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Research article

Implementing energy transition and SDGs targets throughout energy community schemes

Francesca Cappellaro,[1] Gianluca D'Agosta,[1] Piero De Sabbata,[1] Felipe Barroco,[2] Claudia Carani,[2] Alberto Borghetti,[3] Luca Lambertini [4]* and Carlo Alberto Nucci[3]

[1]ENEA, Centro Ricerche Bologna, via Martiri di Monte Sole 4, Bologna 40129, Italy, [2]AESS, via Enrico Caruso 3, Modena 4122, Italy, [3]Department of Electrical, Electronic and Information Engineering "Guglielmo Marconi", University of Bologna, Viale Risorgimento 2, 40136 Bologna, Italy and [4]Department of Economics and Alma Climate Centre, University of Bologna, via San Giacomo 3, 40126 Bologna, Italy

*Corresponding author. E-mail: luca.lambertini@unibo.it

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Abstract

Citizens are expected to play a great role in the future global energy transition, being able to give a decisive contribution to limit global warming to 1.5° and avoid the worst consequences. Empowering citizens is crucial and assigning them the role of prosumers in the new energy market is necessary to ensure a sustainable and fair pathway to the low-carbon energy transition. Creating energy communities (ECs) can also engage citizens by providing flexibility and ancillary services, reducing losses and curtailments in the grid. It also yields environmental and social benefits, activating virtuous circles in the local economy aligned with the SDGs of Agenda 2030.

We illustrate the experience of an EC implementation, using GECO-Green Energy COmmunity project, as a case study. In particular, the in-depth qualitative analysis of the project from a social and technical perspective is provided. The GECO Project is active in the districts of Pilastro and Roveri, Bologna, Italy, being implemented by a consortium including the Energy and Sustainable Development Agency (AESS), the National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA) and the University of Bologna (UniBo). Our findings show the potential interconnections among the development of an ECs and SDGs, especially goals 7, 11, 12 and 13. Placing ECs and prosumers at the centre of the international debate may deliver a more sustainable paradigm in the energy sector, in line with the climate change needs and community approaches.

Key words: citizen energy community, renewable energy community, energy transition, SDGs

Introduction to the Green Energy Community

The International Energy Agency (IEA 2018) states that energy generation and consumption (electricity, heat and cooling) are responsible for 49% of green house gases (GHGs) globally and points out that 'Government policies and preferences will play a crucial role in shaping where we go from here. More than 70% of the $42 trillion in investment in energy supply in the New Policies Scenario, across all domains is either conducted by state-directed entities or responds to a full or partial revenue guarantee put in place by governments' (IEA 2018: 36). Countermeasures to minimize the impact of human activities producing short-lived climate forcers emissions into the atmosphere also need to be developed. Nevertheless, a transition to a low-carbon and sustainable society will not take place through an exclusively top-down movement which is far more complex than adapting an existing system through the assimilation of new technologies and practices (Koirala, Van Oost, and Van Der Windt 2018).

Furthermore, deep decarbonisation in a fair and inclusive transition, aligned with the sustainable development goals (SDGs) of Agenda 2030, especially goals 7 (Affordable and clean energy), 11 (Sustainable cities and communities), 12 (Responsible consumption and production) and 13 (Climate action), is only possible with deep changes in our behaviour as individuals and society (Cavalli *et al.* 2021). This is the reason why the concepts of energy democracy (Burke and Stephens 2017, 2018; Stephens 2019) and climate justice (Sovacool *et al.* 2017; Thomas and Warner 2019) are fundamental to making this trend grow and become feasible in a fair way, *without leaving anyone behind*.

The acceptance of renewable energy (RE) projects deployed on land in large-scale facilities is still quite limited in European countries (for an empirical assessment of the social perception of the impact of renewables, see Delicado, Figueiredo, and Silva 2016; Roddis *et al.* 2018). This is the reason why Local Energy Community (LEC) ownerships are seen as capable to provide a significant contribution to circumventing this barrier in the case of onshore wind turbines and promoting the implementation of distributed photovoltaic (PV) systems, being part of the solution to make feasible a green revolution in the energy sector, able to tackle the climate crisis, economic inequality and social-environmental injustice in a changing environment, promoting sustainable cities and communities. All in all, the awareness of being part of the energy commons, and the relevance of peer-to-peer relationships across potential prosumers can play a key role in paving the way to the formation of LECs, as several contributions have pointed out (*inter alia*, Acosta *et al.* 2018; Bauwens and Devine-Wright 2018; Müller and Welpe 2018).

These considerations set the stage for the need of fostering the arising of energy communities (ECs). Here, we will briefly dwell upon the concept and definition of EC, which, in the EU legal framework summarised in Caramizaru and Uihlein (2020: 7), refer to 'a wide range of collective energy actions that involve citizens' participation in the energy system', giving shape to a new type of social movement allowing citizens to access more participative energy processes characterised by collective decision-making and the awareness of sharing benefits (see Walker and Devine-Wright 2008, among others). This transformation of citizens' role from passive to explicitly active agents redefines their identity as energy prosumers and co-owners of energy facilities (as stressed in Van Der Schoor *et al.* 2016) and therefore paves the way to their active participation in collective decision-making processes together with institutional subjects belonging to the public administration and the industrial texture in which the EC is embedded.

The legal definition of ECs is spelled out in two separate laws of the Clean Energy Package: the first is the revised Renewable Energy Directive (EU) 2018/2001, which frames the concept of Renewable Energy Community (REC). This has been followed by the Internal Electricity Market Directive (EU) 2019/944 which describes the need to identify and foster Citizen Energy Communities (CEC). To the aims of the present article, we may confine ourselves to a short outline of the key points of Directives 2018/2001 and 2019/944. The concept of REC is defined in the Recast of the Renewable Energy Directive—2018/2001, promulgated in 12.21.2018 (EU 2018b). In particular, art. 2, n. 16, states that a REC relies on voluntary participation by individuals, small and medium enterprises and local authorities, and must benefit community members along environmental, social and economic dimensions alike. The concept of CEC is defined in the Recast of the Electricity Directive—2019/944, approved on 06.14.2019 (EU 2019b). Its nature is spelled out in art. 2, n. 11, where one reads that membership and purposes are defined as for RECs, adding explicitly that a CEC may provide energy services to its members in various forms, including supply, distribution and storage.

In the EU, the 'Clean Energy for all Europeans' Package (CEP) attempts to put in place appropriate legal frameworks to enable the energy transition from fossil fuels to cleaner energy and give a special role to citizens and community activities (RescoopMecise 2018; EU 2018a, 2019a). The last deadline for the internalization of the Directives by EU member states through national laws was in June 2021. The CEP calls for extending consumer participation to include trade in electricity, facilitated by special trading structures for small producers, consumers, communities and prosumers. The approved directive package would oblige member states to ensure a more competitive, customer-centred, flexible and non-discriminatory EU electricity market with market-based supply prices, as it emerges from several independent studies (see IRENA 2018; Eurostat 2019; Nouicer and Meeus 2019; EU 2019a;).

The new regulation will also enable ECs to act like aggregators, fostering the coordination of several units (whether prosumers or not) to control generation output and load demand, exploring flexibility and bonding small users to allow their participation in the wholesale energy market. This aspect is closely related to the potential role of a large prosumer populations (Barbour *et al.* 2018; Bauwens and Devine-Wright 2018; Davis *et al.* 2018; Hillman, Axon, and Morrissey 2018; Koirala, Van Oost, and Van Der Windt 2018). To promote such initiatives, a new market design is under construction and two different concepts of ECs are proposed in the CEP (EU 2018a, 2019a).

However, despite consensus on the need for changes in human behaviours, in economic dynamics and in technological challenges to create a paradigm for the energy sector more aligned with the climate targets and Agenda 2030 goals, community approaches have not yet been fully explored as instruments of promotion in the transition to a smart, low carbon, sustainable and fair society. This is particularly true in countries, such as Italy, where schemes 'one to many' and 'many to many' have been endorsed for the first time in 2020 (Italy 2020), in an experimental phase to test the collective self-consumption and ECs' schemes in the country, whose outcomes are reported in Orioli and Di Gangi (2017).

These new possibilities, if correctly implemented by the Member States in their energy sectors, may prove to be valuable instruments for attaining SDGs, especially goals 7, 11, 12 and 13, as the present work shows. The remainder of the article is structured in three parts. The first illustrates the methodological approach and the links between the nature of ECs, with specific reference to the GECO project that motivates this article, and the related SDGs. The most relevant elements that emerged thus far from GECO project are discussed in the second part. The last contains a few concluding remarks.

Methods

GECO project and its links with the SDGs

Our research used multiple research methods, to conform as much as possible with the indicators provided by the methodological framework proposed by Sovacool, Axsen, and Sorrell (2018), thereby blending case studies (Yin 2003) and systematic literature review (Sorrell 2007) to data collection and triangulation (Flick 2004) for data analysis.

The research adopted a qualitative and inductive approach to the problem, since the researchers' interpretative role prevails in relation to the dynamics and the interaction of the object investigated with reality, in particular, regarding to data collection and data analysis. The research is descriptive, applied and exploratory in its objectives, as its main purpose is the production of knowledge through the observation of the social, urban and industrial texture in which researchers sought to establish a direct and in-depth interaction, in addition to the ensuing application of its results.

It is important to highlight that, to date, no scientific study has been found that addressed the theme of ECs directly related to SGDs 7, 11, 12 and 13. In particular, the analysis of an EC experience carried out in the case study of the GECO project helps demonstrate the connection with the targets in the aforementioned SDGs.

The GECO (Green Energy COmmunity) project, launched in July 2019, will lead to the creation of the first EC in Emilia Romagna Region in 2021 according to the new EU model, in the districts of Pilastro and Roveri, in Bologna, Italy (Fig. 1). The community uses the existing network of the local distribution system operator (Cappellaro *et al.* 2018, Valpreda *et al.* 2018) and includes an area where electricity consumption currently amounts to 430 MWh per year (GECO 2019a). The GECO project focuses on citizens' and local companies' actions, which will play an active role in the process of local production, distribution and consumption of energy (GECO 2019b, Cunha *et al.* 2021).

A first survey carried out on the basis of the data owned by the City of Bologna, Italy, showed the existence of around 150 MV/LV cabins in the project area (b). The real data, obtained through a collaboration agreement with the local grid distributor, indicated the existence of more than 250 MV/LV cabins (c). Moreover, while in the current regulation (Law 08/2020) the perimeter of the EC is defined as the single MV/LV cabin, in the new legal framework established by the European Electricity Directive—2019/944 and Renewable Energy Directive—2018/2001, the perimeter will be extended, covering all MV/LV cabins connected to the same primary substation (HV/MV). Thus, from the comparison between the two images on the right side of Fig. 1b, c, there emerges that to cover the entire area of interest of project (a), according to the current standard, it would be necessary to implement more than 250 small-scale ECs, while with the new law, it would be possible with cover all area, in principle, with two ECs.

According to the regulation which was valid until the end of 2021, ECs in Italy can only be implemented based on new RE generation systems (built after March/2020).

> The project promotes the set-up of at least six new renewable sources facilities with storage systems in the area, transforming companies and citizens into prosumers. In particular, the following was planned for 2020/2021: (i) 200 kW PV plant for the CAAB/FICO agro-industrial centre with storage and e-vehicle recharge

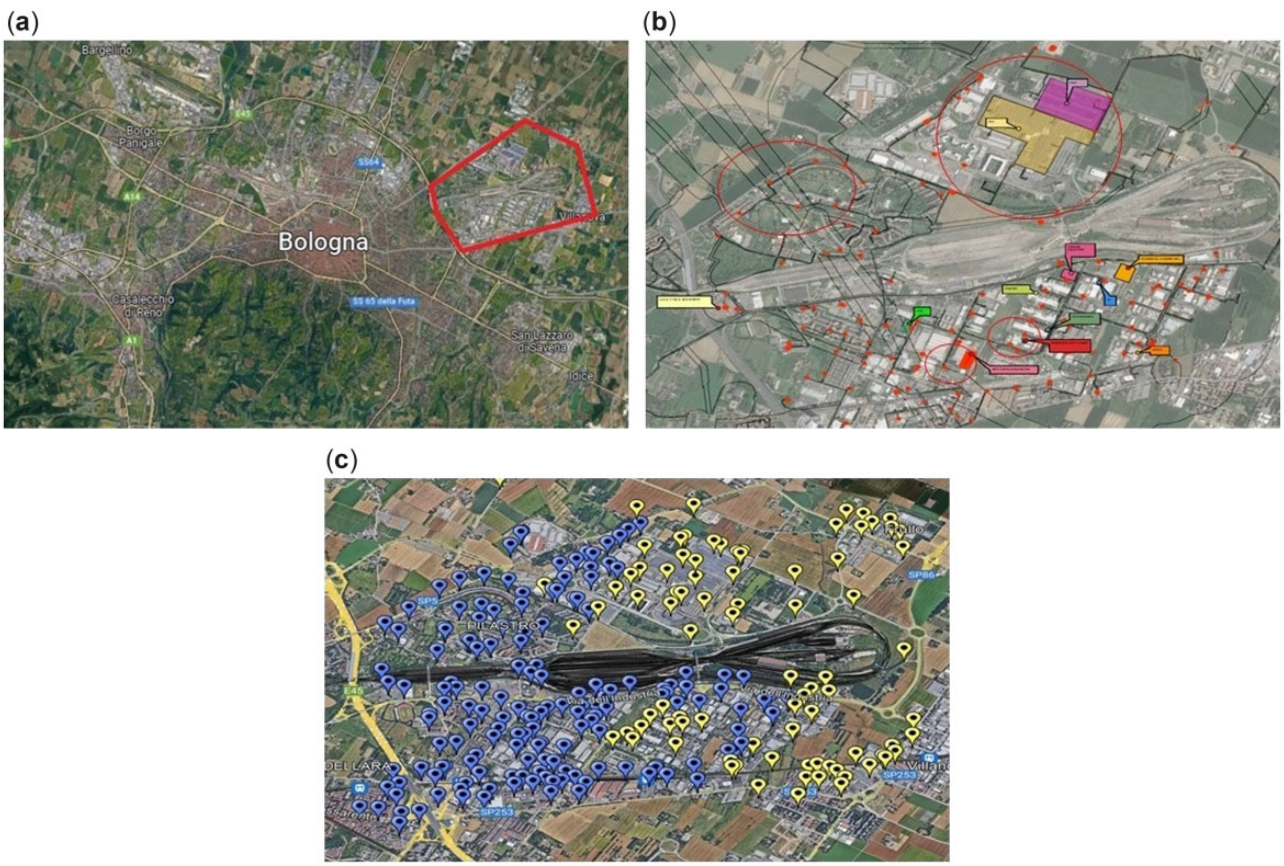

Figure 1: Spatial views of the GECO project in the town of Bologna, Italy (Google Maps accessed on 10/06/2020. (a) the perimeter of the GECO area. (b) the GECO area with the initial assessment regarding MV/LV transformation feeders (in red) and local actors involved in the project and clusters selected in January 2020 and (c) the GECO area with the actual assessment of all MV/LV transformation feeders in the area, divided by the connection to the primary substation (yellow and purple).

columns to be built in the parking area and a 20 kW (electric) and 30 kW (thermal) biogas plant for the disposal of organic waste; (ii) a 100-kW PV system serving several social housing buildings; (iii) 200 kW PV for the Pilastro shopping centre and neighbouring apartment buildings; (iv) two more PV plants of 200 kW each on the roofs of the companies of the Roveri Zone. Table 1 presents a synthetic summary of all feasibility studies developed to date within the GECO project, aggregated by sector.

The background of the GECO project, as well as any other interdisciplinary approach to the creation of sustainable urban communities, can be identified by putting together several seemingly separate but intimately connected research strands developed in different areas and yet use quite similar and largely compatible toolkits and languages to examine the very same issue. The parallel long-standing debates about corporate social responsibility (Alexander and Buchholz 1978; Kitzmueller and Shimshack 2012) and consumer environmental awareness (Kotchen 2006; Garcia-Gallego and Georgantzís 2009) both range across several areas; the Porter hypothesis, which refers to the introduction of appropriate environmental regulation triggering a win-win solution delivering an increase in firms' profits alongside with the adoption of green technologies and RE sources (Ambec *et al.* 2013; Lambertini 2017); and prosumer markets, neglected in economics while being intensively studied in engineering (Parag and Sovacool 2016; Gensollen *et al.* 2018), are obvious and not isolated examples.

The research activity relevant to the GECO project is based on the following considerations:

1. The ECs schemes introduced by the CEP can be a relevant instrument to fulfil the SDGs of Agenda 2030 in Europe.
2. The energy sector in Italy is very complex and closed, having barriers that can discourage the entry of citizens and small players in the energy market, preventing the achievement of SDGs 7, 11, 12 and 13.
3. The broad participation of citizens in the energy markets is necessary to speed up and implement a fair energy transition to a sustainable and low-carbon electricity grid, promoting the achievement of SDGs 7, 11, 12 and 13.
4. Improvements in citizen and business behaviours may promote the implementation of goals 7, 11, 12 and 13 of Agenda 2030.

The following sections outline the connections between the fundamental features of ECs and the targets described in the definitions of the SDGs 7, 11, 12 and 13.

Links with SDG 7 affordable and clean energy

SDG 7 sets as its main targets: (i) ensuring universal access to affordable, reliable and modern energy services, (ii) increasing substantially the share of RE in the global energy mix and (iii) doubling the global rate of improvement in energy efficiency (UN 2020). Regarding SDG 7, the UN also explicitly states that 'Sustainable energy is an opportunity—it transforms lives, economies and the planet' (UN 2020). Moreover, SDG 7 is directly related to the interplay between energy poverty and the environment, these being complex themes lively debated in recent times (Pereira, Freitas, and Silva 2011; Price, Brazier, and Wang 2012; Sovacool 2012; Okushima 2017).

Table 1: Summary of all feasibility studies developed to date within the GECO project, aggregated by sector

	Installed capacity (kWp)	Energy produced (kWh)	Avoided GHGs emissions (tCO_{2e}/year)
Commercial sector	133.30	146 630	69.40
Residential sector	357.60	393 360	186.18
Industrial sector	302.00	617 200	292.12
Public sector	499.41	549 351	260.01
Total	1292.31	1 706 541	807.71

Energy poverty is considered to exist when it is impossible to fully satisfy the energy needs and thermal comfort for a decent standard of living and wellbeing or when the energy expenditure accounts for a significant part of the family income, traditionally more than 10% (see Boardman 2013). However, there are many other thresholds and metrics that are used to analyse and measure this (see González-Eguino 2015; Castaño-Rosa *et al.* 2019; Thomson *et al.* 2019; Sareen *et al.* 2020).

It is estimated that around 11% of the EU population are still unable to keep their home adequately warm in the winter season (EU 2020). This percentage remains stable, even with specific policies to alleviate energy poverty implemented in the last two decades (EU 2020). Moreover, the problems of thermal comfort in the summer period are increasing yearly, as a result of recurrent extreme heatwaves (see Thomson *et al.* 2019).

Della Valle (2019) and Thomson *et al.* (2019) also highlight that the problem of energy poverty is becoming more urgent in urban areas, especially in low-income neighbourhoods where it is not possible to cover energy costs and ensure adequate thermal comfort, especially in extreme weather events. It is therefore essential to implement strategies to combat energy poverty in such areas.

Measures to alleviate energy poverty need to be improved and a way to accomplish that would be to carry out more comprehensive retrofitting of public housing buildings, with the installation of RE generation systems, and allow such buildings to participate in aggregated schemes. ECs and CES schemes are important actions to achieve these goals, since they can help advance energy efficiency at the household level and fight energy poverty (cf. Akbar *et al.* 2014; Sardi *et al.* 2017; Kubli, Loock, and Wüstenhagen 2018).

ECs imply increasing citizens' participation, promoting changes in social behaviour and promoting alleviation of energy poverty and awareness regarding climate and environmental issues among their members.

Concerning the climate change issue, 'Take urgent action to combat climate change and its impacts' is the main objective of SDG 13. Climate change is a continuous and human-imperceptible modification process that, summed up during long periods, generates localised and tremendous climatic upheavals that simply destroy the environment. The number of hurricanes worldwide is one of the proofs of these results. One of the sources of climate change is energy production from non-renewable fossil fuels. Another source is the mobility system based on the use of private cars that consumes copious amounts of fossil fuels.

The establishment of ECs in localised geographical contexts may address this problem by:

- Increasing the awareness and attention to environmental issues across the population, in particular in the younger generation.
- Reducing the distance between sources of power and consumers by fostering the use of renewable sources completely consumed locally.

- Increasing the awareness, of citizens, of their role as energy consumers in a fragile environmental context.
- Introducing the concept of circular economy in citizens' everyday life as a possibility of behaving in a more environmental-friendly way.

Links with SDG 11 sustainable cities and communities

Currently, 55% of the world's population lives in cities. According to the UN-Habitat report (2016), this data is estimated to reach 62% by 2050. The consequences of this growth could affect the quality of the urban environment and citizens' well-being. SDG 11 introduces the sustainability challenge to make cities and human settlements inclusive, safe, resilient and sustainable. Two targets are strictly connected to ECs (https://sdgs.un.org/goals/goal11; accessed 5 August 2022):

- 11.3 By 2030, enhance inclusive and sustainable urbanization and capacity for participatory, integrated, and sustainable human settlement planning and management in all countries.
- 11.6 By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management.

The process of how these goals can be achieved provides a unique opportunity for increasing people's participation. A more bottom-up and transformative approach towards sustainable cities is needed. The process of EC development may offer an innovative framework that can facilitate engagement and strategic forms of citizen representation. This can contribute to increasing the capacity for participatory, integrated and sustainable human settlement planning and management. EC is largely based on a participatory process, and citizen engagement is crucial for the establishment of an EC. Moreover, the EC's primary purpose is to provide environmental, economic or social community benefits to its members. Therefore, the creation of ECs may favour the transformation of cities in a sustainable way (Howard and Wheeler 2015).

As stressed by Vaidya and Chatterji (2020), SDG 11 targets are interconnected to other SDGs, including SDG 13 which encourages urgent action to combat climate change and its impacts. According to UN Habitat (2016), the achievement of both 11.3 and 11.6 targets can contribute to SDG 13, particularly to 13.1 (Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries) and 13.3 (Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning). The EC can support a behavioural change towards a more sustainable lifestyle, especially in sustainable energy production and consumption.

Moreover, the creation of EC can also contribute to reaching the 13.2 target (Integrate climate change measures into national policies, strategies, and planning). Since the EC can favour the transition to RE, therefore EC can favour the achievement of local plans such as the Sustainable Energy Climate Action Plan or international agreements such as Europe's Covenant of Mayors for Climate and Energy.

The implementation and evolution of an EC on a specific territory requires the adoption and development of different technologies enabling data collection, evaluation and comparison. In the last few decades, the research and development of technologies headed towards:

- Large data collection and on-time analysis (big-data, data streaming, monitoring).
- House instrumentation (domotics) allows data collection in citizens' homes and, in some cases, can manage different appliances to reduce costs.
- The introduction of large mass instruments, such as cheap computers and smartphones, simplifies the interaction with single persons and, at the same time, with large communities.
- Evolution and mass adoption of communication technologies, as community enablers such as Facebook, WhatsApp, and similar solutions, enable the creation and interaction in small, medium and large communities in a simple and efficient way.

On the other side, the overwhelming adoption of these technologies creates diffidence and doubts on citizens, in particular those who are not particularly open to technologies, and/or want to preserve their privacy and way of life. Despite these contrasts, technologies are the basis for increasing awareness of energy management, improving the quality of energy consumption, and, in the end, the increase of the quality of life while at the same time reducing the impact on the environment.

Awareness of large parts of a population leads to the achievement of new goals that may be unreachable otherwise: if every single flat in a district of a large city improves the quality of energy consumption by a little the impact on the whole system becomes relevant and very positive. Following the paradigm that awareness is improved by knowledge and implies the capacity of making choices, in the context of EC, improving citizens' awareness through communication and data management technologies leads to a large improvement of the quality of life in cities. In parallel, regarding the functions that an ICT support must offer to an EC, five potential domains of activity supporting an EC were identified (Table 2).

Today the availability of such data is subject to a rapid evolution, for example with legislation that goes in the direction of making citizens aware and really owner of data generated by their activities. Nevertheless, the lack of such data is frequent for third-party applications and the lack of an agreed semantic framework for interoperability makes data collection a complicated exercise.

Links with SDG 12 responsible consumption and production

SDG 12 is aimed at ensuring sustainable consumption and production patterns. Responsible consumption and production are other targets of the EC paradigm. They are key factors that enable achieving SDG 12 goals. ISO states that reducing our environmental impact, promoting the use of renewable sources of energy and encouraging responsible purchasing decisions are just some of the ways ISO standards contribute to sustainable consumption and production. Metering devices and dedicated apps will help to achieve SDG 12 targets.

Attaining SDG 12 requires (i) transparent information disclosure by Companies through timely and detailed sustainable reporting about environmental impacts and the reduction of inefficient fossil-fuel subsidies; (ii) increasing citizens' awareness about their role and the advantages that this awareness produces; and (iii) local administrations' active involvement through sustainable public. In turn, such a goal, if accomplished, will necessarily contribute to the achievement of SDG 13 (Climate Action), in view of the reduction of unnecessary use of energy. Further, advanced models capable of optimized day-ahead and intra-day scheduling of RES and storage resources among

Table 2: Domains of action for an Energy Community (EC), expected potential impact, data availability present or potential within short time scale investments

Domain of action	Expected impact	Data availability
1. Development of consumer awareness and promotion of virtuous behaviour	High	Potentially good
2. Collective counterparty to suppliers ('4.0 purchasing group')	Average	Poor
3. Promotion of local investments	High	Good
4. Interlocution with local government bodies (municipality…)	Poor	Poor
5. Promotion and activation of events, community services and creation of a collaborative atmosphere	High	Potentially average

prosumers forming the EC (which in general have the main target of minimizing the energy procurement cost of the LEC) may help in this respect as well, as they can be suitably adapted to implement demand control just to accomplish SDG 12. The widespread use of RES, which necessarily call for the increasing deployment of distributed storage units, can be considered the main enabler for the achievement of SDG 13.

Specific characteristics of the GECO projects and emerging results

Fulfilling the goals of SDGs 7 and 11 will require resilient infrastructure, sustainable industrialization and a faster innovation pace (SDG 9). It will also require sustainable consumption and production patterns (SDG 12) and of course all of this belongs to the wide area of SDG 13, promoting virtually any action which may contribute to mitigate climate change and its consequences in the long run. An example of those interactions can be seen in the carbon pricing theme, as it will reduce the consumption of fossil fuel, going toward the targets of SDG 13, but at the same time, it will also make energy more expensive, exacerbating energy poverty situations, being counterproductive in relation to SDG 7.

The holistic nature of GECO project might provide a rigorous and systematic effort towards (i) delivering a unified view of these debates, in order to (ii) offering a full-fledged instrument to be applied in the field. As such, the GECO project would also represent a concrete and clear-cut example of climate decision making involving civil, institutional, industrial and academic textures (on the related debate in the field of decision science, see Orlove *et al.* 2020).

In particular, the area of implementation of the GECO project is related to SDG 7. Pilastro district has 18.7% of the residents living in social housing, corresponding to around 1400 inhabitants (GECO 2019b), which are a priority target of the project actions.

GECO project aims at reducing energy poverty by promoting ECs' establishment. This efficient scenario (envisaging a win-win outcome) could be achieved by increasing the efficiency of the electrical system and producing energy locally, while alleviating energy poverty and reducing sector charges (with financial support to energy bills), giving access to low-impact RE technology.

The implementation of ECs and other CES imply a strong engagement of citizens and civil society and are fundamental to the success of such endeavours, complex to manage, time-consuming and capital-intensive ones, yet fundamental to build pathways of transition to a low carbon society.

Since the early stages of GECO project, an engagement process was stimulated. Starting citizens' engagement from the early stage is crucial for assuring a critical mass to the community at runtime. In particular, the GECO engagement process has regarded local stakeholders, such as companies, local associations and citizens initiatives and organizations. A first result was the realization of relevant stakeholders' analysis and map. This was a useful instrument to identify relevant stakeholders who can contribute to the GECO project's objectives.

All these concepts were presented in thematic webinars helping to build EC culture. GECO project organized co-creation meetings aimed at designing educational tools and materials on EC concepts for schools.

Empowering citizens with knowledge and data is one of the main goals of the GECO project: at the moment, data are partially available to people and have little use due to several factors. Some of these can be resumed as follows:

- The image shows consumption at a specific moment, without any other information, concerning, for example, the appliance that is originating this consumption.
- Comparison with other consumers is not allowed: any benchmarking with neighbours is not allowed.
- Deep analysis and economic improvement of energy consumption require the expertise of an energy manager or an equivalent professional that, by now, is unavailable for single citizens.

In GECO, the main idea is to support citizens in the process of understanding their energy consumption and individuating the source of costs that can be monitored and controlled, providing them with the capability of reading the consumption graphic and understanding which information is stored in it.

On the other side, because the candidate revenue source for the community is energy production, flux optimization and the reduction of consumption, the energy manager will be involved in the analysis of the profiles identifying weakness and possible improvements.

Citizens' involvement is crucial for the success of GECO. Providing good quality information to people and keep their interest high is one of the most important challenges. The basis of this process is the data collection from participants' houses, the data reconciliation process from different sources and the successive analysis. For this reason, GECO is dealing with different data sources and data types coming from different sensors and systems:

- Two different systems are being tested to collect and elaborate data from the electric meter.
- The *Smart-home* solution will be installed in several houses. This solution enables users to get data directly from the plug and other electrical appliances as air conditioner or dishwasher.
- A specific agreement with the electricity distributor shall enable the project to receive data from medium to low cabins in the GECO area.
- Other possible solutions are related to identify as much as possible enabling sensors of solutions that guarantee a high degree of quality of data and a reasonable response time to request from the other systems.

Additionally, a dynamic system for characterizing and tagging data files is under construction to automatically extract relevant data from these files and calculate KPIs.

Finally, KPIs are at disposal of the community manager, for example through a graphical representation of them, that can monitor the evolution of the community and decide upon the improvements.

Data on production and consumption represent the most relevant part of the data collection in an EC and, in most of the cases, the source of value of the community itself. In fact, data will be stored into secure systems and, for the part of these data that generate revenues and value, partially stored into tools based on blockchain. In this way, GECO solution can guarantee the safety, security and transparency of data for both internal uses, e.g. the participants of the community, and external entities as Municipalities.

Moreover, the implementation of GECO community has also other two main objectives, namely: (i) propose an Advanced Metering Infrastructure (AMI) that could be implemented within the GECO project to monitor and therefore manage the electricity consumption/generation of the community, and; (ii) introduce and assess the different optimization and management tools already developed and available to be implemented in the GECO community, with focus on their main characteristics, advantages and limitations.

AMI has been accomplished, with particular attention to its components and the main characteristics of each one of those. Emphasis was given to the communication architecture and the communication technologies, since it has been recognized that communication constitutes one of the most vulnerable nodes in an AMI. In-depth analysis of monitoring devices for the electricity consumption/production was realized, focused on the devices already installed in Italy, hence in the Roveri—Pilastro district, and those available in the market. Also, in this case, careful attention has been given to the communication technologies employed by the different devices.

The implementation of local ECs is linked with different aspects, namely

- Planning decisions for both users and distribution system operator (i.e. the utility). In the choice of the size of generation (e.g. solar panels) and storage units, final users are expected to take into consideration not only their own consumption requirements (as today) but also the expected possibility to sell power directly to the neighbourhoods at a price larger than that recognized by the utility. So, the implementation of local ECs is expected to provide an incentive to the further development of the use of renewable distributed generation and storage units. In the planning of network reinforcement, the utility needs to consider the presence of a local EC connected that is expected to reduce the power flows by improving the balance between production and consumption.
- Scheduling, i.e. decisions on the set of units to be in operation for each time slot of the day and the level of production/consumption by dispatchable generation, controllable loads and storage units. Due to the expected presence of storage and PV units, scheduling decisions are divided in two types: day ahead operational planning, which considers the daily cycle of load consumption and PV production by using the load and irradiance forecast for the next day; intraday scheduling that updates the decisions of the day-ahead planning in order to use more refined short-term scheduling information and contingencies. Example of distributed optimization strategies, which allow the automatic definition of the internal transaction prices, and of the coordination between day-ahead and intraday decisions are described in Lilla *et al.* (2020), Pulazza *et al.* (2021) and Orozco *et al.* (2022).
- On-line automatic control of the energy resources of the EC.
- Settling activities for the definition of the payments for each participant of the EC based on the definition of the energy prices of the internal transactions between the prosumers and the network charges for the use of the utility infrastructure.
- Services to the network. Indeed, the EC appears the ideal framework for the implementation of several control schemes that, although already developed from the technological point of view, are difficult to be widely implemented in the traditional framework, such as demand response to price signals, improved reliability measures for critical loads, autonomous operation of part of the grid as a microgrid, participation to the electricity markets for the provision of ancillary services to the grid as a virtual power plant.

Conclusions

The GECO project has delivered several positive indications concerning the concrete possibility of driving two districts of a medium-size European city along a sustainable path through the construction of ECs by achieving the objective of aligning the private incentives of firms and citizens with public ones. As a complementary result, it has also shed light on the operational aspects of the SDGs appearing in the Agenda 2030.

To facilitate the transition to a low carbon society and the construction of a sustainable future, the electricity sector must guarantee a safe supply of modern decarbonized electricity. This will eradicate energy poverty and assist in achieving the full implementation of the SDGs of Agenda 2030, especially goals 7 (Affordable and Clean Energy), 11 (Sustainable Cities and Communities), 12 (Sustainable Consumption and Production) and 13 (Climate Action). In this regard, the creation of ECs and CES can be extremely effective in combating energy poverty by strengthening social and community cohesion in the governance and implementation of RE generation systems that meet local needs, without counterproductive feedbacks on other SDGs. In fact, ECs and CES not only provide competitive energy prices generated from RE, but also help to build trust between different stakeholders, alleviate conflicts and promote investment returns for partners and shareholders, developing cooperation among actors and providing value added to the local economy, thus contributing directly to SGDs 1, 8, 9 and 10.

The GECO project moves in different directions fostering the process of SDGs targets achievement by: (i) supporting people in understanding their consumption profile and comparing it with neighbours to create reciprocal stimuli; (ii) providing economic and managerial models capable to suggest a better community's behaviour for an optimisation of sources and resources; and (iii) creating an environmental culture through the support of experts on communication and teaching.

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Data availability

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