Foster carbon-neutrality in the built environment: a Blockchain-based approach for the energy interaction among buildings

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***Abstract*— Decarbonizing urban environments and reducing their energy consumption is one of modern society biggest commitments. In this regard, both the scientific community and international governments have been giving special consideration on improving the energy-environmental performance of mostly single buildings; recently the focus has been shifting towards a broader Positive Energy District (PED)/ Energy Community (EC) vision, from small clustered group of buildings to neighborhoods up until urban settlements. In this respect, integrating the use of renewable energy resources (RES) and actively involving building users can have a significant environmental impact on local areas. Within this framework, this work discusses the possibility of employing an innovative blockchain-based approach for the energy interaction among buildings. The blockchain technology can, in fact, be useful in managing such scenarios since it would allow to, not only consider buildings occupants behaviors, but also take into account concernings regarding the need for transparency, engagement, environmental and human health benefits, as well as the stakeholders role in the interaction/integration between PEDs/ECs and local/national electricity systems.**

Keywords—Blockchain, Positive Energy Districts, Energy Communities, Buildings, Energy Consumption Reduction, Carbon Emission Reduction.

I. Introduction

Foster carbon-neutrality in urban environments, and thus in the buildings that constitute them, is one of modern society biggest commitments. Recent reports show, in fact, that the building sector energy-use-related CO_2 emissions account for a shared comprised between 17.5% and 39% of the total carbon emissions at global, European and Italian levels [1; 2]. Since the building sector is responsible for 25%-40% of the overall energy use [3; 4; 5], it is well evident how reducing such consumption is of paramount importance for an energy resilient as well as environmental and economic sustainable society as put in evidence, not only by the climate-change scenario, but also by the recent pandemic and war related energy-economic crises [6]. On purpose, in light of recent events, improving the urban energy performance would contribute to strengthen the country energy security (reduced dependency on foreign energy supply), as also encouraged by the EU [7; 8].

In this regard, the aspects of climate and carbon neutrality have been increasingly integrated by global, European and national policies and regulations. Initiatives such as the UN Sustainable Development Goals – SDGs (particularly, "Goal 11 – Make cities and human settlements inclusive, safe, resilient and sustainable", "Goal 12 – Responsible consumption and production" and "Goal 13 – Climate action") [9] or the EU climate-energy frameworks long-term strategies [7; 10], Climate Target Plan [11], and the more recent Green Deal [12] and Recovery Plan Next-Generation EU [13] are now well-established realities transposed nationally by almost all developed countries.

Among the EU measures aimed specifically at buildings, the well-known concept of nearly zero-energy (NZE) buildings [14; 15], according to which new buildings have to be self-energy-sufficient, has recently expanded to that of Positive Energy Building (PEB) [16] which predicts that a building can use renewable energy sources (RES) to generate more energy than it needs and then exchange the surplus, thus subsequently reasoning in terms of Positive Energy District (PED) [17], in analogy with what was proposed by a recent Directive introducing the concept of renewable Energy Communities (EC) [18] and their interaction/integration with the local/national electricity systems.

Therefore, a more decarbonized self-sufficient energy urban metabolism could be achieved by implementing solutions aimed at help reducing consumption and increase energy efficiency rather than focusing exclusively on the production from RES [19; 20].

Within this context, although particular attention has been paid on improving the energy-environmental performance of mostly single buildings [21; 22] by means of technical solutions, some studies have more recently shown how moving to a broader vision (i.e., small clustered group of buildings) [23; 24; 25] by integrating the use of renewable resources [20; 26] and by actively involving building users (enticing them to engage in more sustainable behaviors) [27;

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28] can have a significant environmental impact on local areas [29]. Moreover, the use of recent smart solutions, such as Blockchain, BestGrids, Internet of Things (IoT) and Smart Contracts (SC), have proven useful in managing such scenarios [30; 31; 32], allowing to also take into account stakeholders concernings regarding the need for transparency, engagement, environmental benefits, as well as impacts on human health.

In particular, the blockchain technology application in the energy and building sectors, and in urban environments, has been increasingly gaining importance in recent years, because it allows to ensure trust and transparency thanks to its intrinsic structure.

Investigations have been conducted on the role of blockchain services to exploit the role of citizens in the green energy transition, by increasing the flexibility of the overall energy system and bringing together local pro/con-sumers, alone or as energy communities, and energy market players, for the implementation of more sustainable and fair energy sharing/supply chains [33; 34]. It has also been demonstrated how, when Smart-Buildings communities are involved, a Blockchain-algorithm-based approach can help optimize a cooperative Demand Response (DR) energy framework to manage the daily energy exchanges within the community local RESs [35].

Blockchain-based smart solution for demand-side management of residential buildings to improve Peaks to Average Ratios (PAR) of power load on a neighborhood scale have been also tested, showing the potentiality of the blockchain approach not only in terms of reduced energy consumption, but also as a means to improve occupants thermal and visual comfort, as well as to reduce CO_2 emissions on urban scale [36; 37]. In this regard, with a view to addressing climate change, the application blockchain technology has also been explored, as a potential digital buildings energy performance (BEP) measurement, reporting, and verification (MRV) tool, in order to enter the carbon credit market and lower the building sector carbon footprint [38].

Current trends and future developments of the blockchain approach application to power systems, related especially to the energy market, have been the object of particular attention not only from the research communities but also from governments. In fact, due to its intrinsic structure based on a consensus and cryptographic mechanisms, blockchain technology is able to keeps record of the transactions in a network, which are immutably stored in distributed (Distributed Ledger Technology – DLT) nodes (i.e., network users/buildings) [39], thus allowing a more reliable and transparent functioning of the energy market, also relatable to measurable benefits [40]. That is why, although from a research standpoint the blockchain approach represents a promising and innovative application in the electrical energy sector, it also deserves proper attention in terms of governmental recommendations and regulations, aimed at "standardizing" its use [41].

Within this framework, this work discusses the possibility of employing an innovative blockchain-based approach for the energy interaction among buildings. The blockchain technology can, in fact, be useful in managing such scenarios since it would allow to, not only take into account buildings occupants behaviors (and incentivize them to adopt more sustainable ones), but also properly consider the need for transparency, engagement, environmental and human health benefits, as well as the stakeholders role in the interaction/integration between PEDs/ECs and local/national electricity systems.

II. A Blockchain-based Approach for the Energy Interaction among Buildings or Groups of Buildings

Blockchain was created to ensure greater security in monetary trading through decentralization of information (distributed ledgers), stability, security, and non-modifiability. Distributed ledger is like a cloud database distributed among the various nodes/users of the system (provides greater stability) that various users can access, usually by means of public and private keys (to ensure security and authenticity of information). The encrypted data are transferred between the various nodes, in which users verify the veracity of the transition (of the data) through special shared codes [38]. Swan divides blockchain applications into three levels: digital currency, smart contracts and DAO (Decentralized Autonomous Organization); DAO of an organization contains operational rules designed based on the blockchain approach, and then encoded in the form of smart contracts without the intervention of any centralization unit or third party [42].

In other words, the blockchain approach adopts the characteristics of a computer network of nodes and enables a registry containing data and information (e.g., transactions) to be managed and updated in an open, shared and distributed manner without the need for a central control and verification entity, in a unique and secure manner.

With the aim to push forward urban decarbonization by also including collective measures in the picture, this work suggests the use of the blockchain technology to incentivize building occupants [42] to adopt more sustainable behaviors, as these represent one of the most influential components in the environmental performance of buildings.

Blockchain can be used to incentivize people to perform a certain activity, or rather to be active with respect to the purpose of the community, in this case EC, and thus to pursue its goals. This could be done through incentives based on tokens or cryptocurrencies, which have a digital value and thus a proof of rights. If the community's operating rules are designed based on the blockchain approach, the authenticity and uniqueness of the token/cryptocurrency would be ensured through cryptographic algorithms and distributed ledgers, where transitions are made using a consensus algorithm [42].

In order to optimize a more sustainable energy production/consumption among all participants, the exchange of behavioral information (behaviour-data) among users (pro/con-sumers) in the EC using the blockchain approach is, therefore, here proposed. The use of a blockchain-based system would, in fact, help to overcome an obstacle to such collaboration (personal behavioral information exchanges) posed by privacy constraints, since this information would be encrypted and exchanged directly between users, instead of being stored on an external database (subject to possible cyber-attacks).

Figure 1 shows and example sketch of the proposed blockchain-based approach.

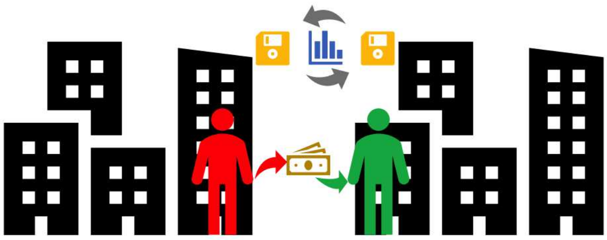

Fig. 1. Example sketch of the proposed blockchain-based approach for the users crypto-behavior-data and crypto-district-currency exchange among Energy Communities/PED.

The hypothesis advanced here is to identify city districts as PEDs and assimilate them into small islands constituting ECs that aspire to self-sustain energetically by producing energy locally, in order to approach carbon neutrality but also to improve the energy-environmental sustainability performance of the national energy system. In fact, involving small actors in the energy market, for a locally joint energy production and consumption, can contribute to improve the collective/national energy balance and flexibility.

To meet this purpose the blockchain technology represents, indeed, a smart solution for the demand-side management of buildings able to reduce their energy consumption (while still ensuring the occupants comfort) and improve the Peaks to Average Ratios (PAR) of power load in the community, by employing users behavioral data to plan and redistribute energy loads over time based on their actual needs, so as to flatten the power load diagram; hence also contributing to lower urban carbon emissions due to avoided energy loss on the power network.

In more detail, blockchain can help improve PAR because it enables the transmission of behavioral data among community users in an encrypted manner, making the information visible to each user in a form useful for pursuing the goal of shifting the on/off/use of equipment (electrical loads). Thanks to the blockchain approach, this can be done in a contracted manner, encouraging each user to change/improve their behavior according to the needs of the EC/PED either through a cryptocurrency gain/loss or through the visualization of the environmental impact that one behavior implies compared to another.

Cryptocurrency can therefore influence climate actions/strategies as a means of incentivizing users toward more virtuous sustainable behaviors aimed at fostering carbon neutrality in urban environments.

Therefore, the blockchain approach could be used for both behavioral data transmission and energy/environmental cryptocurrency transitions, usable, however, only at the local (city and/or at most regional) level, as it would be much more complex to go beyond that due to the large differences regarding the characteristics of electricity grids on a national scale.

In addition, the proposed blockchain-based approach could help make the current power grid smarter from the point of view of integration between generation (now increasingly distributed across the territory thanks to the use of RES) and energy use by end users, who become in effect prosumers in the grid. In this case, of course, Distribution System Operators (DSOs) would also come into play in order to optimize load flows in the grid, for example by installing appropriate storage systems.

In fact, the role of DSOs for energy dispatching/management within the EC/PED becomes crucial in fostering more virtuous behavior of the ECs/PEDs and smarter behavior of the power grid, making it possible to promote mutually agreed decisions on the behaviors among grid users (phase-shifted switching of various electric equipment).

III. Discussions

As reported in the previous section, the use of the proposed blockchain approach would actually result in three main benefits: (i) incentivizing more virtuous energy behavior of individual users based on a cryptocurrency-based system in order to improve the energy performance of the entire energy community (crypto-district-currency); (ii) protection of personal behavioral information for privacy reasons (crypto-behavior-data); (iii) use of behavioral data for energy planning (smart energy planning) of the energy community and thus to identify possible interventions to improve the performance of the associated PED.

Moreover, the use of a blockchain-based system would allow an automatic information exchange. Meaning that, after an initial settling-in phase (more or less long), the system is able to self-regulate by establishing schedules to be proposed/suggested to users to reduce energy peaks. Additionally, for a more effective energy-environment optimization, this process would be constantly updating based on the various behavioral changes implemented by the users.

In such a scenario, users are incentivized to follow suggestions/indications not only by bill savings but also in the blockchain system by earning cryptocurrencies that they can spend to purchase municipal services on the ground aimed at promoting environmental sustainability. For example, for retrofit/management/maintenance of city services and for utility services such as electric/sustainable transportation (car sharing, bike sharing, etc...). The most virtuous energy communities could go so far as to become energy self-sustaining, enhancing in this way the effectiveness of the EC to which the cluster of involved buildings may belong. Moreover, the level of awareness of participating people will be therefore improved. By way of illustration, in the case of car sharing service they might be able to produce enough energy to power the vehicles provided by the municipality/local government.

In this way, local administrations could better allocate their resources, assigning them proportionally and differentially among the more and/or less virtuous neighborhoods/communities, thus making sure to promote equity in their territories (allocating more resources to the most deprived neighborhoods/communities that are unable to be self-sustaining); hence, avoiding disparities between "rich" PEDs and "poor" PEDs.

From a broader planning perspective, in order to improve energy performance over large areas, aimed at promoting sustainability and carbon neutrality of urban environments, the blockchain approach could help make it easier to establish and regulate energy communities in general terms.

One could assume, for example, that in the case of PEDs of a certain size (in terms of consumption) these could be likened to energy purchasing consortia/ESCOs and make themselves independent in the energy market.

In this case, of course, authorizations/concessions/regulations from the governing bodies (local/regional/national/European) would be required in advance, as there is currently great variability among the various European and World contexts on these issues [43].

Of course, those just discussed are just a few of the many considerations that can be made regarding this topic.

IV. Conclusions

In this work, some considerations have been made about the potentiality of using an innovative blockchain-based approach to manage the energy interaction among buildings that constitute a EC/PED, and between these latter and the national power grid, in order to foster carbon-neutrality in urban environments.

Obviously, the question of the physical entity/extension of the EC/PED, and/or the group of buildings needs to be considered, even if this paper is not dealing with it; specifically, it often conflicts with the definition of both actual and virtual physical boundaries related to the electrical power grid, identifiable as different layers. In fact, the possible subdivisions within a physical/geographical layer almost never coincide with those of an electrical/energy layer. This circumstance therefore represents a critical issue, with respect to both the choice and planning/management of such energy communities, to be properly addressed as future research development in this field.

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