Enhance Urban Energy Management and Decarbonization Through an EC-based Approach

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***Abstract*—Promoting energy efficiency and decarbonization in urban settings, hence also in the variety of buildings within them, is amongst modern society major challenges. Urban settings are, in fact, responsible for almost 40% of energy consumption and energy-related pollutant emissions worldwide. In this framework, particular emphasis has been given by the EU and its member States on improving the energy performance of built environments by reducing buildings' energy consumption (retrofit interventions), by fostering the integration of renewable energy sources (RES), and by encouraging the establishment of pro-con-sumer groups/units (e.g., Energy Communities – ECs, consortia, etc.). These latter include users that share and collaborate in the energy management. Consequently, the need has arisen for more efficient energy management within individual ECs and between different ECs and public administrations and other potential stakeholders. Considering that ECs are a relatively recent reality, this paper discusses possible approaches to overcome some of the critical issues that have emerged from the Energy Community initiatives that are beginning to emerge recently.**

Keywords— Energy Efficiency, Energy Community, Positive Energy District, Nearly Zero Energy District, Urban Energy Efficiency, Urban Decarbonization, Smart Cities

I. INTRODUCTION

Optimizing energy management in urban contexts has been one of the biggest challenges of the last decades for both the scientific community and international governments that seek to pursue carbon neutrality to enhance energy security and promote energy equity and accessibility. This is even more evident considering the recent events that have led to the intensification of the energy crisis, in terms of resource availability and of economic and environmental aspects.

According to the latest available reports, in fact, urban environments are responsible for 25%-40% of the overall energy use, corresponding to 17.5%-39% of the total energy-use-related carbon emissions, at global, European and Italian levels [1; 2; 3]. Adding to this, urban transport accounts for a share comprised between 20% and 30% of the energy consumption (which result in 10-20% of human activity-related CO_2 emissions) [4, 5, 6]. It should also be considered that urban areas are subjected to a continuous urbanization process (due to both demographic variations and migratory flows) that requires a constant supply of energy (hence causing significant pollutant emissions) [3, 7]. Such conditions call for a frequent reorganization of services and strategies to provide users with adequate levels of integration in terms of energy equity and accessibility. Moreover, the on-going energy-economic crisis (increased by the Ukraine-Russia conflict) has highlighted even more the need for a more efficient urban energy metabolism aimed at enhancing energy security, as also encouraged by the EU [8, 9].

To address these needs, the issues concerning urban energy efficiency and carbon neutrality, are increasingly integrated in global, European and national policies and regulations that aim at supporting climate change mitigation and adaptation strategies for a clean and sustainable energy transition. Some of the most relevant policies/initiatives concerning this subject include the UN Sustainable Development Goals – SDGs (particularly, "Goal 11 – Make cities and human settlements inclusive, safe, resilient and sustainable" and "Goal 12 – Responsible consumption and production") [10], the EU climate-energy frameworks long-term strategies [8, 11], Green Deal [12] and recovery plan Next Generation EU [9] (transposed nationally by almost all developed countries, such as the recently issued Italian Recovery Plan – PNRR [13]).

In particular, among the EU measures targeting the built environment, the well-known concept of nearly zero-energy (NZE) buildings [14, 15] (introduced by the EPBD Directive [16]), according to which buildings need to be (and/or aspire to be) self-energy-sufficient, has recently expanded to that of Positive Energy Building (PEB) [17, 18]. This measure foresees that buildings can use renewable energy sources (RES) to generate more energy than their needs and then exchange the surplus, thus, leading to Positive Energy District (PED) [19, 20, 21], in analogy with what was proposed by a recent Directive introducing the concept of renewable Energy Communities (EC) [11] and their interaction/integration with the local/national electricity systems.

Within this context, although historically particular attention has been paid on improving the energy-environmental performance of mostly single buildings by means of sustainable technical solutions [22, 23, 24] (and suitable ways of produce [25], implement [26, 27] and dispose [28, 29, 30] of them), more recently some studies

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have shown how moving to a broader vision (i.e., small clustered group of buildings) [31, 32] by integrating the use of renewable resources [33, 34, 35] and by also considering economic benefits [36, 37, 38] and most importantly users' needs [39, 40, 41] can have a significant energy-environmental impact on urban areas [42, 43]. As a matter of fact, as claimed by the Urban Climate Change Research Network (UCCRN) [44], human activities/behaviors are changing urban metabolism in a way that increase energy, environmental and economic related risks. On this last aspect, in fact, according to EU Horizon Built4People project [45] it is crucial to accelerate users-centric innovation in urban contexts to drive the transition towards a more just, sustainable and decarbonized society and economy (i.e., induce lasting behavioral changes towards sustainable living). In this regard, the use of innovative strategies such as those based on the blockchain technology [46, 47], have been increasingly gaining popularity due to their attitude in ensuring trust and transparency for the users.

Consequently, the need has arisen for more efficient energy management not only within individual ECs, but also between different ECs and public administrations and/or other potential stakeholders, to increase local territories' sustainability and resilience to stress/shock conditions, such as indeed those related to energy crises and climate change. Therefore, starting from the above reported observations, and considering that ECs are a relatively recent reality, this article proposes possible approaches to overcome some of the critical issues that have arisen from the EC initiatives that have appeared so far.

II. Current Critical Issues and Possible Alternatives for Improvement

A. *State of the Art and Critical Issues*

Although there is yet no unified approach for their development [48] a number of insights can be extracted when looking at ECs' realization in Europe.

In fact, case studies with information on smaller or bigger Energy Districts (EDs)/Energy Communities (ECs)' initiatives can be found at the 'Europe wide inventory', created for the EU funded project "COMETS" [49]. The inventory includes over 10,000 initiatives and 16,000 production units in 29 countries and is available at *dataverse.no*. The aim of the project was to capture the nature and scope of the actions, thus including all activities that are "led by citizens, strive for economic, social and environmental benefit, and participate in energy transition activities". Information such as administrative data of energy related activities, profiling data, tangible assets, singular activities undertaken by the initiatives and time-tagged information, with yearly resolution. Other similar exercises have allowed for a collection of information on ECs in Scotland [50], in Germany [51], in Canada and New Zealand [52], among others.

The success factors of these cases sometimes refer to the governance model they follow [53, 54], to the community's cultural, territorial, and social profiles [56], the ability for connections and networking among stakeholders, the proximity [57], people engagement and participation and funding schemes [58]. From the several case studies, it has also emerged that Energy Districts (EDs)/Energy Communities (ECs) are typically established by geographic/territorial extent.

This circumstance can bring some critical issues mainly due to the following aspects: (i) spatial boundaries (neighborhoods, districts, wards) usually do not coincide with the electricity and/or road network layers/grids (and/or those covering other types of services); (ii) users/consumers within neighborhoods/districts/circumscriptions are diverse (residential, commercial, service, industrial, etc.) so different energy use profiles result; (iii) contextual factors that affect urban energy performance, such as state of built environment (age and state of conservation), environmental and technological elements, may vary widely within the same neighborhoods/districts/circumscriptions; (iiii) lack of awareness and knowledge development at the local level (v). Last but not least, management strategies that do not empower local actors, or that not seek to establish collaborative models of co governance might be an obstacle in their realization [59].

B. *EC-based Approaches for Energy and Environmental Enhancement of Urban Settings*

Based on the above-depicted scenario, it is evident how ECs represent a relatively recent reality on which significant improvements can and should be made, especially concerning their management aimed at enhancing urban energy and environmental performances. This section attempts to provide an initial contribution to this matter by proposing some ideas for discussions on possible alternative approaches to overcome some of the critical issues that have emerged from the Energy Community initiatives that are beginning to appear recently.

Fig. 1 shows a schematization of possible urban energy interconnections among ECs, public administrations and stakeholders. As can be seen there can be interconnections on various levels and of different kinds, both in terms of the types of ECs involved and with respect to the nature of information exchanged. Starting from these hypotheses, in the following a few ideas will be presented.

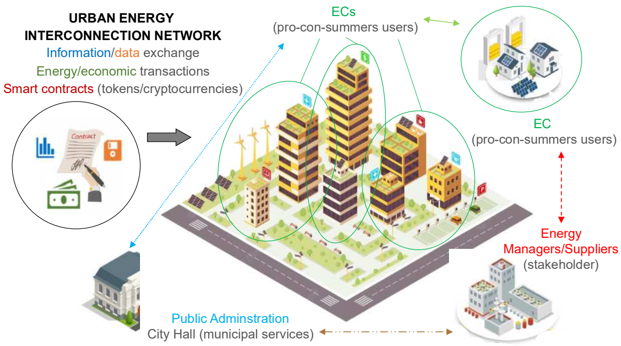

Fig. 1. Schematization of the urban energy interconnection among ECs, public administrations and stakeholders.

A first consideration concerns the physical constitution of the ECs. In this regard, to optimize energy resources at the urban level (and contribute to their decarbonization), it might be more convenient to establish ECs in a spatially dispersed manner rather than according to geographic proximity. This could be done according to different alternatives depending on the specific purpose to be pursued. As a first possibility, ECs could be identified by affinity of energy use sector (residential, commercial, service, industrial, etc.), to determine energy efficiency strategies more appropriately. In fact, in this case, once the types of urban energy users have been identified, ECs could be classified for each type of user to identify the optimal combination of interventions that allows for improved urban energy management and environmental performance. As an alternative, ECs could be individuated by complementarity of energy resource use by sector (residential, commercial, service, industrial, etc.) to normalize (flatten) energy use profiles at urban level (i.e., improve the Peaks to Average Ratios – PAR of power loads). In this case, energy flows could be managed based on the exchange of energy usage information within and among ECs.

A second concern regards the choice of appropriate efficiency measures to be implemented. To this purpose and prior to the deployment of pilot case studies, the use of a modeling/simulation-based approach involving the evaluation of diverse scenarios and/or combinations of energy efficiency measures (e.g., different proportions of retrofit interventions and RES integration) aimed at identifying which are the most effective strategies to implement within different types ECs, could be a convenient way to proceed, in order to rationalize the economic resources at hand.

Another not negligible aspect to consider is represented by the development of a smart system for a flexible management of the energy interconnections between different ECs and amongst such ECs, public administrations (e.g., municipalities) and other potential stakeholders (e.g., energy manager/suppliers) based on ECs energy profiles. To enable ECs users/participants to produce, store, convert and redistribute/transport (not just consume) energy, while at the same time have privacy guaranteed, a smart blockchain system could be used for the exchange of information/data on the energy use habits.

Last but not least, efforts for raising awareness in the energy transition sector might engage, empower and assist people in building trust, participation and allowing thus a more smooth transition to ECs.

III. Discussions

The ongoing energy transition path, urged by global European and local ambitious targets, call for smart, sustainable and innovative ways to enhance urban energy and environmental management to improve cities resilience to the challenges posed by growing urbanization, climate change and energy crisis. In this aim ECs undoubtedly represent a key instrument due to their significant influence on urban energy patterns, being involved in a variety of different services (e.g., private mobility, public transportation, infrastructures functioning, water and waste management, RES, etc.).

Obviously, given the complexity of the topic, a multidisciplinary approach would be desirable. Assessment methodologies, good practices, planning strategies and pioneering approaches in smart ECs (and overall urban settings) should, in fact, be able to enhance not only the energy and environmental related aspects, but also the economy and social wellbeing of the involved parties. However, as mentioned in the previous section, the EC-based approaches here discussed are intended as a contribution to the fostering of innovative ways to re-think EC operation, mainly related to the energy and environmental enhancement of urban settings.

The proposed concept of flexibility in the identification of ECs, that is energy use complementarity (geographically concentrated communities) and/or energy use affinity (geographically dispersed communities), coupled with that of using ad hoc dynamic simulation tools to compare such different scenarios and single out suitable energy efficiency strategies, can be crucial to promote decision-making processes on urban resilience and sustainable development that are based on actual contexts (in terms of specific energy needs) and not just on general guidelines provided by the current regulations.

In both cases, energy use complementarity and/or affinity, the financial resources saved/earned through electricity savings and/or generation from RES could be used to finance further energy improvements to achieve a PED status or (at least) an energy self-sufficient condition of the EC, thus strengthening even more urban energy optimization and decarbonization (i.e., initiating a virtuous cycle).

With regard to an easier management/control/supervision of ECs, these could be assimilated to condominiums (or nonprofit organizations), whose energy operation/interconnection could be managed through a smart communication system between ECs, public administrations and other stakeholders (such as, energy managers and suppliers), based on a reward system (e.g., provision of services and/or economic incentives) that encourages them to implement strategies and maintain (over time) better habits in terms of energy sustainability.

EC participants, which represent a predominant component of the energy-environmental performance of urban settings, could be indeed prompted to exchange information and follow suggestions on best practices not only thanks to the achievable energy bill savings but also through earning tokens that they can spend on municipal environmentally sustainable services (e.g., electric transportation) aimed at decarbonizing urban contexts, similar to what some municipalities are already doing to increase recycling collection rates for waste.

Concerning ECs users/participants energy-related behavioral data the proposition of using a blockchain-based system is based on the assumption of wanting to ensure privacy and transparency for the users (information would be encrypted and then exchanged), so as to more easily facilitate their participation. Such involvement is, in fact, a key aspect to assess ECs energy profiles and attempt to plan and redistribute energy loads within and among them over time based on users/participants actual needs, in order to regulate and optimize ECs energy operations.

Last but not least, the discussed EC-based approaches also have as their objective that of supporting local administrations, decision-makers and any other interested stakeholder in enacting a better distribution of the available energy and economic resources. In particular, inequalities between more or less virtuous ECs should and could be avoided by assigning such resources proportionally and/or differentially according to actual needs.

IV. Conclusions

According to the ambitious goals on urban energy efficiency and decarbonization set out by the current legislation, in this brief paper some considerations were set out about possible alternative EC strategies to try apport a contribution in overcoming some critical aspects emerged so far. Certainly, the presented subject is certainly very broad and complex, so the purpose here was that to simply give an initial discussion point, which will be then deepened and integrated appropriately as future research development by the authors.

From a broader perspective, ideas for debate such as the one here discussed could help to develop strategies aimed at promoting urban energy management and decarbonization with an EC-type approach based not necessarily on geographic extent, but possibly also on the energy needs that characterize the territories involved, and at the same time encouraging the active participation of users, in line with the latest global and European indications. This would indeed represent a great opportunity for local administrators and stakeholders, enabling them to more effectively distribute their economic resources to foster energy equity and accessibility.

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