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Editorial

Challenges in Energy Communities: State of the Art and Future Perspectives

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Within the policy framework of the energy union strategy started in 2015, the European Union (EU) finalized the "Clean Energy for all Europeans Package" (CEP) in 2019. It includes eight legislative texts concerning all the crucial aspects and primary actions to reduce greenhouse gas emissions, improve climate resilience effectively, and ultimately achieve a fair and unified energy transition. In this context, the EU overhauled the old Renewable Energy Directive 2009/28/EC (named RED I) in December 2018, when the new Directive 2018/2001/EU entered into force. Commonly known as RED II [1], this new directive revises the old EU targets for renewable energy sources (RESs) and energy efficiency in the post-2020 energy framework to the 2030 perspective, in line with the 2030 Energy and Climate Framework and the ambitious 2050 Long-Term Climate Neutrality Strategy. With strong inter-relatedness with other legislative texts of the CEP (e.g., the Electricity Market Directive), the RED II strives for a more secure, competitive, and sustainable energy system.

One of the main novelties of RED II (compared with RED I) is envisaging the energy communities (ECs) as a pivotal vector in realizing the energy transition [2]. The directive's perspective assumes that the ownership and proximity factors inherent in the concept of community can be enabling factors in increasing the acceptance of RES projects. Thereby, RED II puts in place innovative friendlier regulatory environments and legal reforms (EU calls it "the most advanced energy legislative framework in the world") to promote ECs and foster collective self-consumption in general [3].

The purpose of ECs is to organize collective energy actions around open democratic participation and governance and to benefit its partakers. In [4], Fina and Fechner outlined an extensive survey of the peculiarities and differences of the ECs legally enabled by RED II while discussing the national transposition of the directive into Austrian law. Similar reasoning is conducted in [5] concerning national transposition into Swedish law. RED II distinguishes two types of ECs, i.e., the citizen energy communities (CECs) and the renewable energy communities (RECs). The significant differences between the two kinds of ECs lie in the types of energy used and the requirement for proximity among the participants. CECs are restricted to electricity and do not require the proximity of members. In contrast, RECs consider all types of renewable energy, but the proximity of participants is a binding constraint.

After presenting a detailed comparison between the Austrian legislation and the RED II, Fina and Fechner [4] identified points of criticism and positive aspects of the directive. The authors outlined how appropriate means of economic support for participants could incentivize the participation of citizens, especially with limited financial means. Even if generating financial benefits is not the primary purpose of ECs, increasing the profitability in the participation could foster the deployment of ECs. The authors recommended grid-independent means of support, such as tax exemptions or premiums for energy transfer within ECs. Then, the authors outlined how the changes in the grid structure could affect established ECs, assessed the meaning of voluntary participation in ECs, and posed some issues about whether the community should be in charge of the control and operation of the

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co-shared RES. They investigated the unanswered questions arising from the possibility for consumption and generation units to participate in more than one EC from 2022 onward. They explored how the national legislation should overcome any administrative barrier to establishing RECs in the heating sector (since RECs, in contrast to CECs, are not restricted to electricity) and fostered the potentialities of the ECs to hinder any form of energy poverty. The role of ECs in struggling against the risk of energy exclusion and poverty, especially in rural communities where ECs can improve energy literacy and resilience, is investigated more in-depth in [6]. Finally, Fina and Fechner highlighted some positive aspects of the Austrian transposition of RED II. These are (i) the clear rules for interaction between grid operators and ECs, (ii) the authorization for RECs to own and operate distribution networks, (iii) the grid levels' use for defining REC participants' proximity, and (iv) the importance of providing financial support for ECs.

In [7], Fina returned to the ECs, this time with Auer, to investigate the prosumers' economic viability when participating in an EC. The authors explored the profitability for residential customers in three different EC set-ups, i.e., purely residential, residential with an additional stand-alone photovoltaic (PV) plant, and residential with a stand-alone PV plant and a commercial customer. To assess the benefits, they use a three-stage simulation model concerning electricity trade within small (using the low-voltage grid) and large (using the medium-voltage grid) RECs. The results show that residents of single-family houses with private PV systems benefit the most by selling surplus electricity to their REC peers. In contrast, the cost savings due to electricity purchases within the EC are insignificant. Residents in multi-apartment buildings benefit significantly by purchasing electricity from the building-attached PV system, leading to almost omitted grid charges. The savings of the remaining members are lower, as they rely on the electricity leftovers of their peers. Using a single stand-alone PV plant in the EC improves the overall profitability of the EC but gives rise to marked inequalities among members. In these cases, it could be helpful to employ advanced democratic power-sharing models as proposed in [8] or other sharing mechanisms [9]. Finally, the participation of a commercial customer in the REC is generally advantageous since his presence enhances local electricity usage with minimum impact on the results of residential customers.

ECs can be viewed as the holistic integration [10] of the pivotal community energy concept with RESs, microgrids, and peer-to-peer energy markets. The community energy concept refers to the deployment of RES projects, energy demand reduction initiatives, and heat production on a small, local scale. These actions may be governed by the community or through a partnership with commercial or public sector partners, and they must always be capable of providing the members with direct beneficial outcomes. More integrated community energy systems may combine rooftop photovoltaics, small wind turbines, energy storage systems, district heating, and biogas or hydrogen production systems and comprise collective demand side activities [10].

In [11], the authors outlined the status of community energy initiatives in Italy. Focusing on three specific case studies, the authors explore the conditions for developing and succeeding ECs within the Italian energy system. The paper helps to understand better the meaning of crucial terms such as community, participation, inclusion, and co-property and shows the dynamics of creation and organization structures that move behind ECs. Conceptually (and somehow romantically), a local community may be based on sharing common values, a sense of place, identity, and localism. However, community members often share interests, even if a common cultural-cognitive substrate can be present. The authors in [11] showed that most of the community energy initiatives they observed were proposed through a top-down approach: five have been proposed by a municipality and seven by commercial actors. Only five initiatives were initiated with a bottom-up approach by either a group of citizens or green associations. The authors outlined that the best institutional framework for participatory approaches and locally owned RECs is the cooperative legal form because it provides higher levels of inclusion, involvement, participation, and co-determination. The authors also investigate the financing structure adopted in the ECs.

The study shows that when companies or municipal utilities start the EC, they usually resort to some form of project financing and open to citizens' financing in a successive phase. Contrarily, when the citizens' communities or municipalities start the initiative, they usually provide the financial contribution.

The importance of sharing in (cooperative) ECs is addressed in [12]. The authors outline how sharing policy is more important for fostering PV RECs than a pricing policy for the sale of energy excess. The authors identify barriers to ECs in four consumer interest areas, i.e., policy, economic, technical, and social. Through an extensive literature review, they seek solutions to overcome these barriers. Although the development of technological solutions for solar ECs is still ongoing, they clarify several issues about the foundation and social acceptance of ECs. They explain the importance of communications between all parties involved (e.g., consumers, stakeholders, and policymakers). They outline that peer-to-peer electricity trading can be more economically beneficial than trading with the grid. They address how remuneration, self-consumption, climatic conditions, consumers' demand profile, tariffs for solar and utility-provided electricity, and even age and education of members affect the implementation of solar RECs. Finally, the authors debate whether solar energy is or not the best solution for local energy production in a RES, observing that a hybrid system including some other source of different nature may be more advantageous for members.

When strictly dealing with energy matters, cooperatives are named "energy cooperatives" [13]. They are voluntary associations of energy consumers and producers whose purpose is to pursue energy independence, and they can be a viable form of support for distributed civic energy. Even under the cooperative structure, the cooperative nature of ECs does not exclude a competitive interaction among their partakers who act to achieve better individual results, not only collective ones. The union of the cooperative and competitive nature gives rise to the term "coopetition" (or "coopetitive nature" of the EC), which is much more than coining a new term, as the authors of [13] extensively explain. Based on measurement data provided by the distribution system operator and economic analysis of actual market data, the authors conclude that the profitability of ECs depends on their members' nature and supply and demand profile. Although an EC's profitability is generally lower than the one associated with a standard prosumer scenario, the authors demonstrate that it is possible to obtain benefits within the EC both on the global and the individual levels. Members purposefully combine competitive and cooperative behaviors: they generate and capture rents and build relationships to search for the best financial effects, as seen from the community's perspective, and translate them into individual benefits.

It is a matter of fact that the energy management of ECs is another essential piece of the puzzle for implementing the community energy concept on a large scale. Generally, an EC's energy management system (EMS) employs some optimization processes to manage generation and consumption and minimize the costs (or maximize the profit) on the consumer (or the community) side. The objective (or multi-objective) function, however complex it can be, (relatively) always has an economic nature. The authors of [14] investigated the impacts that the billing procedure and the regulatory schemes can have on the EC's financial results and optimal energy management. Namely, they addressed the intricacies of different types of regulatory schemes concerning feed-in tariff, net metering, self-consumption, and electricity billing. The authors concluded that the feed-in tariff is the most favorable regulatory structure for the prosumer. However, it is less profitable in terms of cost and impact on the whole electrical system. This observation calls into question the policymakers who have the difficult task of finding a balance between opposite forces to promote ECs and guarantee the economic feasibility of the electricity sector at the same time.

Machine learning techniques and, more generally, artificial intelligence approaches are welcomed to facilitate any optimization process. They proved to be particularly suitable for maximizing the self-consumption (and self-sufficiency) of ECs' members, which is where most of the profit lies. These techniques are usually employed [15,16] to forecast time series of generation and consumption on a horizon of a few hours, one day, or a few days to help the EMS adapt consumption profiles to the local RES generation [17]. In [18], the authors develop a day-ahead forecasting model for local wind power, using tree-based techniques and neural network architectures, and propose an algorithm for generating representative profiles of the community members' electricity consumption at a specific time of the year. Interestingly, they test and quantify the impact of the proposed approaches on a pilot REC established in an industrial area in Tournai, Belgium. The results are encouraging, even if the authors did not observe significant changes in consumer habits, partially due to the COVID-19 pandemic. The authors are determined to extend the test period in future research to obtain more significant data.

The authors of [19] further investigated artificial intelligence approaches for deploying optimum demand-side management programs. Notably, they used a distributed scheme where the distributed agents that cohabitate in the same environment can interact intelligently to make decisions and achieve goals. They investigate different scenarios, and, among several findings, they observe that under some "distorted" schemes, selling self-generated energy could be more advantageous than self-consumption. According to the no-profit nature of ECs, the policymakers must prevent these situations, which promote injections into the grid for profit purposes at the expense of self-consumption.

Energy management in ECs predominantly focuses on electricity systems. However, the two contributions in [20,21] present a different perspective. In [20], the authors investigate the management of ECs in multi-family buildings equipped with heat pump-driven heating systems and photovoltaic panels. Even if the loads remain electric-driven, their heating nature cast light on new results. The authors outline how switching from decentralized heating systems to a centralized heating system and enabling the share of on-site PV-generated energy improves the profitability of the members in multi-family buildings. This result is particularly evident in poorly insulated large condominiums. In [21], the authors focus specifically on thermal energy communities (TECs) with three possible generation options, i.e., geothermal wells, heat pumps, and solar thermal technology. Using an agent-based modeling and simulation approach, the authors explore the impact of four main factors: number of households, formation capability (minimum member requirement), satisfaction factor, and drop-out factor. The main results are the following: the size of the neighborhood (i.e., number of households) is not a crucial factor; a large enough fraction of households must join a TEC in the beginning; it is of primary importance to focus on the satisfaction of the households who joined the TEC; if a household does not participate at the beginning, it does not seem very likely for it to join afterward.

Energy communities present unprecedented opportunities to move toward an effective energy transition. However, they pose significant challenges to existing power systems regarding control, management, and coordination, and they require considerable research effort to overcome the persistent technical, economic, social, and political barriers. The authors hope the present editorial could help steer future research on this manifold field.

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