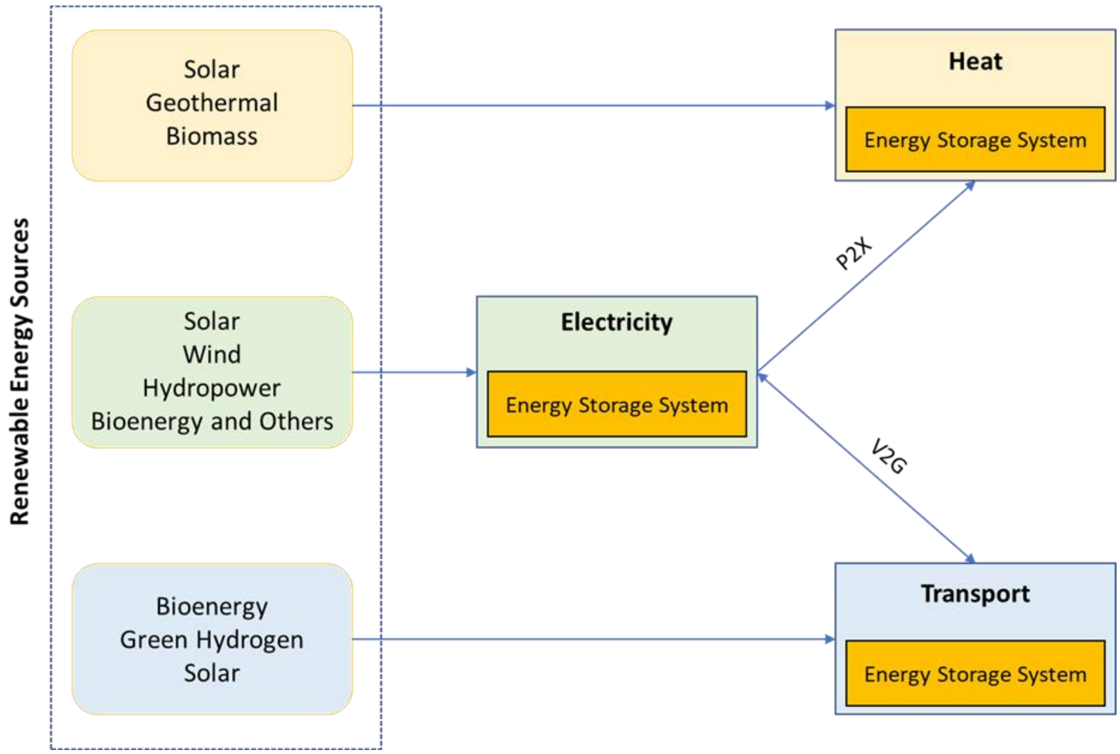

Figure 1. Example of coupling electricity, heat, and transport sectors. Adapted from [7].

In short, the potentials of sector coupling are:

- Reduces the intermittency problem of renewable energy sources (RES).
- Drives decarbonisation through greater utilisation of RES.
- Storage of surplus generation in other energy sectors and other forms (batteries, hydropower, electric vehicles, hydrogen tanks, hot water tanks).
- Introduces flexibility in meeting energy demand.
- Increase energy security.
- Reduces grid dependency.

Increased integration of renewable energy into the energy mix calls for flexibility in the energy system to account for the more significant fluctuations in production compared to conventional fossil fuel-based energy systems. Flexibility measures can be carried out from both the demand and supply sides. Demand-side management measures cover peak shaving during periods of high electricity consumption to reduce stress on utilities and load shifting to periods of low electricity prices [8]. Flexibility enables and encourages energy exchange among community members in an EC and allows energy trading among multiple ECs. This reduces grid dependency for meeting energy needs and congestion in existing grid lines.

Operational Perspective

ECs chiefly benefit from a mix of renewable energy sources, including solar, wind, biogas/biomass, hydrogen, and hydro, complemented by energy storage systems. A diversified energy profile reduces dependency on a single source and increases the reliability and resilience of the community's energy supply. However, this diversified energy profile calls for an efficient management of the distribution and consumption of energy within the community. How power is dispatched within a renewable EC is essential for its functionality and reliability.

An optimised power dispatch plan or model ensures the operational performance of the local distribution network, considering voltage stability and power quality, all the while reducing the energy cost. Evaluating multiple energy sectors is often complex and calls for an extensive understanding of the various sectors and identifying local dispatchable resources. To achieve this, measures call for implementing smart grid technologies. Smart meters, for instance, provide real-time recording of energy production and consumption data, offering insights for optimising the community's energy utilisation. Integrating local energy storages for charging during periods of surplus production and discharging during periods of high demand or grid disruptions allows for efficient energy management. However, the success of an EC is not limited to technical measures; there are also social and regulatory aspects. Community engagement and education are essential for the successful operation of an EC. Members should be educated about the benefits of renewable energy and energy-saving practices to promote a culture of sustainability and active participation.

Additionally, there is the financial aspect of an EC. The business model developed needs to be sustainable and incorporate energy trading and revenue-sharing schemes. These must follow local regulations and policies while adapting to changing energy standards and guidelines.

European ECs are one step towards the clean energy transition and achieving a sustainable future. These collective endeavours have the potential to transform how energy is produced, distributed, and consumed. Boasting a mix of renewable energy sources, sector coupling and smart management, ECs can reduce the carbon footprint and enhance energy independence and resilience. ECs are a blueprint for transforming the current landscape into more sustainable, cleaner, decentralised, and community driven.

The FEDECOM Context

In the context of the FEDECOM project, flexibility and sector coupling play pivotal roles in optimizing energy systems and promoting sustainability [9]. FEDECOM implementation revolves around three large-scale pilots in Spain, Switzerland, and the Benelux region. The Spanish pilot aggregates three mixed residential, tertiary, and industrial sites, which include diverse electric, thermal and hydrogen generation and distribution systems. The Swiss pilot site consists of 3 energy communities located mainly in residential suburban areas, about 6 kms from Lugano. The Benelux pilot locations are (1) Brussels Brico Retail Community in Brussels suburb (Belgium), (2) Voorhout Village (Netherlands), and (3) Besix HQ and Eemnes Community in Dordrecht (Netherlands). FEDECOM's primary objective is to enhance the efficiency of control strategies within energy communities by harnessing intermittent renewable energy sources and integrating various energy vectors, such as electricity, heat, cooling, and mobility. This approach aims to unlock demand flexibility, increase the adoption of renewable energy, and improve grid stability. By employing cooperative demand response strategies, power-to-x technologies, and storage solutions, FEDECOM seeks to maximize the use of renewable energy, enhance grid operations, and promote cross-community integration. Additionally, FEDECOM emphasizes long-term planning, facilitating optimal system design and renewable energy integration while considering environmental factors.

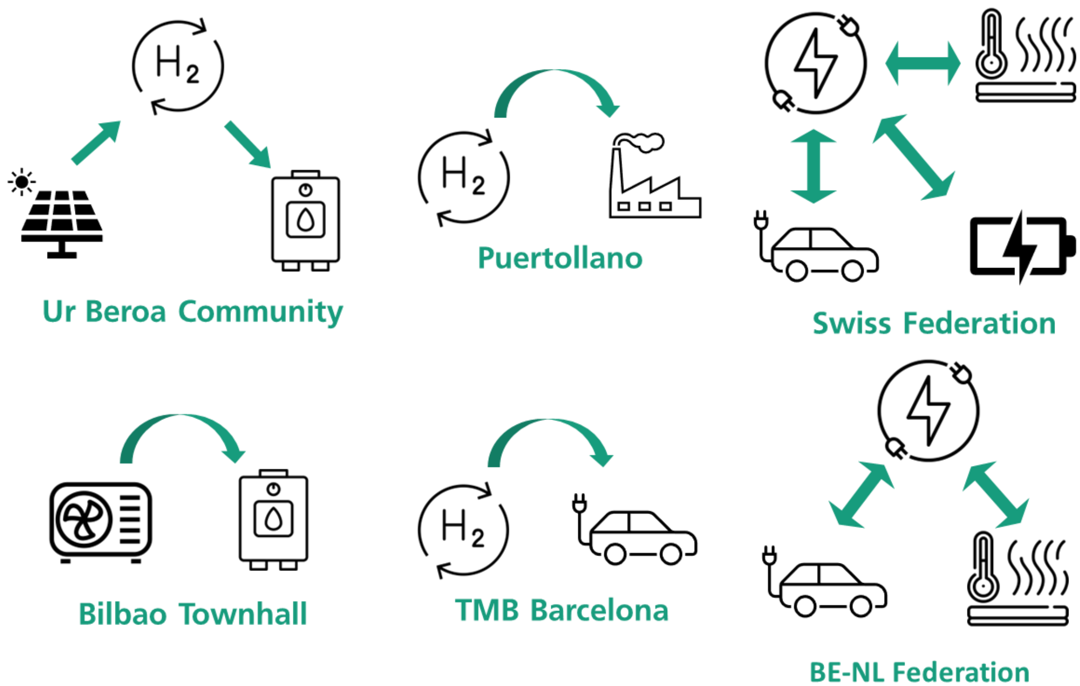

Figure 2. Sector coupling opportunities in FEDECOM energy communities.

FEDECOM's strategy also incorporates a comprehensive life-cycle assessment methodology that evaluates the integrated impact of different energy sectors. This approach includes assessing operational scenarios, focusing on the flexibility potential of storage and cross-vector integration, and considering various renewable energy sources and power-to-x technologies. The goal is to minimize the total annual cost of the energy system while accounting for its environmental footprint, thereby ensuring both economic and ecological sustainability. Through these efforts, FEDECOM aims to pave the way for resilient and adaptable energy systems that benefit grid operators and consumers alike.

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The FEDECOM project has received funding from the European Union's Horizon Europe programme. This communication reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein. FEDECOM - «FEDErated -system of systems-approach for flexible and interoperable energy COMmunities» - Project under the Grant Agreement No. 101075660.

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