A Holistic Approach to Energy Communities: From Symbolic Value to the Definition of an Algorithm for Fair Incentive Allocation

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Abstract

The transition to a renewable energy-based system requires commitment and accountability both at individual and collective levels. In this context Renewable Energy Communities, as drivers of technological and social innovation, are recognized as an interesting tool. However, their complexity necessitates a holistic interpretative approach to fully realize their potential.

Introduction

The need to outline a path of energy production and consumption that promotes the transition from an energy system based on fossil energy sources (oil, coal, and natural gas) to a system based on a significant deployment of renewable energy sources while maintaining the stability, balance, and resilience of the grid, requires a collective responsibility and strong commitment to achieve global sustainability goals and mitigate climate change.

This implies a paradigm shift, not only technological, which views distributed generation also as recognition of the role of the end-user in defining the change itself.

Despite the development of various energy policies aimed at promoting the use of renewable energy sources and increasingly ambitious goals for reducing greenhouse gas emissions, particularly at the European level, the path towards a true 'transition of era' still appears to be winding.

In light of collective awareness regarding the impacts of energy production and consumption on the environment, there are still strong resistances (including, and especially, mental ones) towards redefining consumption patterns and adopting a psychological approach to the energy issue that is based on its multidimensional and multidisciplinary nature.

The concentration of electricity production through the construction of large power plants[1] in locations relatively distant from the area of use has, over time, defined not only a physical distancing from its - often perceived only as a potential risk source and therefore subject to local conflicts and protests - projecting the "energy good" into the dimension of the "taken for granted" [1] [2] and beyond the control of the end-user.

The gradual, and in many respects troubled, reconfiguration of renewable generation technologies aimed at enhancing the use of non-programmable renewable energy sources (NPREs) - such as solar and wind - in conjunction with traditional renewable energy sources (RESs) (such as hydro, geothermal, and biomass) has, on one hand, aimed to redefine the (electric) generation process towards reduced use of fossil fuels - with the goal of containing GHG emissions into the atmosphere and mitigating the effects of global warming, increasing energy self-sufficiency, reducing the risk of negative repercussions from geopolitical imbalances, and accelerating the decarbonization process of the economy. On the other hand, it has also imposed a weighty redefinition of the entire energy system - which is nevertheless called to respect criteria of balance, safety, and resilience of the grid - to facilitate the access of a new type of stakeholder, namely the energy prosumer.

The reconfiguration, limited to defining the process just on production and only at an individual level (in the case of residential photovoltaics), has only partially translated into a real collective approach to the "energy issue."

Within this interpretative framework, Renewable Energy Communities (RECs) are inserted as sociotechnical configurations and potential paths of innovation.

Renewable Energy Communities: an interpretative framework

Although for over two decades, in a more or less structured manner, "Community Energies" have entered the practice of movements and enthusiasts and into scientific debate as a potential paradigm shift – as demonstrated by [3] [4] – it is only with the publication of the Clean Energy for All European Package, and in particular with directives 2018/2001 (RED II) and 2019/944 (IEM Directive), that the concept of "energy community" rightfully arrives in the European political debate and effectively closes the rhetorical interpretative flexibility on the possible definitions accompanying the establishment of a RECs.

In front of about ten possible definitions of energy communities found in the specialized literature [5] [6] [7] [8] [3] [4], the RED II [9] clarifies the concept of RECs by enclosing it within a specific technological interpretative framework - which is based on the instant self-consumption of energy produced by renewable energy sources - and identifying the spatial boundaries for potential participants' actions (leaving the specification definitions to the member states).

Renewable energy production facilities, proximity, co-responsibility, the principle of open access, and prioritizing 'social, economic, and environmental benefits, even before financial profits' are the keywords outlined in the directive to guide the establishment of renewable energy communities. This process, often described as a promising pathway toward transitioning to distributed energy generation, optimizing consumption, and thus promoting a more rational use of energy, aims to create an electricity market that is more inclusive of citizen involvement. It also aims to foster marked forms of social inclusion, ensuring access to energy for the most vulnerable segments of the population. Consequently, it contributes not only to an ecological energy transition but also to one that addresses social justice concerns.

A defining process that, in practice, aims - in the extreme complexity derived from the multidimensional nature of the subject - to facilitate a real approach, both physical and psychological, to the production, consumption, and management of locally produced energy.

However, according to [10], research on energy communities has tended to focus primarily on technical aspects, examining energy savings and emission reductions achievable in the building sector through optimization of the dimensions and management of Renewable Energy Sources (RES). Energy communities, however, signify more than just a techno-economic commitment to creating and managing energy resources collectively; they represent a fundamental shift in perspective [11]. When individual energy producers and consumers aggregate into an energy community, they cease to be mere constraints or fixed energy loads to be met. Instead, they become dynamic elements of an energy system capable of actively contributing to achieving community goals through their own behavior. In this manner, energy communities empower energy producer-consumers and foster social collaboration to attain shared objectives, such as reducing energy costs and attaining energy self-sufficiency [12].

Additionally, they combat energy poverty and vulnerability while striving for higher levels of environmental well-being.

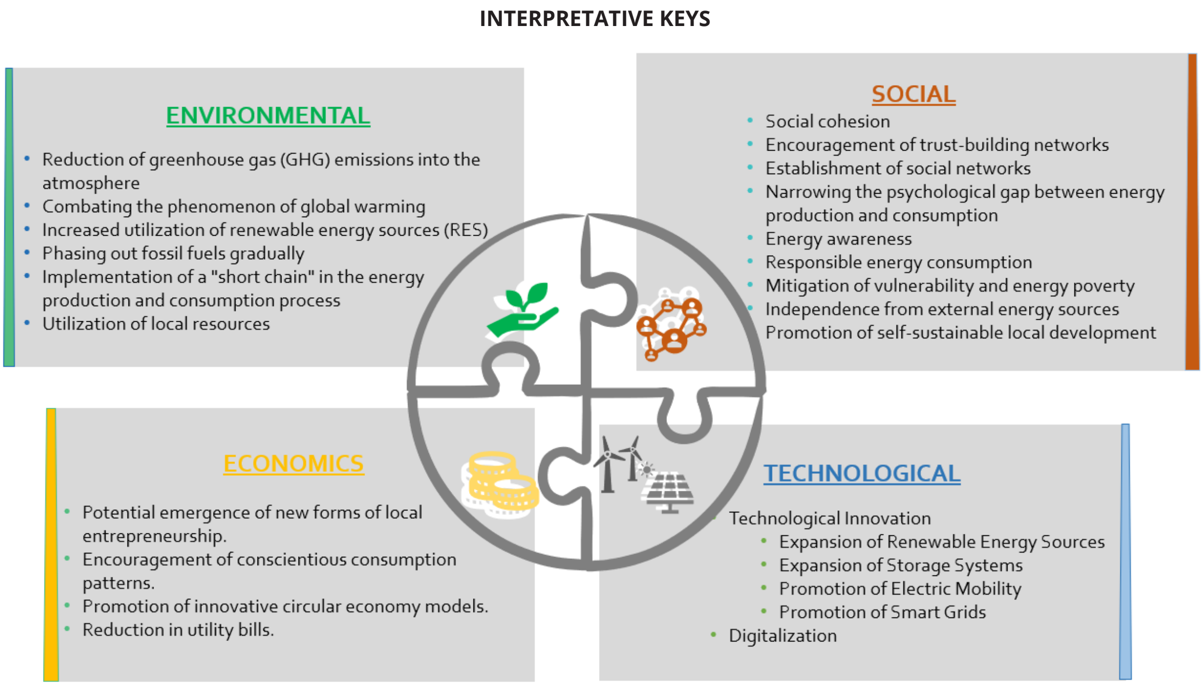
Figure 1 illustrates the interpretative keys that define the value aspects and horizons of meaning guiding the establishment of RECs.

Renewable Energy Communities in Italy

In Italy, the early transitory implementation of the RED II directive - inserted in Article 42 bis of the Milleproroghe Decree [13] - has defined an intense process of promotion of Renewable Energy Communities, resulting in the birth of several "experiments" at the national level. Currently, according to data released by GSE [14], there are 115 overall configurations of self-consumption with "active service", including 82 collective self-consumption groups (AUC) and 33 REC, for a total of 140 installations with an average power - per configuration - of about 20 kW and the involvement of 900 end-users.

The final transposition of the directive, initiated with the publication of Legislative Decree No. 199 on November 8, 2021, in the Official Gazette [13], and concluded on January 24, 2024, with the publication of the implementing decree of the MASE (CACER Decree) [15], has brought substantial changes to national regulations. These changes include expanding the scope of REC (from the perimeter of the secondary substation to the primary substation) and increasing the size of installations (from 200 kW to 1 MW). Consequently, this favors the broadening of participation to a significantly larger number of "users" in the potential configuration and the involvement of increasingly extensive territories.

Starting from these premises, we have investigated - through the construction of a regional database on



SOURCE: Prepared by RSE

post-experimentation energy community proposals, analysis of regional laws on the topic, and literature analysis - how the phenomenon is evolving both in terms of "vision" and "mission".

Specifically:

- What are the objectives of the renewable energy communities currently being defined, and how are they developing?
- What are the prevailing organizational models, and what is their impact on the governance models defining the process?
- What are the forms of engagement and openness to participation?
- How will organizational models redefine themselves considering an expansion of "participation boundaries"?

These are just a few of the research questions currently being explored, using a multilevel perspective, at the 'meso' level of the creation/birth process of Renewable Energy Communities (RECs). This approach acknowledges the necessity, on one hand, to identify territorial and local strategies that ensure the social acceptability of initiatives and stimulate interest and participation by mobilizing shared values and interests. On the other hand, it seeks to identify the conditions necessary to establish an institutional framework capable of promoting and supporting community-oriented energy production and consumption.

While on one hand, in accordance with the dictates of the RED II, it remains firm that the objectives of RECs must be defined in terms of "economic, environmental, and social benefits, rather than financial ones, for the members of the community and the territories hosting it," on the other hand, it is increasingly evident that:

- The extreme technological complexity underlying RECs - in their most advanced versions - requires increasing levels of specialization in managing the process.
- The increase in the size of installations not only opens up to the "diversification" of technologies underlying renewable energy production but also increases the scale of investments necessary for project realization.
- The need to integrate generation systems with energy storage systems and consumption management technologies.
- The widening of the electrical perimeter - from the secondary substation to the primary substation - shifts the boundary of possible participation from a few hundred connected users to several thousand connected to the primary.
- Defining increasingly effective mechanisms for fair distribution of REC incentives.

All of this implies several possible scenarios directly linked to the decision-makers' capacity to steer the process, those who physically promote the endeavor, the chosen legal structure, as well as the ability to assess the impacts (social, environmental, and economic) that projects and initiatives will have on territories in the short, medium, and especially long term.

Towards the development of an algorithm for fair distribution of incentives

The nature of RECs, as identified in the European [9] and Italian [13] [15] regulatory frameworks as a 'legal entity' with purposes extending beyond mere financial profit, coupled with potentially capital-intensive investments, necessitates the establishment of cohesive agent networks. These networks should be oriented towards objectives involving active participation and significant non-economic costs as well.

While energy storage systems (a technical solution) can effectively "balance" the intermittency of solar sources [16], it's important not to overlook the impact that the behavioral component and processes of enhancing awareness in energy consumption can have on the process. This can be achieved through strategies related to the concept of Energy Flexibility (EF), particularly focusing on short-term strategies like Load Reduction and Load Shifting. Both aim to reduce power demand during peak periods by engaging users in direct actions, such as temporarily reducing power and modifying the timing of energy usage [18] [19].

Among the various possible strategies, Load Shifting is considered particularly effective because it directly engages community members in adopting conscious behaviors regarding the timing of energy usage [20], thereby facilitating energy management and production.

In this theoretical framework, given the significant mobilization of public funds allocated to support the establishment of RECs in Italy, also as part of a twenty-year incentive regime, a methodology for distributing REC revenues (or collective self-consumption schemes) is being developed. Drawing inspiration from cooperative game theory, this methodology assumes that players (in this case, members of the configuration) derive a common benefit from collaborating to achieve a shared goal. The identified goal is to promote virtuous consumption behaviors aimed at increasing shared energy, while the benefit lies in the reduction of users' energy expenses, achieved through the revenue generated by participating in the configuration.

The algorithm emphasizes the reduction in energy expenses achievable by users of a REC/AUC through cooperation in adjusting their consumption to favor increased shared energy. Distribution is carried out by allocating incentives generated by energy sharing, the avoided costs recognized by the TIAD [21], and revenue obtained from selling energy to the grid at market prices based on:

- The entities investing in the configuration.
- The types of fiscal support utilized (e.g., tax deductions).
- Availability of additional revenue streams, such as leasing spaces for equipment installation to serve the configuration.
- Users' readiness to adopt flexibility measures to encourage increased shared energy.

The assumptions underlying the distribution process are:

— Rewarding sharing.
— Avoiding penalizing members who, while not sharing high volumes of energy, still bear the costs of participating in the REC.

In accordance with these two principles, the algorithm utilizes the sale of energy injected into the grid by the configuration's plants to cover their installation and maintenance costs. The allocation of the revenue share to cover these expenses depends on the nature of the entities investing and the economic value of the sale. The latter may be sufficient to generate profits (residual margins of the sale after deducting expenses).

The incentive and costs avoided by the TIAD are divided based on each user's level of energy sharing. The algorithm assesses the average monthly expenditure of all users during the plant's production period and allocates the incentive so that each user's expenditure is equal to or lower than the average value. Users with a monthly expenditure below the average value receive a small portion of the incentive as a contribution to participation. This portion is determined based on the user who shares the least energy in the month.

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Footnotes

[1] In hydroelectric power plants, first, and then in thermoelectric ones.