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Review

Energy Communities Overview: Managerial Policies, Economic Aspects, Technologies, and Models

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Abstract: Recently, there has been an ongoing global debate on the issues of energy safety, energy autonomy, and energy alleviation policies in developed and developing countries. The energy communities can integrate distributed energy resources, especially among local energy systems, playing a decisive role to support people around the world in the transition process towards sustainable development and renewable energy sources (RES). The main research dimensions of such a manifold approach are environmental sustainability, the reduction of greenhouse gases (GHGs) emission, the ordinal exploitation of RES, the social awareness in actions towards global consumerism in an environmentally caring manner, the increase of energy efficiency, and the pollution relief caused by the expansion of urban/built environment worldwide. This review study focused on the roles and the ways of how "energy communities" (ECs) could support contemporary energy management and priorities to ensure energy safety, autonomy, and alleviation, regionally and globally. In this context, a systematic, last-decade publications of ECs was conducted and the retrieved documents were organized in alignment with the following four groups of literature overview. Group 1 covered the dimensions of technology and environment, being coupled with Group 2, covering the dimensions of socio-culture and anthropocentricity (mainly focusing on the built environment). A similar coupling of Group 3 and Group 4 was made, where Group 3 covered the legislative dimension of ECs and Group 4 covered the ECs devoted to Europe–European Union (EU), respectively. The emerging key literature aspects, the proposed measures, and the applied energy policies on ECs were also conveyed and discussed.

Keywords: energy communities; enabling technologies; managerial policies; economic aspects; legislation; energy security; environmental sustainability; review

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1. Introduction

In recent years, with the accommodation and control of increasing renewable energy (RE), the power system has undergone a paradigm shift, leading to more Decentralized Energy Resources (DERs) in the grid. Consequently, Energy Communities (ECs) are a cooperative strategy of novel sharing RE DERs, in alignment with consumption minimization and flexible utilization of energy by active consumers to ease the high energy loads of the power grid (Weckesser et al. 2021). ECs are recognized by the EU and the Clean Energy package as a concrete spectrum of collective energy actions that foster citizens' participation across the energy systems. In this context, there are approximately 3500 ECs in the EU (in the reference year 2019) and in Denmark specifically, there are around 700 (in the reference year 2019) (Weckesser et al. 2021). The development of ECs is related to meeting specific social and/or environmental targets, where local communities are given the opportunity to share or exchange energy resources in a non-commercial manner (Weckesser et al. 2021).

An energy community initiative involves responsibilities and benefits sharing, being derived from energy production. Notwithstanding the recent regulations of EC projects that are recently conceptualized in remote mountainous and island areas, they actually existed before DER use became a common reality (Cielo et al. 2021).

At the European RED-II Directive, ECs support a legal tool enabling an open and voluntary participation of stakeholders, being autonomous and effectively controlled in the nearby areas of the renewable energy projects installed. These shareholders can be members or natural persons, small and medium enterprises (SMEs), or local public (municipality) authorities while the primary purpose of an EC is caring to offer environmental, economic, and social community benefits among those (shareholders) of local interest, where ECs are operative. Contrarily, the financial profits are not prioritized in Ecs. Subsequently, ECs play a decisive role for the achievement of decarbonization, the confrontation of energy poverty, and the realization of energy justice (Streimikiene et al. 2021) or, similarly but with a more political meaning, energy democracy (Cielo et al. 2021).

EC structures, being foreseen in the EU regulation, have recently been proven as legally credible and regulatory realistic among EU state members. Considering the novel rules on energy production and use as well as the contemporary economic incentives, the availability of technical and economic simulation tools is crucial to determine if the initiative is both competitive and advantageous in terms of cost–benefit. It is noteworthy that simulation can take into account different entities working together for the EC: the community itself and a technical partner taking care of installation and management; energy savings and reduction of greenhouse gas (GHGs) emissions that positively impact the environment; and positive economic returns and new working possibilities for the EC technical partners who are responsible for its maintenance and management (Cielo et al. 2021).

In a relevant study, it was shown that among energy communities there is a pronounced importance of power systems that they have been transitioning from systems based on traditional fossil fuel generators to those involving renewable energy (Jo et al. 2021). Indeed, RES in power systems are feasibly proven capable and desirable to tackle environmental problems caused by energy resources' utilization and generating designing and operation problems in power systems, such as that of the duck curve, and the increase in flexibility requirements (Jo et al. 2021). Resolving such problems requires system operators to operate thermal and hydro works as traditional bulk power generation resources. Nevertheless, such solution demands high investment costs due to the wide diversification of RES. Subsequently, in overcoming problems generated by traditional generators, there have been several research attempts to adopt RES technologies in both large-scale and small-scale levels. In particular, the key aspect of large-scale approaches is the appropriate management of the output of RES-fed power systems in the High Voltage (HV) mode. Moreover, an increase of the amount of curtailed renewable energy is forecasted due to the trend of RES widespread use (Jo et al. 2021).

Another terminology abided to ECs is that of renewable energy communities (RECs) which are particularly interesting as generation is moved to the edge of the power system, then, the Low Voltage (LV) grid can be stressed. In this energy route, the ongoing sharing of photovoltaic (PV) electricity generation could lead to voltage violations in LV grids, reforming the existing load profile with potential changes inducing reversed and varied power flows. In this context, the more active members rise proportionally, the risk of overloading increases especially among smart communities with peer-to-peer trading and high adaptation of PVs to energy grids and mitigation strategies are proposed (Weckesser et al. 2021).

A typical REC is functional under a peer-to-grid (P2G) energy sharing policy. Such an energy sharing policy for the natural gas network and distribution is illustrated at Figure 1.

Another energy community (EC)-based framework involves energy life cycle assessment (LCA)-based indicators based on fuzzy numbers as key determinants of sustainable energy performance. Such ECs enable decision-makers to reach a consensus while overcoming problematic issues such as human error, ambiguity, and uncertainties in calculations, Figure 2 (Kluczek and Gladysz 2022). These indicators are suitable for an effective assessment due to LCA appropriateness and robustness to meet Agenda 2030 goals, while simultaneously determining energy indicators and sustainability evaluation methods based on life cycles dedicated to the energy sector (Kluczek and Gladysz 2022).

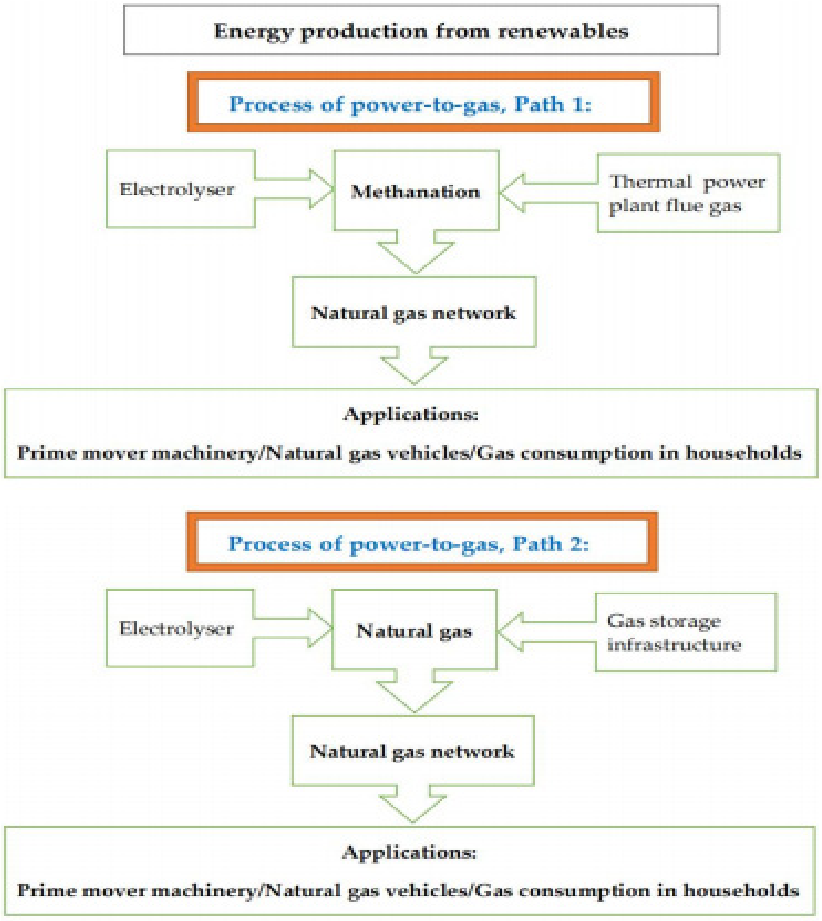

Figure 1. Procedural profile of the P2G process. Source: Liu et al. (2021).

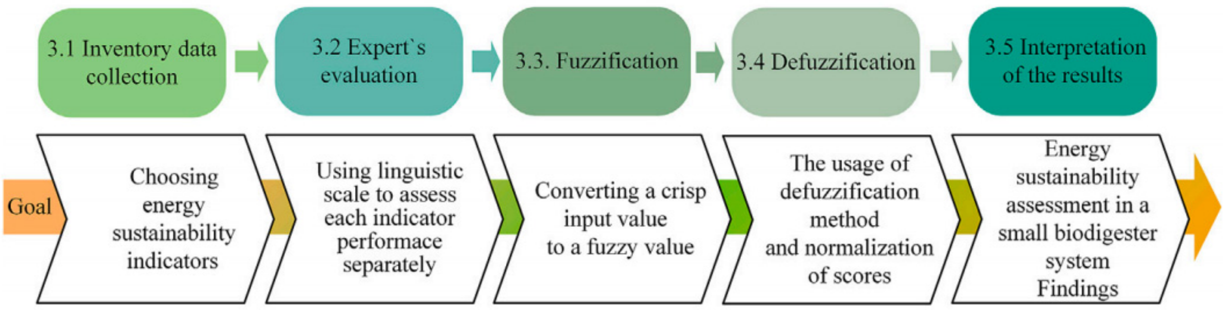

Figure 2. A schematic framework for energy sustainability (impact) assessment based on expert knowledge. Source: Kluczek and Gladysz (2022).

In Figure 2, a methodology for energy sustainability evaluation by incorporating fuzzy numbers is shown (Kluczek and Gladysz 2022). This methodology is based on expert judgments while an energy sustainability assessment is based on choosing specific and physically measurable indicators. Then, experts use linguistic scales to quantitatively assess these indicators' performance by using fuzzy (and later defuzzified) numbers of the integrated-aggregated energy sustainability assessment. Environmental, economic, and social indicators are considered while developing an energy-related sustainability index in which these three aggregated sustainability indicators are described as fuzzy numbers (Kluczek and Gladysz 2022). The economic indicators include energy subsidies, and they may be economically costly to the potential end-user and taxpayers; thus, the overall/final value of economic energy sustainability is influenced. Simultaneously, increased GHG emissions into the atmosphere can be reported. Moreover, energy subsidy indicators affect the developmental prospects of economies and their engagement in energy subsidy planning. Therefore, the key drivers in developing countries are the set of income per capita (including subsidies and wider economics reforms) and net energy criteria that are designed and interrelated (Kluczek and Gladysz 2022). The procedural operation of a community microgrid is depicted in Figure 3.

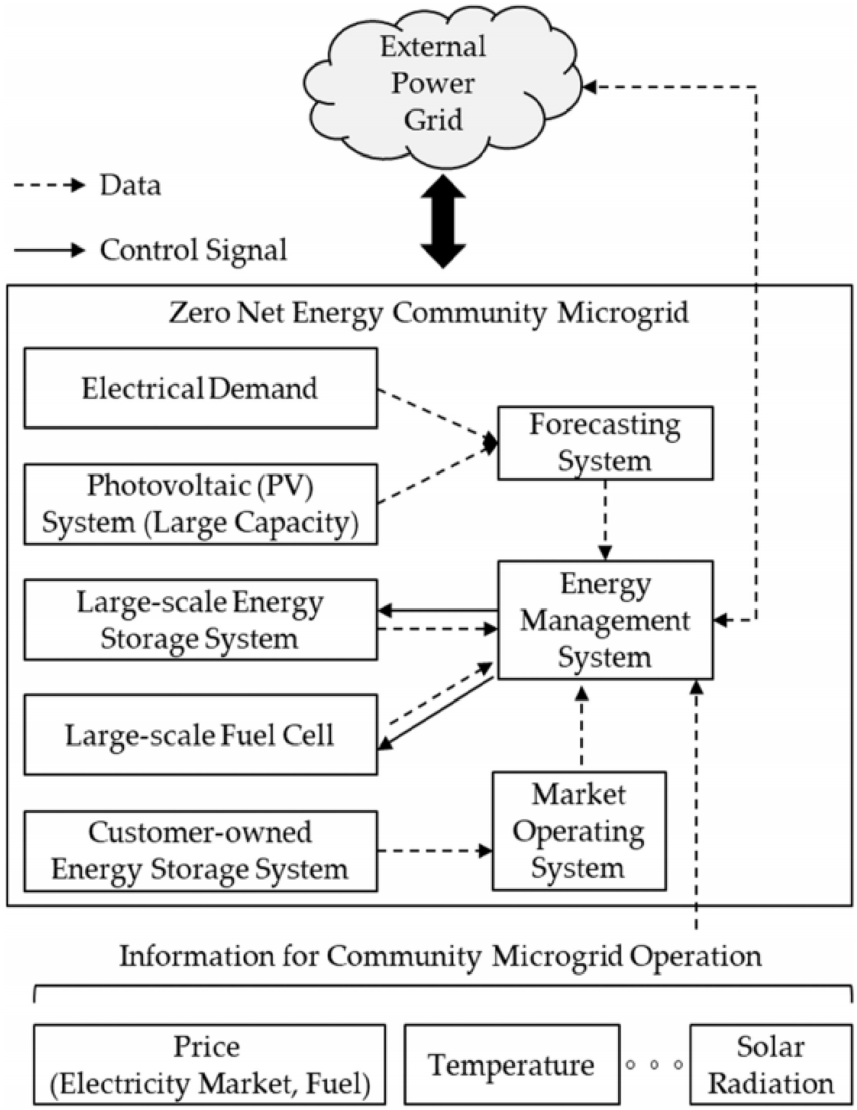

Figure 3. The procedural operation of community microgrid. Source: Jo et al. (2021).

Based on Figure 3, a zero net energy community microgrid can be defined as a distribution system for a community, which offsets all of its energy use from the distributed generation resources and Energy Storage Systems (ESSs) available within the environment established for the community. All information referring to the operation of microgrids is collected by the community microgrid operator regarding the DERs and the electricity demand. This information can be utilized by the operator to meet electricity demands by determining the optimal schedule of the ESSs and Fuel Cells (FCs). Only in cases where the power balance is not met, then the additional demand can be met when the microgrid receives electricity from an external power grid. However, inefficient operation can be caused in cases where the operator cannot control the charging/discharging of the customer-owned ESS (CESs), resulting in the increased capacity of the ESSs and FCs in the microgrid (Jo et al. 2021).

Another critical point that cannot be undermined is the grid impact, while comparing different optimized operational strategies of RECs with a shared Battery Energy Storage System (BESS). The REC configuration in the distribution grid is, therefore, varied to account for various power flow scenarios/cases (Weckesser et al. 2021). In the relevant literature, it was stressed that the design criteria for distribution grids depend on the supplied customers; thus, different grid types such as city, suburban, and village can be considered. In this configuration, the distribution grid contains two low-voltage and one medium-voltage grid, while various energy community configurations based on type of customers can be assessed, following relevant control strategies (Weckesser et al. 2021). The developed strategies are related to the following targets: Strategy 1 concerned the EC's goal aiming at the lowest system cost for electricity for the EC in energy markets. Strategy 2 concerns the relevant EC optimization through peak shaving and peak power exchange versus total system costs. Strategy 3 concerns the maximization of electricity consumption by the self-sufficiency (locally consumed energy or energy stored in the communal battery) of the EC's own PV. The battery can be located either behind the meter (Strategy 3a) or in front of the meter (Strategy 3b), and this differentiation directly impacts taxation. Strategy 4 concerns the diversified connection schemes and setups of voltage feeders at different distribution grid types (city, suburban, and village). This operation-related strategy involves combinations of low- and medium-voltage feeders as well as different sectors of the distribution grid, such as the household sector and the commercial customer sector (Weckesser et al. 2021).

The problem addressed by this review paper is determined by the fact of unstable socioeconomic conditions that are prevailing due to Russia's invasion of Ukraine as well as the socio-economic crisis spread by the prolonged COVID-19 pandemic worldwide. Both of these globally affected situations are causing significant strategic changes for meeting the targets of energy demand, production, and consumption patterns in the households and industrial sectors. In this context, there are also challenging issues including the development of renewable energy, the environmental protection by meeting the setting targets of GHG emissions reduction, and the national energy policies and strategies of energy production downsizing.

The aforesaid constraints of (a) the COVID-19 pandemic and (b) the Russian invasion in Ukraine both make global energy a big problem, especially in the second half of 2021 which was further defined by high and steady increases in energy prices and the subsequent threatening situations of energy poverty and poor energy alleviation. In response to this problem, the scope of this review study is to collect and systematize the generated energy management of policies and initiatives that have been deployed and promoted in order to confront these energy-induced problems. Subsequently, the scope of this review study is two-fold: (a) to reveal the role of ECs and (b) to determine the main research priorities under which the ECs are operated, also revealing what the key determinants and the priority issues with which the ECs are related at regional, national, and international levels of investigation are.

Based on the aforesaid scope of this review study, the measures of energy consumers' alleviation from this economic burden can be detected, being able to further support national and international energy planners to design and support the development of a variety of feasible solutions and realistic energy-related choices, such as the shift from fossil fuels to RES, the increase of energy efficiency, as well as the identification of stressors for the reduction of climate emissions in alignment with finding new energy suppliers.

2. Methods and Analyses

This review study has been organized in alignment with two groups of literature themes. In particular, all collected studies were registered in the Scopus database, all containing the key phrase of "energy community". Therefore, a systematic and last-decadeintensified literature retrieved all documents referring to the key phrase of "energy community" during the last decade of publication (period of 2010 onwards). The period of literature search and data collection was within the first quarter of 2022. Then, the "energy community" results of group 1 covered the dimensions of technology and environment, while the other group, group 2, covered socio-cultural and anthropocentric (mainly focusing on the built environment) dimensions. Table 1 contains the studies' allocation with subcategories per group and per type of context, while the in-groups' joint studies (having two or more common contexts of investigation) are collectively presented in Table 2. Moreover, the miscellaneous studies regarding the energy communities (covering mainly those geographical and sectoral contexts) are illustrated in Table 3, accordingly.

Table 1. Allocation of literature dimensions into contexts of energy communities per group: Group 1—technological and environmental dimensions of energy communities, Group 2—socio-cultural and anthropocentric dimensions, Group 3—legislative dimension, Group 4—Europe–European Union (EU) dimension of energy communities.

Group # / **Contexts of Referencing**	**Group 1 (Technological–Environmental)**	**Group 2 (Socio-Cultural and Anthropocentric)**	**Group 3 (Legislative)**	**Group 4 (Europe–European Union, EU)**
Energy	Energy strorage	Local energy	Social Development Goals (SDGs); renewables	Social Development Goals (SDGs); energy poverty; energy security
Environmental	Renewables	Security of energy supply	Social Development Goals (SDGs); climate change mitigation and adaptation	Social Development Goals (SDGs); climate change mitigation and adaptation; energy through renewables
Socio-digitalization	Artificial Neural Networks (ANNs) (including networks security)	Energy convergence; Information and Communication Technologies (ICTs)	Social Development Goals (SDGs); social media influencers	Social Development Goals (SDGs); circular economy; digitalized economy
Urban		Anthropocentric environment (built environment)	Social Development Goals (SDGs); climate change mitigation and adaptation; wastes treatment; 5Rs principles: Recycle, Refuse, Reduce, Reuse, Repair, Re-gift, Recover	Social Development Goals (SDGs); transactional economy; poverty eradication; alleviation of energy poverty among vulnerable and marginalized social groups

Based on the allocation of studies into the aforementioned four groups in Table 1, it can be seen that in the current planetary, environmental, and social emergency, it is essential for researchers to seek strategies for sustainable development. In this context, the implementation and envisaging of the Social Development Goals (SDGs) in contemporary societies impose sustainable development strategies to take action by ascertaining the protagonistic roles of citizens' rights and responsibilities (Otamendi-Irizar et al. 2022). Given that global challenges must be addressed through local action, the transition towards energy decentralization through Local Energy Communities (LECs) is also considered of utmost importance, making it important to identify the key characteristics in order for LECs to act as drivers of effective operation, local sustainable development, and social innovation (Otamendi-Irizar et al. 2022). These strong linkages developed among the ECs with the technological, environmental, social, and humanitarian dimensions of the relevant literature are organized and mapped into Table 2a,b.

Table 2. In-groups' allocation of literature dimensions into contexts of energy communities in two pairs: (**a**) Groups 1 and 2, (**b**) Groups 3 and 4 (studies are presented in reverse chronological order and in last name of first author alphabetical list).

(**a**)

Group 1 / Group 2	Energy Storage	Renewables	Artificial Neural Networks (ANNs) (including Networks Security)
Local energy	Vespermann et al. (2021) In-group 1 (energy storage and ANNs): Korjani et al. (2021) In-group 1 (energy storage and renewables): Cielo et al. (2021); Cuenca et al. (2021); Jo et al. (2021); Secchi et al. (2021); Weckesser et al. (2021)	In-group 1 (energy storage and renewables): Kaiser et al. (2022); Cielo et al. (2021); Cuenca et al. (2021); Grignani et al. (2021) Jo et al. (2021); Secchi et al. (2021); Weckesser et al. (2021)	In-group 1 (energy storage and ANNs): Piselli et al. (2022); Korjani et al. (2021)
Security of energy supply	Rossi et al. (2021); Talluri et al. (2021); Vokony (2021); Burgio et al. (2020)	Casalicchio et al. (2022); Pastore et al. (2022); Simoes et al. (2022); Sudhoff et al. (2022); Mutani and Usta (2022); Mutani et al. (2021); Lowitzsch et al. (2020); Mahzouni (2019)	Conte et al. (2022); Bianco et al. (2021); Savelli and Morstyn (2021)
Energy convergence; Information and Communication Technologies (ICTs)	Fina et al. (2022); Gjorgievski et al. (2021)	Krug et al. (2022); Cosic et al. (2021); Azarova et al. (2019)	Oprea and Bâra (2021); Tuerk et al. (2021); El Moudene et al. (2019); Van Summeren et al. (2021); Tholens (2014)
Anthropocentric environment (built environment)	D'Alpaos and Andreolli (2021); Liu et al. (2021b); Mazzeo et al. (2021); Minuto et al. (2021); Colombo et al. (2014)	Felice et al. (2022); Martens (2022); Liu et al. (2021a, 2021b); Ullah et al. (2021); Fina et al. (2020); Vernay and Sebi (2020); Viti et al. (2020); Suha and Kim (2019); ur Rehman et al. (2019); Visa and Duta (2018); Garmsiri et al. (2016)	Fouladvand et al. (2022); Reddy et al. (2022); Mazzeo et al. (2021); Todeschi et al. (2021); Makris et al. (2018); McCabe et al. (2018); Stump et al. (2012)

(**b**)

Group 4 / Group 3	Social Development Goals (SDGs); Energy Poverty; Energy Secuity	Social Development Goals (SDGs); Climate Change Mitigation and Adaptation; Energy through Renewables	Social Development Goals (SDGs); Circular Economy; Digitalized Economy	Social Development Goals (SDGs); Transactional Economy; Poverty Eradication; Alleviation of Energy Poverty among Vulnerable and Marginalized Social Groups
Social Development Goals (SDGs), under the fields of: renewables, climate change, social media, waste management	Di Martino et al. (2022); Ullah et al. (2021); Mihajlov (2010)	Heldeweg and Saintier (2020); Viti et al. (2020); ur Rehman et al. (2019); Garmsiri et al. (2016)	Van Summeren et al. (2021)	Hoicka et al. (2021); Stauffer (2016)

Based on Table 2a,b, it can be stressed that LECs, another entity related to ECs under multi-energy systems, have been locally and collectively organized in order to support the development of sustainable energy technologies through consumers' engagement, offering various benefits to them, and contributing to planned energy and climate objectives. Subsequently, LECs are expected to decisively support energy transition, since they also consist of multiple distributed energy systems (DESs). DESs interconnect local grid and heating networks, while also sharing power and thermal energy with no costs for (community) users (Yan et al. 2020).

LECs are also suitable for large scale development since LECs can utilize a collective self-consumption framework in order to require new control methods which are linked to users' preferences. In the relevant literature, such a LEC-based model with diverse actors, i.e., photovoltaic generators, electric vehicles, storage system, and tertiary buildings, has been reported (Stephant et al. 2021). Moreover, pushing the boundaries of self-sufficiency, LECs rely on load demand forecasts; thus, scheduling energy usage ahead of time. In such a selection, the forecasting method sustains two characteristics: quality and value. Such a traditional forecasting method of ranking is based on the quality metric named "Mean Absolute Percentage Error" (MAPE) (Coignard et al. 2021). It is also noteworthy that LECs are considered key determinants of sustainable cities, being directly relevant to the integration of electric mobility with energy systems based on RES; thus, lowering the adversely affected environmental conditions in urban areas and supporting the materialization of microgrids. Typical energy-consuming applications at ECs in urban areas are those of electric mobility services, which commonly include the use of electric buses, car sharing, bike sharing, and e-scooters. All these services are challenging the transportation modes in a sustainable manner, especially in densely occupied built environments such as those of university campuses (Piazza et al. 2021).

Table 3 shows two representative fields of ECs referring to geographical and sectoral contexts of analysis. In particular, in the upper half of Table 3 is presented a detailed literature coverage of ECs in alignment with the geographical context of analysis. Regarding the geographical context of ECs, it is noteworthy that one of the main research objectives is to couple them with central/national power systems by utilizing each country's technological status of energy development, such as well developed heat supply network at the built environment and well designed grid of electric vehicles charging stations. In such a case, Backe et al. (2021) stated that building heat systems and electric vehicle charging can jointly achieve a cost-efficient decarbonization in the European power market. These authors determined a 0.4% transmission expansion decrease by 0.4% and an 3% average cost reduction of European electricity cost by the combined development of Norwegian heat systems with the European power system. Moreover, the provisional strategy of 20% energy supply of Norwegian buildings with district heating fueled by waste and biomass and the remaining electric heating supply by heat pumps can result in a 19% energy cost decrease in Norway (Backe et al. 2021).

Based on Table 3, a wide geographical and sectoral dispersion of research production for ECs can be noted. Indeed, a large portion of literature production is related to ways of regulatory opportunities, barriers, and technological solutions while integrating energy in buildings and districts with certain and formalized planning contexts as that of the EU energy community framework (Tuerk et al. 2021). Moreover, economic optimization and market integration offer new use cases, revenue opportunities, and at the same time, new insights of investigating regulatory limitations regarding EU Clean Energy Package provisions (Tuerk et al. 2021). Regarding the geographical and the sectoral contexts of ECs, Table 3, it is also noteworthy that formal institutionalization of ECs is neither a precondition nor a guarantee of implementing energy regionalism (Herman and Ariel 2021). However, national ECs should be based on regulatory convergence (such as in the case of EU). The main goal of converging ECs in several southeast EU member states is to integrate and harmonize the energy sector of the non-EU member countries with the energy sector of the EU by (among other things) offering the prospects of easier access to foreign investments. This however requires implementation by those countries of the mandated rules as set by the ECs, which in practice are similar to the rules and laws that are required within the EU itself (Verhagen 2019).

However, the introduction of a political integration model in this highly sensitive research area of EU energy cooperation might run the risk of hurting the incremental technical integration process that has slowly emerged over the past few years as in the case of the politically fragmented MENA region/the energy community with southeast Europe. This critique makes questionable whenever European Commission (EC) insists on repackaging its enlargement concept in regions with very different types of relationships vis-à-vis the EU (Tholens 2014). In such an EC development, a response on the capacity expansion of the cross-border transmission and national generation and energy storage within the EU electricity and heating system with and without ECs among specific European countries is technically challenging. Among the critical attributes of ECs, their flexibility makes it plausible to investigate differences of flexibility responses by ECs towards local versus EU cost minimization and global cost minimization (Backe et al. 2022). From an environmental side, EC development can decrease total electricity and heating system costs on the transition towards a decarbonized EU system in alignment with the 1.5 °C target; thus, less generation and energy storage capacity expansion on a national scale can achieve climate targets (Backe et al. 2022).

Table 3. Miscellaneous fields of energy communities referring to geographical and to sectoral contexts of analysis (studies are presented in reverse chronological order and in last name of first author alphabetical list).

Geographical Context (A–Z)	References #
Brazil and Italy	Cunha et al. (2021)
EU	Lode et al. (2022); Sciullo et al. (2022); Vuletic (2021); Soeiro and Dias (2020); Frieden et al. (2021); Verhagen (2019); Petrov (2012)
Flemish and Dutch energy communities	Van Summeren et al. (2021)
Japan	Sokołowski (2021)
Multi-regional (Europe, Australia, and New Zealand)	Sokołowski (2019)
North America	Herman and Ariel (2021)
North Europe	Backe et al. (2021); Walnum et al. (2019); Heaslip et al. (2016)
Southeast Europe	Karova (2011); Tangor and Sari (2021); Prelevic (2016); Kumar et al. (2017); Padgett (2012); Karova (2011); Mihajlov (2010); Renner (2009); Vailati (2009); Walendy (2004)
South Mediterranean EU	Tholens (2014)
Subtotal of references on geographical context	**26**
Sectoral context (A–Z)	**References #**
Distributed energy sources among energy communities	Coignard et al. (2020)
EU energy communities of sectoral and planning interest	Backe et al. (2022); Otamendi-Irizar et al. (2022); Beridze (2021); Boulanger et al. (2021); Frieden et al. (2021); Hanke et al. (2021); Hoicka et al. (2021); Tholens (2014)
External differentiated integration in the context of energy communities	Kurze and Goler (2020)
Fog computing using Internet of Things (IoT)	Oprea and Bâra (2021)
Integration of energy buildings and districts	Tuerk et al. (2021)
Liquefied Natural Gas (LNG) regasification for port energy communities	Fioriti et al. (2021a)
Multi-agent system towards demand-side flexibility	Reis et al. (2020)
Optimal allocation method at energy communities	Casalicchio et al. (2021)
Photovoltaics-generated electricity sharing among renewable energy communities	Radl et al. (2020)
Smart energy community—A metanalysis	de São José et al. (2021)
Typology of future clean energy communities	Gui and MacGill (2018)
Two-stage mechanism design for energy trading	Khorasany et al. (2021)
Subtotal of references on sectoral context	**19**

In this context, ECs can provide a joint legal and regulatory framework for organizing and governing a community while providing new regulatory space for specific activities and market integration, such as innovative Information and Communication Technologies (ICTs) enabling a wide range of actors to be actively involved in creating and operating energy communities (Tuerk et al. 2021). This "locality" characteristic is crucial since local communities do not often control their DERs such as electric vehicles, home equipment, or electric heating. Therefore, the comparison of a novel local energy market (LEM) framework with a low-tech price reaction mechanism to coordinate DERs in the context of the recent French collective self-consumption framework was deployed by Coignard et al. (2020). This research focus was two-fold: to develop a literature overview at the intersection between transactive energy concepts and recent regulations for collective self-consumption, as well as to evaluate the performance of the proposed LEM on a simulated platform with ten households over a year. They were practically shown ways of the coordination requirements needed to reach different levels of self-sufficiency for solar-based ECs (Coignard et al. 2020). Similarly, Radl et al. (2020) argued that under current market conditions, battery energy storage systems are rarely profitable for increasing PV self-consumption but RECs enable individuals to be prosumers without the necessity of owning a PV system, thus, fostering more community-centered PV investments in the short term (Radl et al. 2020).

Further investigating the conceptualization and relevancy of Differentiated Integration (DI), it can capture dynamics and processes often neglected in established approaches. DI can be developed beyond EU borders, since it entails more than the inclusion of non-EU Member States in selected EU policies (Kurze and Goler 2020). Such an external DI implies the extension of general integration dynamics (i.e., widening, broadening, and deepening) beyond EU borders and, to this end, energy communities can be adopted by international organizations that are initiated by the EU through processes of deepening, broadening, and widening since its foundation. Such a DI operation can support researchers' understanding of the EU as a transformative power (Kurze and Goler 2020).

Overall, the fact that the main goal of materializing qualitative overviews of EC concepts and strategies at the national and global levels of analysis cannot be undermined. Such a quantification should realistically frame the development of ECs to understand the most feasible actions leading to economic growth and sustainable development. To achieve this multi-parametric objective, the following are recommended: (a) an updated review on policies dealing with ECs at EU and their state member levels; (b) a qualitative overview of European-funded projects under EU-funding programs, such as that of the Horizon 2020 work program; and (c) a qualitative overview of selected and mostly successful existing ECs in Europe and abroad. Such a three-pronged methodological approach of ECs can generate thoughtful considerations and useful experiences to be learned for the transition implementations of real cases and actions to be undertaken (Boulanger et al. 2021).

2.1. Technological and Environmental Contexts of Energy Communities—Group 1

The literature production devoted to technological and environmental contexts of ECs revealed that the technological development, such as flexible and exploitable RES, types of fueling local building heating systems (electric or gas), as well as a well-developed grid of electric vehicles fleets and charging stations play a decisive role in strategic plans drawn against energy poverty. However, there was also a critique raised of such an "energy poverty regionalism". Indeed, treating energy poverty by energy cooperation stresses that cooperation can be more successful at the regional level, but it largely fails to understand and conceptualize energy cooperation as part of the wider regionalism phenomenon (Herman and Ariel 2021). In this context, it was meant that security and geopolitics are prioritized with other factors of regional integration processes, such as motivations and interests offered. Two regions which exhibit extensive energy cooperation also differ in several ways to each other: North America and the European Energy Community (Herman and Ariel 2021), arguing that a regional anchor is key in North American and

European energy regionalism (Herman and Ariel 2021). In Table 4, the literature overview of the technological context energy storage, Group 1, is presented.

Table 4. The context of energy storage—Group 1 (studies are presented in reverse chronological order and in last name of first author alphabetical list).

Reference #	Scopes and Research Objectives	Methodology and Analysis	Research Outcomes and Key Findings
Cielo et al. (2021)	The methodology of this study was focused on examining how different sizes of PV and energy storage can determine an energy community containing a solar photovoltaic system with electrochemical energy storage. Two independent and normalized key performance indices were developed in alignment with a multicriteria optimization procedure: self consumption and self-sufficiency of the energy community. The evaluation was implemented on an hourly energy balance through the minimization of the power flow to/from the electrical grid.	Indicative real case study business models were conducted at an energy community of northwestern Italy: (a) the REC undertook the capital expenditure for photovoltaic and battery, (b) an independent company acted as a "technological partner" to acquire, manage, and share the community's revenues and assets, and (c) the condition of cost and revenue sharing between community and developer.	The interchange of PV and the energy storage sizing was investigated under a Pareto plane, while the performance configuration was based on economic indicators. These indicators determined the deviation from an "optimum point", showing positive economic and environmental performance: internal rate of return reached values higher than 11% and almost 45% carbon dioxide emission reduction for all the configurations of REC in Italy.
Cuenca et al. (2021)	RES are confronting technical constraints and electrical grids' expansion obstacles due to inherent structural precursors of their high penetrated distribution and inflexible dispatch nature. Therefore, grids' flexibility could be achieved by new entrants/energy providers, feeding the energy system (storage and demand response capabilities) with new financial flows.	In this study, a review of the ECs conceptualization was performed, regarding abiding technical and economic motivations, available resources in the literature, trading schemes, price negotiation algorithms, and benefits for the grid. Furthermore, policy framework in the EU was driven to make ECs a reality.	The critical points of investigation and the future considerations of the relevant projects worldwide are related to: the drivers, the barriers, the stressors, and the enablers offered.
Jo et al. (2021)	A viable solution to control the supply and demand balance in high-voltage power systems, while exploiting renewable resources, was proposed. The employment of zero net energy community micrograms are managing the local demand and minimizing the impact to the power grid.	The application of an optimal scheduling method for a zero net energy community microgrid with customer-owned energy storage systems (CES) assumed that at the CES market the microgrid operator was functioning under a bilateral contract. CES aggregators participated in the market, being constitutional components of it (the CES).	The scheduling method proposed the single energy storage system of an aggregated CES (ACES). The method effectiveness was demonstrated and testified by examining indicative cases.

Table 4. *Cont.*

Reference #	Scopes and Research Objectives	Methodology and Analysis	Research Outcomes and Key Findings
Korjani et al. (2021)	A strategy was developed as a virtual power plant in alignment with the artificial intelligence and a time series prediction for a battery energy storage system management and planning in a micro-grid.	An economic analysis was performed and it revealed that the state of charge should be managed to avoid economic losses due to cycle ageing. In addition, the proper battery sizing and the optimization of economic viability can be achieved via the load profile of the micro-grid.	The proposed management strategy can avoid the economic losses observed with a non-managed storage system. Moreover, ensuring that the micro-grid does not deviate from the load profile agreed upon with the transmission system operator, it is able to increase economic returns, reduce battery degradation, increase self-consumption, and reduce micro-grid fluctuations.
Liu et al. (2021)	In this study, the improvement of energy-saving, the increase of emission reduction efficiency, and the reduction of system investment operating costs by coupling electric vehicles (EV) and hybrid energy storage (HES) with the distributed energy system (DES) was reported. However, fields of future consideration are those of system modeling, optimization design, application site, and comprehensive performance analysis of the novel DES. The improvement of the exergy efficiency of the system was determined by: DES and HES combination enable the system to store excess PV power generation through Li-ions, while effectively reducing the electricity that the system interacts with the municipal power grid. The P2G technology can convert excess electricity into natural gas, thus effectively reducing the amount of natural gas purchased by the system.	A combination of technologies was analyzed, including photovoltaic, HES with P2G, and EVs with DESs. These technologies were developed to form a DES that combines HES. Taking the annual net energy import volume and annual cost as targets, a two-layer collaborative optimization method was applied. Both system optimal configuration and operation strategy were considered, offering a novel system to supply energy for a nearly zero-energy community. By integrating power excess with the municipal power grid, the system is obligated to purchase the power from the municipal power grid. Subsequently, energy purchase costs and penalty costs were paid and caused a relatively high cost per unit supply area.	Annual net energy import and annual value cost of the proposed system reached 2,170,772 kWh and 2,272,786 yuan, respectively. The key determinant of this performance was the operation strategy in charging during the daytime. Besides the proposed method, comparing to the multi-parameter collaborative optimization method, it was decreased by 3.1% and 5.0%, respectively. The division of multi-decision variables into two-layer collaborative optimization methods caused the possibility reduction of falling into the local optimum in the optimization process. Subsequently, the increased reliability and the accuracy of optimization results were achieved. The scale of PV power generation is optimistically increasing at the optimization process, while the excess power is storing at the Li-ions. The two-layer collaborative optimization method can be applicable to the collaborative optimization design of other complex energy systems. The suitability of the proposed operation strategy with other energy systems regarding source, load, and storage is reported.

Table 4. *Cont.*

Reference #	Scopes and Research Objectives	Methodology and Analysis	Research Outcomes and Key Findings
Liu et al. (2021b)	The study developed a peer-to-peer energy trading and optimization management of renewable energy systems. Moreover, an integration of these systems with energy storage of hydrogen and battery vehicles was examined at the application of power supply for a diversified net-zero energy community. This feasibility study on the diversified net-zero energy community revealed significant findings for stakeholders to install and manage systems of renewable energy and green vehicle storage interest, which further achieve carbon neutrality in the built and transportation sectors in urban areas.	The developed typical net-zero energy community models were compared with different storage vehicle types (hydrogen vehicle/battery vehicle) and energy trading modes (peer-to-grid/peer-to-peer). An optimal interactive impact on vehicle numbers and management strategies can be determined by multi-objective peer-to-peer trading optimizations of the net-zero energy community, under the cooperation of hydrogen and battery vehicles and the complementary operations of hybrid vehicle storage. An improved peer-to-peer trading management strategy was proposed considering the peer trading priority.	The hydrogen vehicle-integrated system can achieve superior supply performances, while the battery vehicle-integrated system showed an improved performance in terms of grid integration, economic and environmental aspects. In case the battery vehicle number in office buildings is relatively small, then, the time-of-use peer trading strategy should be adopted. The strategy without time-of-use management can be selected when the vehicle numbers in diversified building groups were relatively large for a techno-economic-environmental optimization. The improvement of the peer trading strategy refers to the following environmental and economic gains achieved: net grid import reduction by 18.54%, carbon emissions reduction by 1594.13 tons, net electricity bill savings by 8.31% and lifetime net present value by US$ 458.69 thousand.
Secchi et al. (2021)	The capacity optimization of Battery Energy Storage Systems (BESSs) of REC prosumers equipped with photovoltaic (PV) generators was studied by the impact of a bi-objective strategy. The deployment of the Non-dominated Sorting Genetic Algorithm-II (NSGA-II), having supported the joint objectives of maximizing the self-sufficiency of the REC from the main grid and minimizing the BESS capacity of all REC members, was set as the solution of a relevant designed optimization problem.	The prosumer-driven perspective excluded those REC members who are unwilling to install a BESS through a linear optimization constraint. In such a way, probabilities of over- or under-voltages can be compliant with the limits specified by Distribution System Operators (DSOs), while the line and BESS losses were estimated within the optimization loop through grid-level simulations performed in OpenDSS. The two types of grid, that of a standard peer-to-grid (P2G) and the REC-oriented peer-to-peer (P2P) energy sharing policy, were analyzed and quantified the performance at different seasons of scenarios on current energy and future energy demands, under which electrical heat pumps were widely used.	In the summer season (i.e., when PV and BESSs are most exploited), the selection of the optimal BESS capacity solutions can result in the reduction of the overall energy losses roughly by 20–40% for both P2G and P2P battery controls. The P2P policy sustains a slight edge over the P2G one, resulting in a 10–50% reduction of CO emissions. More even spread of economic benefits collected by energy savings among REC members was reported in the P2P energy sharing policy, while the return on investment can be generally higher in cases of electricity demand increase.

Table 4. *Cont.*

Reference #	Scopes and Research Objectives	Methodology and Analysis	Research Outcomes and Key Findings
Vespermann et al. (2021)	This study considered the roles of prosumers, consumers, photovoltaic, and energy storage systems, to formulate the market design for a local energy community. These aspects are all linked to community in alignment with the local distribution grid.	Radical market design options are based on the models of cooperation and non-cooperation game-theory, thus, assessing the economic benefits of energy storage for prosumers without a direct ownership of a storage system. Market outcomes were valued in terms of community cost and individual cost. Based on uncertainties and investigating financial instruments under which multiple prosumers can utilize storage systems, it was determined that a prosumer that owns a storage system can provide physical or financial rights, rather than participate in the local market as an arbitrageur.	It was pointed out that access to economic sources for energy storage systems can enhance energy communities while simultaneously reducing the cost volatility for most prosumers, and remain unchanging the expected operational cost of the whole community.
Weckesser et al. (2021)	The development of a linear programming optimization model sizing the energy community's Photo-Voltaic and Battery Energy Storage System enabled the optimal sizing of the relevant distribution grid.	The coupled utilization of linear programming model and power flow analysis was deployed to investigate the impact of different energy community configurations on distribution grids. The research objectives were that of different distribution grids, energy community configurations, operating strategies and battery placements. Battery's position at the beginning of the feeder by the energy community, it did not impact the observed minimum and maximum voltage.	Low-voltage grid loading reduction can reach up to 58%, based on the operating strategy followed by the energy community. The optimal sizing capacities of PVs and communal batteries were up to three times larger for the case of city grid, following the operating strategy of maximizing the energy community's own economic benefit than in other operating strategies and grid types.
Good and Mancarella (2019)	A stochastic energy/reserve mixed integer linear program was developed for a community energy system with consideration of local network constraints. This multi-energy formulation concerned the issues of multi-energy storage, energy vector substitution, end-service curtailment, and power factor manipulation.	This research approach was proven robust, ensuring that occupant thermal comfort cannot be kept at mutually agreed conditions in the event of a call.	A relevant case study illustrated how the different flexibility options can be used to integrate more electric heat pumps into a capacity constrained smart district while ensuring revenues from multiple markets and services offered.

Based on Table 4, it is critical to note that there are cases where the impact on the grid depends on the battery operation strategy. In particular, the minimum and maximum (especially in LV grid) voltages are affected by the battery location. Moreover, a battery positioning at the end of the feeder or at the commercial customer, does not greatly impact the voltage. Battery position also slightly impacts the loadings of LV and MV lines, thus, the favored positioning of the battery is that of the beginning of the feeder, especially at the connection of the communal battery (Weckesser et al. 2021). Under certain energy production schemes, peak shaving should reach up to a 70% economic and technical maximum, thus, further peak shaving is detrimental to the system's effectiveness. Similarly, at energy plans when a break-off point exists for energy communities, then, only the peak shaving cases up to 30% P_{max} are commonly considered, since the utmost importance goal is to relieve the grid (Weckesser et al. 2021). In Table 5, the literature overview of the context of renewables, Group 1, is presented.

Table 5. The context of renewables—Group 1 (studies are presented in reverse chronological order and in last name of first author alphabetical list).

Reference #	Scopes and Research Objectives	Methodology and Analysis	Research Outcomes and Key Findings
Conradie et al. (2021)	The local communities' participation in a REC in Flanders, Belgium was studied by using an extended model of Ajzen's Theory of Planned Behavior. Such a model determined the attitude, subjective norms and perceived behavioral control among the citizens of these areas.	The perceived control, attitude and intent were determined under the co-examination of economic, social, behavioral, and attitudinal variables at a structural equation modelling, by using data of 727 participants.	Research outcomes indicated that attitude and subjective norms are both strong predictors of intent, while perceived behavior has a significant, but modest impact. A significant relationship among attitudes towards renewable energy, environmental concern, financial gain, willingness to change behavior, and attitude among RECs was also shown. These results were proven reliable in alignment with previous studies in this domain and formulated recommendations for increasing REC participation.
Di Silvestre et al. (2021)	The new European Directive RED-II on the promotion of the use of renewable energy sources was introduced the concept of the REC. This entity was able to change the relations among end-users and the other actors of the energy sector. In particular, the electrical sector appeared to play a certainly influential role through the implementation of this paradigm.	The need for self-consumption and for exploiting the full potential of renewable energy in a REC. Besides the level of "power-grid" and "energy-users" exchanging energy influenced, as well as the rules that determine energy-users connectivity to the energy grid, they were examined under "Demand Response" energy management programs. Subsequently, the study outlined the existing legal framework and investigated various aspects concerning the interaction of REC with the power system.	It is noteworthy to highlight what issues determine the full implementation of REC at energy grids and power systems focused on Italy.
Fioriti et al. (2021b)	In this study, a business model for aggregators of ECs was proposed, and its optimization problem, accounting for all crucial aspects: (i) risks' alleviation of the agency problem, (ii) rewards awarded to the EC to be distributed with fairness, (iii) aggregator services payment with fairness, and (iv) exit clauses ruling what happens when a user leaves the EC, to be appropriately defined.	A mathematical model was developed by employing several fair game-theoretic reward distribution schemes, some of which were proposed for the first time. A case study was developed and results showed that the aggregator enable costs reduction by 16% and improvement of renewable penetration and self/shared consumption by 35–51% with respect to the base case.	It was suggested that the aggregator fair retribution was around 16–24% of the added benefit produced with respect to the base case, and that stable reward distribution schemes, such as Shapley/Core, Variance/Core or Nucleolus, were stable and recommended. The results highlighted that an added benefit may be attained by some non-cooperative ECs without providing any positive effect to the power system. There was a methodology-based study for policy makers and developers enabling them to draw national-level policies and market-offerings.

Table 5. *Cont.*

Reference #	Scopes and Research Objectives	Methodology and Analysis	Research Outcomes and Key Findings
Hanke et al. (2021)	This study provided an empirical consideration of RECs' capacity in activating and motivating socially underrepresented and vulnerable communities towards mitigating energy poverty and fostering energy justice.	A total of 71 European RECs were conveyed towards RECs engaging a social role. Such a social dimension of RECs aimed at encouraging vulnerable groups to actively co-determine their energy future by distributing affordable energy and improve the energy efficiency at their domestic applications.	The three viewpoints of distributive, recognitional, procedural, energy justice in RECs were defined to provide plausible support the energy household needs among underrepresented- and energy poverty-affected groups.
Hoicka et al. (2021)	The recast of the Renewable Energy Directive (RED II) can enable RECs owned by local members—or shareholders who are authorized to share energy within the community—to release private financial flows to ensure social benefits through RES. This RED II was transposed into law/action by the 27 EU member states by June 2021. The appreciation energy transition through jointly studying technological solutions and open decision making, in alignment with knowledge of engineering, spatial planning, and social science.	The benefits and the challenges of widespread development of RECs were highlighted, using examples from the pending transposition process, while providing policy advice for effective implementation of the RED II with respect to RECs.	Renewable energy, spatial organization of potential resources, demographics, push-back from incumbents, and social inclusion of vulnerable and marginalized groups can all be counted as variables for financing and ownership models.
Liu et al. (2021a)	A net-zero energy community could ideally involve university campus, commercial office and high-rise residential building groups as per actual energy consumption and simulation data, formulating a peer energy trading management approach.	Power supply for a diversified community consisted of three hydrogen vehicle storage groups, based on the TRNSYS platform, and involved the development of hybrid solar photovoltaic and wind turbine systems. Allocating an individual peer trading price to each building group according to its intrinsic energy characteristic and grid import price was performed though the development of an individual peer energy trading price model for the diversified community. Energy trading price modes, improvements of grid flexibility, and overall economy are all feasible based on a time-of-use peer trading management strategy.	Peer energy trading management in the individual trading price mode can meet an increase the renewable energy self-consumption ratio by 18.76% and 11.23% in terms of "load cover ratio" and "net-zero energy community" compared with the peer-to-grid trading, respectively. Reduction of the net grid import energy by 8.93%, grid penalty cost by 142.87%, annual electricity cost by 14.54%, and carbon emissions by 8.93% (982.36 tCO_2) were also reported, resulting from the time-of-use trading management applied in the individual trading price mode. Renewable energy and hydrogen storage applications can provide a comprehensive feasibility study on densely populated areas that are determined by peer trading price model and management strategies.

Table 5. *Cont.*

Reference #	Scopes and Research Objectives	Methodology and Analysis	Research Outcomes and Key Findings
Rossi et al. (2021)	RECs gained popularity in all countries, including Italy, being multi-users energy systems. Therefore, the adoption of Distributed Energy Resources by the ECs can determine their overall life cycle environmental benefit, through examining the EC-designed and environmentally driven solar compensation mechanisms.	The designing of new feed-in tariffs was studied in alignment with the following three-stepped iterative methodology: (i) optimization of economic sizing for solar technologies, (ii) a LCA, and (iii) the solar compensation mechanisms (via feed-in tariffs), through using the current value of carbon taxes; they determined the emissions avoided by communities. This general methodology was specified in a case study in Italy.	Setting carbon taxes to the current value of 15.4 EUR/tonCO_2eq, then, national emissions mitigation in an annual basis reached the proposed solar compensation from 121.1 MtonCO_2eq/yr to 108.2 MtonCO_2eq/yr. A tax increase to 20 EUR/tonCO_2eq resulted in an emissions reduction to 84.3 MtonCO_2eq/yr. At higher values of carbon taxes, there were negligible additional environmental advantages since the grid gets saturated by ECs.
Streimikiene et al. (2021)	Assessment indicators of low carbon just energy transition they were developed in this research study. Policy recommendations were drawn upon just low carbon energy transition by shifting to 100% renewables in power generation.	This research framework supported the assessment of three main dimensions of sustainable energy development: environmental, social, economic.	The development of such a EC framework stressed out the ways of how: (a) policies on climate change mitigation at the household sector could achieve energy renovation at the built environment, (b) micro-generation technologies' could be better promoted and utilized as well as (c) other policies that affected household's energy poverty and vulnerability were comparably deployed in the two selected countries of Lithuania and Greece.
Ugwoke et al. (2021)	The transforming implications from rural communities towards sustainable renewable based energy supply and the strategy integration were investigated by deploying a hybrid integration approach with the Low Emissions Analysis Platform model. In this model a forecasting community-scale energy planning for 2015–2040 at the two rural Nigerian communities of Onyen-okpon and Giere was performed. Four (demand-side) scenarios were conducted.	It was shown that the integration of strategies can be clearly benefited by the composite scenarios while availing energy use reduction with significant energy demand and GHGs emission reductions likewise. The best performance was reported in scenario 3—the demand side management. This scenario was based on demand and emissions reductions, energy conservation, and energy expenditures overall reduction.	Productive uses were taken into account for clean and sustainable economic production revealing useful insights for design and implementation of localized energy policies across different sectors in the community. This availed the opportunity of concurrently defining targets and reaching multiple goals, while addressing the impacts on reducing emissions and ensure access to stable energy and productive energy services.

Table 5. *Cont.*

Reference #	Scopes and Research Objectives	Methodology and Analysis	Research Outcomes and Key Findings
Ullah et al. (2021)	"Net-zero energy" was considered at the built environment within the last few decades. The technological advancements of net-zero energy communities were identified through in-depth literature review study under identifying and analyzing 23 case study settlements based on their design methodology along with some practical global-driven applications.	Different mitigation strategies, technologies and measures were adopted for outdoor heat sources, building adaptation techniques, GHGs emission reduction, and renewable energy technologies for electrical and thermal uses, along with control strategies. The main research focus was on onsite energy generation while 17 settlements were further considered at various adaptation techniques to significantly lower the energy demand of the buildings. Mitigation strategies of the outdoor heat sources enabled lowering the ambient temperature, GHGs emissions and energy demands of the community.	Shedding light on the problems and challenges of existing net-zero energy settlements can make recommendations towards the achievement of net-zero energy among social communities under the consideration of environment, energy, economy, and climate change dimensions. Moreover, suitable energy management and control strategies can be adopted for the smooth operation of energy.
Fina et al. (2020)	In this study, a model based on neighborhood energy communities (ECs) was deployed in order to estimate the cost-optimal large-scale economic potential of shared rooftop PV systems.	Initially, the estimation of cost-optimal rooftop PV capacities for representative neighborhood ECs in characteristic settlement patterns (SPs) was optimized through an optimization model. Then, the allocation of buildings to SPs and ECs enabled the determination of the number of ECs in the large-scale area of investigation. Finally, an up-scaling enabled the optimal large-scale, and the EC-based rooftop PV potential. A cost-optimal economic rooftop PV potential of approximately 10GWp in a case study of Austria was identified to meet the Austrian 2030 policy goal of a 100% renewable electricity generation.	Accommodating the cost-optimal rooftop PV capacity is difficult in cities and towns, comparing to rural areas. Therefore, the implementation of future ECs should be extended across the boundaries of different SPs, not to be narrowed on a neighborhood level. The performance of alternative sensitivity analyses was based on the variables of retail electricity prices, variation of distribution grid tariff structures, and PV system cost. Therefore, future research and recommendations were concluded based on the trade-off between these sensitivity parameters.
Heldeweg and Saintier (2020)	RECs are considered legal entities to be embedded in linking separate socio-legal institutions (of civil energy networks) at shaping (a transition towards) a just new energy system.	Energy decentralization and democratization are recognized among the main aspects to investigate how energy justice could be achievable. In this context, there is growing research of such new forms of institutional environment and the communities in the Netherlands and the UK were the subject of the proposed model.	"On the ground" stepping (legislative and regulatory) can be successful with a coherent and multi-disciplinary institutional perspective. This research aimed to provide a platform for such a research effort.

Table 5. *Cont.*

Reference #	Scopes and Research Objectives	Methodology and Analysis	Research Outcomes and Key Findings
Vernay and Sebi (2020)	Considering that RECs are gathering citizens, social entrepreneurs, and public authorities who all make investments to production, sell, and management of renewable energy, it is rational that RECs play a decisive role in energy transition. RECs necessitate a pool of generous resources and coordinating actions in a collective and sharing manner, due to RECs' fragileness at an individual level.	The main characteristics of an energy community ecosystem should support the emergence, growth, and optimally realization of the energy sector by the RECs involved. In a joint case study between the energy/national communities of France and the Netherlands, it was reported that energy community ecosystems attained uneven levels of maturity.	The conditions of an energy community ecosystem can fully realize its potential whenever: (a) it revolves around keystone actors who support diversity; (b) being locally-to-builders structures that can act as catalysts; and (c) developing both competing and symbiotic relations with incumbent energy actors.
Viti et al. (2020)	The study simulated the energy flows and assessed the potential economic benefits of a cluster of buildings acting collectively as an energy community in a case study of northern Italy. The comparison of EC performance was aligned with a configuration in which customers acted as Single Self-Consumers (SSCs).	The evaluation aspects of all economic scenarios developed, they were that of self-consumed electricity generated savings on the energy bill of EC, and the positive economic performance indicators. Carrying out this sensitivity analysis on system and transport charges of the electricity bill, a remarkable impact on the economics was shown, making the EC less attractive for investors and citizens without proper supporting schemes.	The simulation of different supporting tariffs (economic scenarios) aimed at determining those schemes that could effectively support the integration of Energy Communities in the national energy market. This analysis is also significant considering that the transposition of EU Directives to binding national laws, due by 2021, it is still pending. The acceleration of the diffusion of building-integrated RES can result in higher overall self-consumption rates than SSCs. In this research outcome, it is noteworthy that ECs should be considered customers acting collectively as energy prosumers.
Mamounakis et al. (2019)	A novel pricing scheme was deployed in order to manage virtual energy communities and to promote behavioral change towards energy efficiency.	A Community Real Time Pricing (CRTP) scheme together with an Energy Community Formation Algorithm (ECFA) were proposed. Users were clustered in Virtual Energy Communities (VECs) according to their level of flexibility in modifying their Energy Consumption Curve (ECC), and the relationships developed in Online Social Networks (OSNs), modelling peer-pressure capabilities.	CRTP with ECFA can simultaneously achieve considerable reduction in the system's energy cost and greater aggregated users' welfare than with the state-of-the-art real time pricing. The pricing policy of CRTP–ECFA is fair since users were rewarded according to their exact contribution to reduce system costs and to promote the desired behavioral change.

Table 5. *Cont.*

Reference #	Scopes and Research Objectives	Methodology and Analysis	Research Outcomes and Key Findings
Suha and Kim (2019)	A nearly zero energy community building can be achieved while assessing the energy performance of the combined passive and active design solutions and RES technologies.	The selection of four buildings and the determining parameters of energy consumption were identified through the analysis of electricity and gas consumption from a broader pool of 16 community buildings. Methodological validation was made by the measured data of electricity and gas, while verification of a newly constructed community building was performed by an energy simulation model.	The nearly zero energy target was investigated by the selection of a combined PV system with additional PV modules and the geothermal system. The improvement of an energy performance was testified by a combined passive and active design strategy. The efficiencies of energy-consuming appliances of domestic hot water, possible renewable energy systems such as the PV system, the solar thermal system, and the geothermal heat pump system were determined by offsetting their energy uses reviewed for.
ur Rehman et al. (2019)	The objective of the optimization problem was to minimize two objective functions—that of the imported electricity and that of the life cycle costs; they formed an optimization.	The demand of the building appliances, the district heating network auxiliaries and the electric vehicles were included at this study. TRNSYS was utilized to simulate these systems. Lastly, multi-objective optimization was done using MOBO (Multi-objective optimization tool). The onsite energy fraction, matching, and exported electricity were also co-evaluated. In all the systems, investments were made in the wind turbines, storages, and in the PVs to improve the performance of the optimized solutions, while co-evaluating the cases of increased number of electric vehicles.	Regarding the imported energy and storage, the turbine-based cases of 600 kW (200 wind turbines) were proven better in comparison to cases without the turbines and storage. The high performing system (200 turbines with storages and 75 electric vehicles) implied that the corresponding onsite variations of energy fraction (OEF) and energy matching (OEM) counted of 1–97% and 76–62%, respectively. Moreover, an imported electricity reduction to 2 kWh/m^2/yr was reported. Without storage the onsite energy fraction (OEF) and energy matching (OEM) varied from 1–58%, and, from 90 to 27%, respectively.
Karunathilake et al. (2018)	Technologies' ranking can involve co-existence of competitive requirements and stakeholder interest, and inherently induced uncertainties, thus making a fuzzy multi-criteria decision-making approach necessary. In such an approach, the framework of RE screening and multi-stage energy selection was deployed.	Different pro-environment decision scenarios were investigated to reveal relevant maker priorities, showing an optimum performance of the technologies in small hydro, onshore wind, biomass combustion, and landfill gas. The triple bottom line sustainability was further deployed to determine the theoretical pitfalls inherent in energy-related decision making.	The pre-project planning stage of RE projects is considered a flexible tool to better assess the disposable/available/alternative decision plans and designs of energy policy makers.
McCabe et al. (2018)	The context of community energy in a supporting role of social housing and renewable energy was investigated.	An introductory exploration of the potential application of community energy to social housing was represented in order to mitigate barriers to energy provision for low-income groups.	The development of renewable energy offered potential for achieving distributive justice. Individuals and communities emerged as major determinants in shaping just energy transitions.

Table 5. *Cont.*

Reference #	Scopes and Research Objectives	Methodology and Analysis	Research Outcomes and Key Findings
Visa and Duta (2018)	This is a book edition that addresses the main challenges in implementing the concepts that aim to replace the regular fossil-fuels based energy pattern with the novel energy pattern relying on renewable energy. Considering that the built environment is one of the major and well-known energy consumers, the challenges of this energy-intensified sector can be resolved considering the participation role of the community, the inhabitants, and its administration. In this context the Nearly Zero Energy Communities (nZEC) can represent the transition phase implemented.	The research topics covered the large-scale implementation, under which the nZEC concept on a sustainable built environment, they are as follows: -An integrated view on the community -Various implementation concepts for renewable heating and cooling -Renewable electrical energy production at community level -Sustainable water use and reuse -Specific instruments supporting education and training towards the RES-role at a community level.	This research study contains the collective studies published at the proceedings of the 5th Conference for Sustainable Energy, 19–21 October 2017, organized by the R&D Centre Renewable Energy Systems and Recycling, in the R&D Institute of the Transilvania University of Brasov, under the patronage of the International Federation for the Science of Machines and Mechanisms (IFToMM)—the Technical Committee Sustainable Energy Systems, of the European Sustainable Energy Alliance (ESEIA) and of the Romanian Academy of Technical Sciences.
Garmsiri et al. (2016)	In an effort to reduce GHGs emissions, there should be alternative forms of energy, such as hydrogen, to allow RES replacing hydrocarbon fuels in the transportation sector. Towards a net zero energy community, the transportation energy sector can be viewed independently from the construction sector of local communities.	The research focus was the interrelation of transportation energy with a net zero energy community by exploiting embodied waste hydrogen from chlor-alkali plants. Such a method integrated the energy use in transportation using hydrogen to meet the community (net zero) energy demands in a community.	Typical electrochemical and industrial processes vent or flare hydrogen into the atmosphere, through sodium chlorate or chlor-alkali as a reactor for water purification and paper bleaching processes, having the by-production of hydrogen. The capture of vented or flared hydrogen is further exploitable to transportation sector energy needs.
Mihajlov (2010)	This study focused on the fact of energy demand continuously increasing; in turn raising concerns about energy supply. In this study, the contribution of the energy sector in southeastern (SE) Europe was examined in alignment with the context of the European energy policy process. The prospected visibility and openness to funding of the energy sector in SE Europe were signified.	The affirmation of this regional energy system consistency with the European energy policy process makes this SE Europe energy sector less fragile. In this direction, the implementation of energy and environmental reforms by the SE European Energy Community Treaty are aligned to the EU's respective policy.	There is low-level awareness of the environmental requirements that have been set for renewable energy and its implementation in SE Europe. Therefore, the research outcomes could focus on establishing a common integrated energy market in SE Europe and the EU while resolving the existing problems raised.

Based on Table 5, it is noteworthy that ECs play a determining role towards the achievement of energy transition goals, but a full commitment requires a coordinated designing and operation which it is not always possible to be managed by the community itself. The supportiveness of aggregators and Energy Service COmpanies (ESCOs) could be feasible under the precondition that their goals are tuned to those of the community, not generating agency problems (Fioriti et al. 2021b). In this respect, it remains challenging in an open, competitive, and resilient electricity market to ensure the harmonization among varied rates of energy production in the recently developed era of massive RES penetration. Subsequently, increasing the modern pricing schemes can effectively incentivize eager users to meet their managerial plans while modifying their energy consumption patterns. The existing energy pricing schemes (such as in cases of real time pricing) have to equally treat all users, not adequately compensating for behavioral changes, thus mitigating the behavioral change dynamics (Mamounakis et al. 2019).

In parallel, according to Table 5, a growing literature production on energy justice implied that vulnerable and energy-poor households are severely affected by complex energy injustices in disproportional energy transition. RECs sustain the potential to support and motivate citizens (especially those groups which are underrepresented) to pursue energy transition as a just transition. The participation of citizens to RECs particularly benefits low-income and energy-poor households by affordable energy tariffs and energy efficiency measures. Such an energy justice framework could analyze RECs' social contributions in different countries (Hanke et al. 2021).

The EU ambitious commitment is to adopt low carbon energy and drive up to 2050 economy transition and, to this end, ECs being considered as legal entities where different actors and citizens cooperate in energy generation, storage, and management; they are all protagonists (Viti et al. 2020). In this context, low carbon transition is linking sustainable energy development path with RES, thus primarily addressing the energy poverty vulnerability and justice issues (Streimikiene et al. 2021). Community-scale energy planning should also play a decisive role towards developing sustainable ECs through conscientious efforts to realize energy and emission plans of local interest. These ECs, as well as the synergies developed at community and energy planning strategies, are all rather unrepresented areas for the developing world (Ugwoke et al. 2021).

Conceptually, RECs are defined as citizens, SMEs, or local governments who collectively invest, produce, and use local renewable energy, with private citizens controlling a majority stake. RECs play a decisive role in a community goal of sharing an increase of sustainable energy production while overcoming participation barriers. Therefore, towards fostering citizens' intent to participate in a REC, it is important to firstly understand what are the determining characteristics of a REC (Conradie et al. 2021). In this respect, the impact of a REC on policy level is yet to be seen, despite the fact that energy decentralization and energy democratization have been extensively discussed in academic/research levels. Among the EU state members such an implementation at policy level remains a state responsibility, knowing that those national policies are still overwhelmingly centralized. This regulatory framework determines the decentralization and the democratization of energy and, subsequently the "just transition" accomplishment (Heldeweg and Saintier 2020).

Another critical point of popular research interest is the joint relation of net-zero energy communities powered by RES. The transition to community-level net-zero energy systems implies the identification and selection of the best energy technologies that should be operative at local level while simultaneously considering technical, economic, environmental, and social aspects of wellbeing. In such a perspective, the consideration of true costs and benefits of energy use can be determined by a cradle-to-grave life cycle perspective (Karunathilake et al. 2018). Solar and wind energy are the significant renewable energy sources that can be used to tackle the climate change issue. Therefore, in the relevant literature, different architectures of community-level energy systems were designed and compared towards achieving a positive energy community in cold climate. Such a design proposed a centralized solar district heating network, which was integrated with renewable-based electricity network to cover the energy demand of a block of 100 houses in their heating and electricity needs. The proposed RES-based energy system consists of PVs, wind turbines, and stationary electrical storage (ur Rehman et al. 2019). In Table 6, the literature overview of the context of Artificial Neural Networks (ANNs) (including networks security), Group 1, is shown.

Table 6 notably revealed that contemporary approaches of energy integration and management should acceptably deploy local peer-to-peer (P2P) transactions in their communities. Such a P2P trading scheme requires a comprehensive understanding and planning of various key aspects of methodological significance such as that of peer privacy, computational efficiency, network security, and operational economics (Wang et al. 2021).

Table 6. The context of ANNs (including networks security)—Group 1 (studies are presented in reverse chronological order and in last name of first author alphabetical list).

Reference #	Scopes and Research Objectives	Methodology and Analysis	Research Outcomes and Key Findings
Wang et al. (2021)	The introduction of a novel hybrid community P2P market framework for multi-energy systems supported a data-driven market surrogate model-enabled deep reinforcement learning (DRL) method. This method facilitated P2P transaction within technical constraints of the community delivery networks.	A market surrogate model based on deep belief network (DBN) characterized P2P transaction behaviors among community peers without disclosing their private data. Moreover, the DBN network achieved privacy protection. Considering that energy inputs and outputs of peers are highly correlated with real time signals of retail energy prices, an integration of the market- and community-based models can be achieved regarding the generation of online retail energy pricing.	The study revealed that the proposed market framework can achieve energy cost saving for community peers at 7.6%, comparing to none P2P transaction scheme. Moreover, a 284.4 USD economic benefits increase for CA in one day is accomplished, compared to other comparison algorithms. Overall, by integrating network constraints into specific retail energy price can ensure feasible regional-community networks.
Mazzeo et al. (2021)	The energy demand coverage of a building district was achieved through proposing Artificial Neural Networks (ANNs) for sizing and simulating a clean energy community (CEC), CEC deployed a joint technological background of PV-wind hybrid system, energy storage systems, and electric vehicle charging stations. ANNs were primarily used to forecast the energy performance indicators, satisfying the load fraction and the utilization factor of the energy generated. Secondly, ANNs were used to estimate the indicator factor of grid energy.	ANNs were operated in alignment with a very large database of climatic conditions, flexible power system configurations, and varied electrical loads. Then, the yearly CEC energy performance can be directly predicted by these ANNs without performing system dynamic simulations by sophisticated models of each CEC component. In this context, a requirement of only eight dimensionless input parameters is needed. Such were the fractions of wind and battery power installed, yearly mean and standard deviation values of the total horizontal solar radiation, wind speed, air temperature, and load. Modeling evaluation was materialized by the Garson algorithm, explaining each input influence on each output.	A typically optimized ANNs consists of a single hidden layer with twenty neurons, thus inducing a very high prediction accuracy of CECs which are differentiated from those functioning at the ANN training.

2.2. *Socio-Cultural and Anthropocentric Contexts of Energy Communities—Group 2*

In Table 7, the literature overview of the context of local energy, Group 2, is presented.

Based on Table 7 it can be stressed that, through the deployment of distributed generation, consumers can provide significant values in the energy sector transformation in alignment with energy efficiency improvements, and sustainable energy-related practices' adoption. The precondition of forming ECs is the occurrence of common interests and goals among the consumers. Through ECs, consumers are capable to commit their individual and collective goals at an economic, environmental and social point of view, and to simultaneously contribute to the decarbonization of the energy system (Gjorgievski et al. 2021).

Among the most important issues regarding the local energy features of the ECs involves the encouragement of customers to reduce their connection capacity to avoid higher costs, mainly due to the capacity-based network tariff structures. However, the administrative grid sustains certain connection capacity and overloading beyond that limit can increase connection capacity, forcing prosumers to proceed in such an extra pay of their electricity bill for the rest of the year. Therefore, the energy generation and consumption profiles of LECs have to be optimized taking into account the comfort level of occupants (Tomar et al. 2021).

Table 7. The context of local energy—Group 2 (studies are presented in reverse chronological order and in last name of first author alphabetical list).

Reference #	Scopes and Research Objectives	Methodology and Analysis	Research Outcomes and Key Findings
Coignard et al. (2021)	This study considered the significance of ECs success as those parameters quantifying practical outcomes for local ECs, including self-sufficiency, cost of electricity, and fairness.	The study stressed the significance of creating a broader framework of evaluating and forecasting performance among ECs, and highlighting the relationship between quality and value metrics for ECs ranging (in the specific analysis) from 2 to 95 participants.	When selecting a forecasting method, the research results showed that simply relying on quality metrics can be misleading. This study, being illustrated with a study case, revealed that value metrics were prioritized over quality metrics, implying a clear difference of potentially affecting the coordination platform design for local ECs.
Gjorgievski et al. (2021)	This study enhanced our knowledge in the fields of social arrangements, technical designs, and their impact on ECs. Such variables were discussed in alignment with the institutional roles and the developed interaction among different actors.	Under the consideration of EC-members goals and outside actors, authors developed a literature review to benchmark in alignment with methods, modeling objectives, design processes, and technical constraints to be addressed.	In this study, a multi-parametric analysis on economic, environmental, technical, and social dimensions of ECs were quantified. Then, numerical indicators quantified these impacts, and provided a critical discussion of the research findings. Thereafter, future research directions were proposed.
Piazza et al. (2021)	This study proposed a methodology to optimally define and design electric services for a Local Energy Community which took energy from a microgrid based on the exploitation of renewable energy sources and storage systems.	The study considered the application of the proposed methodology based on a mixed-integer linear programming model, being applied to a university campus in Italy. Survey results were created to identify the needs of end-users, the model determines the optimal configuration of the electric mobility system made of shuttles, cars and bikes as well as charging points. The optimization model also investigated the opportunity of upgrading the set of renewable energy and storage technologies present in the microgrid of the campus to which the electric mobility infrastructures should be connected.	The study involved some different scenarios analyzed in order to compare the proposed electric mobility services from technical and economic dimensions, referring to the considered case study.
Reis et al. (2021)	This study provided a comprehensive valuation of how emergent energy communities and (eight) business models/archetypes can support a regulatory framework of energy transition and energy evolution in the EU context.	The specific archetypes were characterized and compared by the Business Model Canvas and the Lean Canvas frameworks. The reported differences among the business models were affected by the strengths and the barriers for energy community development. The prevalent model was that of traditional self-consumption place-based communities, whereas the scarcely occurred business models were those of differentiated services in demand flexibility, aggregation, energy efficiency, and electric mobility.	Novel business models are expected to crucially determine energy communities, being key players in the energy transition and ensuring the regulatory framework of energy evolution.

Table 7. *Cont.*

Reference #	Scopes and Research Objectives	Methodology and Analysis	Research Outcomes and Key Findings
Savelli and Morstyn (2021)	Social relationships can influence individual behaviors and personal choices while building up solidarity and encouraging cooperation. Therefore, smart local energy systems functioning and cooperation facilitation towards shared objectives can be conveniently accomplished through harnessing social relationships among citizens, connecting them to live at the same community area, and helping them improve their quality of living. In this context, shared objectives typically include: energy poverty reduction, clean technologies adoption, and energy justice establishment.	Smart energy neighborhoods were conceptualized and defined as a local energy system sharing the local energy infrastructure, developing network of social relationships through group-focused concerns, and following smart adaptive mechanisms towards participation, coordination, and cooperation.	The study discussed the key-characteristics of smart energy neighborhoods, stating their beneficial role that could play within future energy systems, their possible design, and key challenges at a realistic implementation of them.
Stephant et al. (2021)	Based on a game theory configuration to model the users' preferences through conducting a mathematical-optimization framework based on users power profile, the authors of this study employed an Alternating Direction of Method of Multipliers (ADMM) distributed algorithm in a practical side.	It is noteworthy that after reaching a reciprocal satisfaction among all users who ensured that the local energy community did not import more power from the grid than allowed, then, there is no need of a central agent to reach the system equilibrium.	The simulations performed on real data for different scenarios representing diverse users behaviors, showing that the developed approach converged to a stable state, and resulted in a maximization of local energy exchanges.
Tomar et al. (2021)	The research objectives of this study were the overloading reduction of the grid connection, and the increase of local RES utility; since they can avoid penalties to be administered throughout the year due to casual intermittent overloading in peak hours. Moreover, considering the energy specifications and performance of PVs generation, heat pump (HPs), and cooling loads, a novel data-driven flexibility optimizer model was proposed for day-ahead scheduling of energy profiles for LECs.	The applied methodology revealed ways of flexibility from a university campus network, including both electrical and heating/cooling systems in an integrated way. A two-layer optimization strategy was developed to guard the occupant's comfort level. The time scale of two months' simulation was performed, considering the scenarios of winter and summer. A 16% reduction in the peak demand was detected, being negligible energy usage differences at the proposed and the baseline cases.	Two types of flexibility indicators were estimated to offer a deeper insight into the performance. Considering the type and the voltage level of the connection, there were estimated economical gains of 9 % and 16%.
Yan et al. (2020)	The optimization of operation strategies of energy devices in each DES, and the decision of the amount of electrical and thermal energy sharing among DESs they are targeting to minimize the total expected net energy and CO_2 emission cost of the LEC, under scheduled day-ahead demand of community's users. The intermittent and uncertain nature of renewable generation and the intra and inter DESs coupling of energy devices and processes remain challenging.	The establishment of a stochastic mixed-integer linear programming model with uncertain renewable generation modeled by a Markovian process can confront the difficulties and the drawbacks associated with scenario-based methods. The problem was solved by using branch-and-cut.	The total expected cost of the LEC was reduced by the integrated management of the DESs, compared to the costs attained under other operation modes having no interconnections among DESs. It was demonstrated that the potential benefits achievable with LECs through the optimized management of local energy resources can ensure efficient use of the available energy. Moreover, the advantages of the stochastic approach against the deterministic one were also highlighted.

Table 7. *Cont.*

Reference #	Scopes and Research Objectives	Methodology and Analysis	Research Outcomes and Key Findings
Fleischhacker et al. (2019)	The methods developed in this study offered stakeholders the tool to calculate the capabilities and restrictions of the local energy system.	The models were applied to a case study using data from the Linz city (Austria). Four scenarios enabled researchers to better understand aspects of the energy community, such as the lock-in effect of existing infrastructure and future developments.	The research results showed that it was possible to reduce both objectives, but the solutions for minimum costs and minimum carbon emissions were competitive and contradicting to each other. The study quantified the highest effect of emission reduction by the electrification of the system. It was also concluded that a steady transformation of the local energy systems was necessary to reach economically sustainable goals.
de Vries et al. (2016)	Building on user and grassroots innovation literature, user innovations in five Dutch civic energy communities were explored. Less attention was paid to the interplay of social, symbolic, and technological innovations that seemed to be at the heart of many civic energy communities.	In this study, the interplay and the activities of civic energy communities were explored, as configurational user innovations, i.e., creating user-designed arrangements of loosely related sets of components.	The configurational work combined off-the-shelf technologies linking them with novel technical and non-technical ideas in terms of business models for local energy provision, rather than endeavor clear-cut changes to existing devices. This configurational work can abide to learning processes at a community level, while evolving technical identity and a versatile selection of community building activities. In such a way, the growing network of resources is necessary for implementation of user innovations.

Another critical local energy-oriented issue is the fact that cities' growth implies ECs promoting distributed energy resources and implement measurable energy efficiency. For a better understanding of ECs motivation, research should improve a Pareto Optimization of existing open source models, targeting both costs and carbon emissions. In this context, clustering algorithms are able to improve models' scalability and performance (Fleischhacker et al. 2019).

In an applicable context of local energy generation, the following cases can be denoted:

- "Clean Energy for All Europeans" legislative package is the core of European energy policy enabling citizens and communities to actively adopt and promote local energy generation, consumption, and trading. While the literature on energy community business models is sporadic, a stable systematization of community arrangements is missing; thus, there is still space for further motivation and active contribution of energy communities in the future of the European regulatory framework (Reis et al. 2021).
- The "Clean Energy" package supports the smoothing process of energy transition recommended by the EU. Energy transition can, therefore, be achieved through measures and policies that can ensure the security, the sustainability, and the competitiveness of energy supply systems. Such measures and policies entail the introduction of suitable physical and regulatory infrastructures to meet energy market requirements, integrate RES, and ensure security of the energy supply, while a risk-based approach in the electricity sector is managing electricity problems in a proactive manner (Mutani et al. 2021).

In Table 8, the literature overview of the context security of supply, Group 2, it is presented.

Table 8. The context of security of supply—Group 2 (studies are presented in reverse chronological order and in last name of first author alphabetical list).

Reference #	Scopes and Research Objectives	Methodology and Analysis	Research Outcomes and Key Findings
Mutani et al. (2021)	A risk-based methodology was deployed to assess the first "oil free zone" in northwest of Italy (Turin). A quantitative risk analysis method was conducted considering the risk of blackouts on the national electricity grid, the probability of such occurrences, the extent of damage, and the risk of exposure. The risk assessment was applied through a place-based approach, considering private and public consumers, producers, and prosumers.	The observed risks were compared with their tolerance limits and assessed for different scenarios to reduce the risk of energy supply blackouts, including: a reduced energy consumption, an increased energy production, and an optimized energy supply and demand. The possibility of establishing an energy community was considered in a scenario-oriented basis. It was reported that according to users considered, relevant actions generated exclusive results aimed at reducing the risk of energy supply blackouts, accordingly.	All the stakeholders can benefit from participation of users in EC, not only from an environmental dimension (through the production of energy from RES) but also from an economic dimension. These results were in alignment with the requirements of the EC and the Italian "Integrated National Plan for Energy and Climate", in terms of energy transition pertaining to the sustainable development of a territory.
Iakovenko (2019)	This study discussed the overall scope of Articles 106(2) and 107(3) TFEU as grounds for derogation from state aid requirements, together with EU case law and Commission practice regarding state aid in relation to security of energy supply. The study also provided suggestions as to how EU law might develop and support measures that may be adopted from the energy markets.	The research objectives were the investigation of those key aspects that seem to be extremely important for the EU with regard to the development of the internal market and the impact of national support measures in the energy sector on this process. State aid cases involved security of energy supply projects that set out, demonstrating that some disproportionate measures have been adopted within the EU and that a risk of hindrance of market development may exist across the EU state members. Moreover, strategic considerations regarding long-term security of supply in the EU are needed to clarity the limits and the legal bases and their justification under the TFEU.	The Energy Community Contracting Party perspective was provided to demonstrate the complexity of state aid. This may be especially relevant for certain EU state members which regard the diversification of supply through the development of indigenous sources as one of their main strategic priorities in the energy sector.
Mahzouni (2019)	The insights from the extant literature on institutional entrepreneurship in emerging fields enabled a better understanding of how the innovative idea of "energy community" arose, became new practices, and institutionalized over time. This study was undertaken when the people of St. Peter, a Black Forest rural town in Germany, decided in 2008 to build their own energy co-operative for the operation of the biomass District Heating Plant (DHP).	The key driving forces for this endeavor comprised a wide range of sustainability-related discourses, such as climate protection, energy supply security, and regional economic development. The biomass DHP, as an environmentally friendly heating system, has become a taken-for-granted "inspirational" practice to other communities in the region. This study elucidated the process of legitimation and sense-making of the notion of the St. Peter energy community.	The key conclusions referred to institutional entrepreneurs' dispersed across space, social status, sector, and governance levels; whose agency was distributed among multiple levels of action and multiple stages of development while exploiting a range of social skills to justify their action for institutional change. Community-based initiatives should address both individual interests (stable prices and supply security) and collective concerns (environmental protection) while transforming existing energy practices into more renewable ones.

In Table 9, the literature overview of the context of buildings, Group 2, is presented.

The modern revolutionary changes in power delivery systems with the advent of smart and flexible grids require systems that are functioning at a way of intraoperation and seamless integrated technology. Therefore, research scenarios should pave the way for energy clusters that call for new methodologies applied at the dynamic energy management of DERs (Rosato et al. 2021). In this respect, the relevant literature production has been directed to examine heat harvesting being rejected from the cooling and refrigeration systems in buildings showing high year-round cooling and refrigeration demands (e.g., ice arenas and grocery stores), and using heating excess to heating purposes of other nearby buildings.

Moreover, the integration of a small group of buildings with diverse thermal demands via a network of low- and micro-thermal temperature to allow harvesting of thermal energy wasted and shared at minimal thermal and mechanical losses (Di Lorenzo et al. 2021).

Table 9. The context of buildings—Group 2 (studies are presented in reverse chronological order and in last name of first author alphabetical list).

Reference #	Scopes and Research Objectives	Methodology and Analysis	Research Outcomes and Key Findings
Di Lorenzo et al. (2021)	The study proposed a model of innovative power-sharing that enables a power-system architecture for aggregation of users to share the power produced by common generators and energy services. The model was proven suitable for both multi-tenant buildings and groups of multiple buildings and it can be applicable for both existing and new buildings. It can also support easy scalability to larger systems and suitability for an easier integration with storage systems.	The applied model revealed the capability of unidirectional energy sharing from energy produced by common generators in such a way that each user remains passive towards the distributor, except for a single active user that assumes the role of balance node. Therefore, the model can be implemented among residential and tertiary multi-units buildings in alignment with a) national regulations, and b) power sharing contracts.	The study discussed the feasibility of the model through a dynamic Matlab/Simulink model, which was used towards its effectiveness in several case studies. The significance of this study enabled a better approach of energy sharing in buildings with a novel new strategy, based on an innovative system architecture that can be effectively implemented.
Abdalla et al. (2021)	The study introduced a reduced model of potential harvesting thermal energy between buildings by calculating the amount of heat energy simultaneously shared between the connected buildings on a five-minute time resolution. The proposed model can evaluate changes in greenhouse gas emissions and the amount of energy that is still required from supplemental heating sources after harvesting relative to conventional stand-alone building systems.	This study revealed that changing the operating temperature of the micro-thermal network when primarily sharing between diverse thermal demand buildings showed a minor effect on greenhouse gas emissions but can have a larger effect on electrical energy consumption. The model was applied using actual utility energy consumption at one of the potential clusters in Ontario (US).	It was measured that approximately 48% of the cluster's total heating requirements can be covered by instantaneous sharing between buildings, and an additional 12% can be covered by daily short-term thermal storage. This reduced heating demand resulted in an approximately 74% reduction in total greenhouse gas emissions.
Kazmi et al. (2021)	The study argued about the need for data-driven solutions that model not just the behavior of building occupants but also of energy flexible resources in buildings, distributed generation, and grid conditions in general. This understanding can then be utilized to improve the design and the operation of energy communities in a variety of real-world settings. However, in practice, collecting and analyzing the data without a proper understanding of the local context, it can make these projects often at risk of failure due to misplaced expectations.	This study provided an overview of open-source datasets, models, and tools, as well as relevant ways that can be utilized in optimally designing and operating real-world energy communities.	The study proposed the utilization of open source datasets and models from related projects, which were carried out in the past. Likewise, a number of open source, general-purpose tools can support practitioners to design and to operate LECs in a near-optimal manner. These resources are important because they not only support a grounding of expectations, but they also provide LECs and other relevant stakeholders, including utilities and distribution system operators, with much-needed visibility on future energy and cash flows.

Table 9. *Cont.*

Reference #	Scopes and Research Objectives	Methodology and Analysis	Research Outcomes and Key Findings
Rosato et al. (2021)	The proposed a new management scheme of energy clusters (e.g., smart building, energy community or virtual power plant) that was based on a data driven decision-maker that daily deployed the activities of the day ahead, providing an optimized scheduling which will be the base for the operations for the next day.	The study leverages an optimization process based on the elastic net regularization that proved to be an effective support the best scheduling of the distributed resources according to specific key performance indicators, that were unbalanced. The decision process worked on predicated data obtained through a recently assessed short term forecasting based on long short-term memory neural networks properly adapted to distributed environments. The defined method of the best scheduling of resources offered insights from data and run what-if scenarios. Moreover, feasible rules can optimally aggregate the distributed resources and demand-side management programs. This aggregator was tested on a real energy cluster making use of real data over two years period.	The results showed the effectiveness of the proposed approach that was able to predict any sort of unit and manage any sort of program. The significance of this work was to approach the energy management as an optimization and decision problem in a more robust way of reasoning, by employing forecasting/optimization over all the quantities In the community, resulting in a thoroughly complex and efficient method.
Lopes et al. (2016)	The reported study addressed load matching improvement in Net Zero Energy Buildings (Net-ZEBs). The related relevant literature showed that currently research work can be mainly focused on improving the load matching of individual buildings.	The concept of a Cooperative Net Zero Energy Community (cNet-ZEC) was introduced, extending discussion to the enhancement of load matching at a wider community level. Both building and community levels were compared in order to assess the work proposed through the analysis of three distinct scenarios where five Net-ZEBs work individually or in community.	The research outcomes were obtained through a detailed simulation based on 1-min resolution stochastic load profiles and recorded weather data. In the period of a year, the CNet-ZEC can increase the electrical demand covered by onsite electricity generation up to 21% and the on-site generation that can be utilized by the building up to 15%. The key-concerns of CNet-ZEC are referring to: demand heterogeneity of the buildings that should be integrated at ECs; the higher number of controllable devices; as well as the availability potential of higher amount of energy to satisfy the community demand.

2.3. Legislative Context of Energy Communities—Group 3

The legislative dimension of ECs is one of the most challenging and creative dimensions of regional (Tsagkari 2021; Buschle and Karova 2019; Minas 2018; Hroneska 2014) and sectoral (De Lotto et al. 2022; Iakovenko 2019) interest. In such a multidimensional context, the EU is also experiencing an ongoing nuclear renaissance; thus, this development accounted for primarily by the increasing energy demands of all EU member states, bringing once again to the fore the often forgotten-about European Atomic Energy Community (Euratom). A prospect of increasing nuclear energy production in the EU is increasingly gaining impetus, especially through the current fuel crisis generated by the Ukranian–Russian contradiction, making it highly important to set and comply with rules and instruments provided under the Euratom Treaty from a legal point of view. The Euratom Treaty's reputation has been damaged, being characterized from a literature corpus as an "undemocratic treaty", especially regarding the insufficient institutional leverage given to the European Parliament. Taking the Lisbon amendments to the Euratom Treaty into account, there was still much to be desired (Cenevska 2010). Therefore, research attention should be drawn to existing problems that could contribute to the establishment of a common integrated energy market in SE Europe and the EU (Mihajlov 2010).

In a legal terminology point of view, it is notable that in the absence of a single definition of security of supply, one may observe diverging views among EU state members as to the policy required to ensure it. Indeed, in this context, the entity of "security of supply" is considered a core issue in EU energy law and it is an integral part of the EU's energy strategy. In many cases, this entity is an important argument to structure EU's rules on competition on the internal market. Moreover, both Directive 2009/73/EC2 (also called 'Gas Market Directive') and Directive 2009/72/EC3 (also called 'Electricity Market Directive') recognized "security of supply" as a basis for the imposition of public service obligations (PSOs) on undertakings operating at these markets (Iakovenko 2019). Despite this, EU legislation does not lay down any across-the-board definition of the meaning of security of energy supply. Moreover, there are no explicit clarification criteria for cases in which state measures that guarantee security of supply fall within the scope of the Article 106(2) of the Treaty on the Functioning of the EU (TFEU) or Article 107(3) TFEU. Therefore, further analysis can clarify the Articles 106(2) and 107(3) TFEU in the state of evolution of EU competition law, taking into account that EU member states use their discretion to decide on national services of general economic interests (SGEIs) objectives or the need of investment aid (Iakovenko 2019). In Table 10, the literature overview of the context of legislative framework, Group 3, is presented.

Table 10. The context of legislative framework—Group 3 (studies are presented in reverse chronological order and in last name of first author alphabetical list).

Reference #	Scopes and Research Objectives	Methodology and Analysis	Research Outcomes and Key Findings
Braeuer et al. (2022)	ECs in the residential building stock sustain high potentials, but they are largely untapped in multi-family buildings. In many countries, rapidly evolving legal frameworks attempt to overcome related barriers, e.g., ownership structures, principal–agent problems, and system complexity.	A mixed-integer linear program (MILP) optimization model was deployed to assess the implementation of multi-energy systems in ECs in multi-family buildings with a special distinction between investor and user. Such a model was applied to the German Tenant Electricity Law. In this model, the variables of hourly demands from appliances, heating and electric vehicles, the optimal energy system layout, and dispatch were determined.	A generation of plentiful performance indicators demonstrated how the legal framework can affect the technologies' inter-dependencies and economic viability of ECs with multi-energy systems. While certain economic technology combinations may fail to support national emissions mitigation goals, this could lead to lock-ins in EU largest residential building stock. The subsidies cannot always lead to the utilization of a battery storage. However, self-sufficiency ratios of more than 90% were reported for systems with combined heat and power plants and heat pumps. Social CO_2 mitigation costs of social CO_2 was ranged at 147.5–272.8 €/tCO_2, implying a strong influence of the heat demand on the system layout.
Di Martino et al. (2022)	Analyzing tweets collected from communities, social media or even messaging systems, enabling the conclusions of important findings, especially in this Big Data era. This phenomenon is of particular interest among knowledge workers who analyse textual content published on the Internet in order to obtain information that can be used of legal and decision-making interest.	In this study, a batch analysis of information was drawn from tweets by examining texts of news downloaded at different times of the day related to ECs, using techniques of Sentiment Analysis, Natural Language Processing, Machine Learning, and Big Data Analytics.	While the content produced on social networks is invaluable for knowledge extraction, the very process of extracting meaningful knowledge is not trivial and involves data and text mining methodologies and techniques that are by no means simple, having also legal protection rights of distribution and dissemination.

Table 10. *Cont.*

Reference #	Scopes and Research Objectives	Methodology and Analysis	Research Outcomes and Key Findings
Fina and Fechner (2021)	The Renewable Energy Directive and the Electricity Market Directive they are both parts of the Clean Energy for all Europeans Package (issued in 2019) and they provided supranational rules for RECs and citizen ECs. Since national transpositions need to be completed within two years, Austria proceeded already in drafting the relevant legislation.	A detailed comparison of the EU guidelines and the transposition into Austrian law was developed, revealing how and to what extent the EU guidelines can be transposed into Austrian law, and simultaneously identifying loopholes and barriers. Such Austrian reforms can support legislators and policy makers worldwide in their process of designing a coherent regulatory framework.	It was noteworthy that experts from different areas of specialization and interests (such as project developers, scientists concerned with energy communities, energy suppliers and grid operators) should be closely involved in the law-making process offering different perspectives towards a supportive regulatory framework for ECs to be created.
Plewnia and Guenther (2021)	Peer-to-peer energy (p2p) communities connect electricity consumers and producers on platforms allowing them to trade energy with each other. By synchronizing local production and consumption, connecting decentralized actors, and creating new markets, they can promote a more sustainable energy system.	A multi-case study and expert interviews were conducted to investigate how the business models of these organizations operate and what value they may provide to stakeholders and the energy system. It was found that, due to current legislation, organizations in Germany mostly facilitate virtual, supra regional p2p energy communities. While these do not offer all the benefits of local p2p energy communities, they do facilitate a range of advantages to stakeholders and the overall energy system.	It is concluded how sustainable business models can offer "system transition value," driving the dissemination of new technologies, the redesign of markets, and the education of customers to foster a more sustainable energy system.
Tangor and Sari (2021)	This study aims at introducing a new alternative one (rational choice-historical institutionalist explanation) in order to conceptualize the role of the community. This article consists of three sections.	The first section compiles and evaluates the theoretical literature regarding the energy community. The second section explores rational choice and historical institutionalism's potential to explain the community's evolution. The third section deals both with the community's impact on the EU's external energy policy and the Europeanization of energy policies of the contracting parties.	Institutional improvements within the community for better implementation results are foreseen as policy implications.
Alaton et al. (2020)	EU introduced two new actors in the European energy system in 2019: Renewable and Citizen Energy Communities (RECs and CECs). Therefore, since then, these two new actors and their effects on the energy system are crucial when implementing the European legislation that incorporates ECs into researching and planning suitable ECs for the electric grid.	This paper converged the differencies between the letter of the law and those numerical models of ECs. A legislative elemental list of RECs and CECs was considered by regulators, distribution system operators, EC planners, researchers, and other stakeholders when modeling ECs.	The provision of relevant case studies of EC models can be explicitly focused on including elements of the European Law, in order to bring together legislative, technological, and modeling specifications and characteristics.
Fina et al. (2020)	An estimation of the economic viability for residential customers when participating in RECs can be focused on PV electricity sharing. The applied simulation model considered the omission of certain electricity levies as well as the obligatory proximity constraint being linked to grid levels, thus introducing a stepwise reduction of per-unit grid charges as an incentive to keep the inner-community electricity transfer as local as possible.	The cost savings in residential RECs are broadly ranged from 9 EUR/yr to 172 EUR/yr. The lowest savings were gained by customers without in-house PV systems, while owners of a private PV system make the most profits due to the possibility of selling as well as buying electricity within the borders of the REC. Cost savings increases were reported when the source was closer to the sink, as well as when more renewable electricity was available for inner-community electricity transfer.	These results should alert policy makers to find additional support mechanisms to enhance customers' motivations to participate if RECs are meant as a concept that should be adopted on a large scale.

Table 10. *Cont.*

Reference #	Scopes and Research Objectives	Methodology and Analysis	Research Outcomes and Key Findings
Minas (2020)	Achieving the 2030 climate and energy targets in the EU is strongly abiding to the decision of extending the 2030 Framework to the contracting parties of the ECs which actually implies a truly gigantic effort.	Energy community (EnC) was considered as a hybrid legal space in which the European Commission, EnC Secretariat and contracting parties all co-created legal order. Major challenges were defined towards the extension of the 2030 Framework to the EnC, including the EnC's structure and composition, weaknesses in national implementation, and a limited dispute resolution regime.	The research findings were reflected on the role of law in the external dimension of EU climate policy. While the ECs' contracting parties agreed to adapt the revised Energy Efficiency and Renewable Energy Directives, and the Energy Union Governance Regulation, in 2019, the ECs parties faced significant obstacles, while the EU energy community has limited compliance mechanisms.
Sokołowski (2020)	The paper investigated the regulation of RECs and CECs within the EU, the making a comprehensive understanding of RECs: establish a register to tackle regulatory and administrative barriers, adopt RECs national/European goals, and introduce the exemplary role of national authorities in their promotion.	The creation of a separate support scheme for RECs (e.g., a tariff supporting small RECs and a separate tender for other RECs), brought elements of legal recognition of CECs (membership condition, operational condition, and energy services condition).	An affirmative answer was given about whether renewable citizen energy communities can be eligible under EU law.
Sokołowski (2018)	The European Commission presented in 2016 a legislative package titled: "Clean Energy for all Europeans", with the proposal for a new Directive on common rules for the internal market in electricity (recast) as its part. The package determined consumers as the "active and central players on the energy markets of the future".	In this study, a collective approach of the generation of electricity in ECs was discussed. The research incorporated previous European policy documents and programs, repealed and to be amended legislation that indirectly, or potentially, addresses the issue of ECs, as well as the legislation that regulate directly it (for instance the new Directive on common rules for the internal market in electricity).	The call of cooperation of energy consumers and local production of electricity from renewable energy sources it was deeply rooted in the European agenda for the internal energy market.
Stauffer (2016)	Air pollution is classified by the global burden of disease as a top ten risk factor for health globally and is associated with a broad spectrum of health effects. Several countries in southeast Europe (SEE) suffer from particularly bad air quality. Coal power generation is worsening the air pollution situation. SEE countries are still largely dependent on power generation from coal plants.	The engagement of health and medical actors is crucial to strengthen the energy community Treaty's health and environment rules, such as EU laws for cleaner air that would lead to higher air quality standards in SEE countriesm thus, preventing ill-health and premature deaths. Electricity consumers, citizens, and protection of their health should be a central part of energy policies. The responsibility of the health professionals should be also taken as protecting public health by engaging in policies that so far are not regarded as a part of the health domain.	International policies in the energy and environment realm have mechanisms to help to protect public health in those countries that otherwise would not drive the positive changes themselves. The responsibility of the health professionals to protect public health lies also in following a health in all policies approach, also to engage in energy and environment policies

Recently, the so-called Clean Energy For All Europeans Package (Winter Package) provided all EU with a new set of legal acts in the area of energy regulation. It can be signified that all these acts try to bring an answer to climate change and close environmental catastrophe. Those acts (directives and regulations) bring to life many instruments and institutions aiming to fight the climate change and global warming. One relevant instrument is that of "citizen energy community", being introduced and defined by art. 2 sec. 11 of Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on common rules for the internal market for electricity and amending Directive 2012/27/EU (O. J. L 158, 14.06.2019, p. 125). Another relevant instrument is that of "renewable energy community", which was introduced and defined by art. 2 sec. 16 of Directive (EU) 2018/2001 of the

European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources (O. J. L 328, 21.12.2018, p. 82). All those institutions are categories of "citizen energy initiatives" (sec. 43 et seq. of preamble to Directive 2019/944).

Moreover, regarding the considerations of legislative framework among ECs, it can be denoted that there has been an organizational transfer from the EU to the EC, while, at the same time, the transposition of EU law into the contracting parties of southeast Europe (SEE) and beyond has also proceeded (Tangor and Sari 2021). In such a context it is notable the lack of national legislation or capacity to implement policies in SEE which would also protect public health and international Treaties, being proven highly capable to curb air pollution. The Energy Community Treaty that extends the EU's internal energy market to SEE countries is, therefore, both an opportunity and a threat which can function as enabler to healthy energy forms, or blocking in SEE coal power that fuels climate change and air pollution. The Treaty also motivates public health experts to become engaged in (Stauffer 2016).

2.4. Europe–European Union (EU) Contexts of Energy Communities—Group 4

In this group of Europe–EU context, it can be inferred that the congestion management and the capacity allocation show that the SEE Regional Electricity Markets (REM) deal with the same priority issues as the other REMs do, and that the progress of REM are a feasible natural step towards the creation of a single European electricity market. Issues of concern are the EU membership perspective of the SEE countries and the expectation that the SEE REM shall become part of the internal electricity market, as well as the overlap between some members of the SEE REM and the other European Regulators Group for Electricity and Gas (ERGEG) ERI (Karova 2011). In a similar study, the emergence of the EnC of SEE should abide to the EU's external energy policy, the specific regional approach of the EU at the Western Balkans, and the neo-functional ideas of those European Commission officials who are crucially involved in the process. Those officials involved are guiding a "popular" version of neo-functionalism as the idea that peace can be established with integration starting in a highly technical area and with creating the institutional capacity for a possible spill-over into other areas. EU's rules and institutions in the energy sector make the EnC as an innovative new mode of governance in SEE (Renner 2009). In Table 11, the literature overview of the Europe–EU contexts of ECs, Group 4, it is collectively presented.

Based on Table 11 data, significant findings regarding the locality and the decentralized characteristics of ECs can be inferred. Indeed, while ECs powered by RES should play a pivotal role to intensify RES technologies that reflect a growing wave of prosumer movements, especially in industrialized economies such as those of Japan, further development of ECs necessitate the appropriate regulatory framework to promote the concept of a sustainable regional community internationally, focusing on a more preferential approach to/model of ECs. Such a model can be suitable and adaptable to other ECs from the hosting country, in terms of membership, non-discriminatory treatment, barriers, support schemes as well as grid connection and management. In a real-world applicability of model designing, it is also noteworthy that the establishment of municipal power producers and suppliers (small-scale entities that cover local areas), they can lead to broader popularization and the use of distributed energy at both the maternal country and at its EC's receptors/beneficiaries (Sokołowski 2021). Not surprisingly, a national or European model on ECs embodies the "assets" of nature, character, and scope of a regulatory model of its renewable energy sector, thus it can be subject to be attributed as "exporting tool" for the development of Ecs outside the EU (Sokołowski 2019). Based on Table 11, it can be argued that the today and the future of ECs in Europe can be determined, among other things, by:

- The provision of ensuring that accession countries have to adopt EU rules as a condition of membership. However, the reliance on external incentives is limiting the effectiveness of bilateral accession conditionality, especially for pre-accession countries with uncertain membership prospects (Padgett 2012).

- Political and legal aspects of electricity transmission contain those aspects that should explain the impact of the EnC Treaty and of the acquis communautaire on energy on the electricity transmission sector. In such a reality the status and the interconnection capacity among countries and the current level of cross-border electricity trades impose the need and the criteria for electricity transmission investments in the Energy Community of South East Europe (ECSEE): Albania, Bosnia-Herzegovina, Bulgaria, Croatia, Macedonia, Montenegro, Romania, Serbia, UNM in Kosovo (Vailati 2009).

Table 11. The Europe–EU contexts of ECs—Group 4 (studies are presented in reverse chronological order and in last name of first author alphabetical list).

Reference #	Scopes and Research Objectives	Methodology and Analysis	Research Outcomes and Key Findings
Lode et al. (2022)	ECs are considered as emerging players in the European energy market. The relevant policy-making can promote ECs development by introducing legal entities, stakeholders experience, as well as various challenges during their set-up. To this end, the main key factor of ECs success regards the consideration of stakeholder objectives.	Authors analyzed case studies in 7 countries: Belgium, Spain, the Netherlands, and Greece, where the multi-actor multi-criteria analysis (MAMCA) was applied in the design phase of ECs. Commonalities and differences for each case were highlighted, providing insights into the variations among EC options, stakeholders, as well as their preferences regarding the targeted ECs.	Aspects considered as utmost importance were that of emission reduction, community building, energy cost reduction and grid stability. EC options with greater end-consumer participation and shared benefits were preferred at all cases by all stakeholders.
Sciullo et al. (2022)	ECs for the past decades were proven an alternative way to organize the energy chain and to challenge the incumbent systems intended as collective action initiatives in the energy field involving citizens' participation. Europe recently adopted the Clean Energy Package in which ECs found a formal recognition by the EU as potential actors of the transition of the energy system towards a wider and more decentralized use of RES, although it remains challenging the transition of ECs to foster their diffusion and scaling up.	This analysis provided some preliminary evidence about the factors and dynamics that seem to have played, and may play, a role in hampering or facilitating EC model diffusion. The key aspects of consideration were those of: the energy mix and market structure; the institutional and policy landscape; the wider social attitudes towards environmental issues and cooperation among citizens.	It was shown that a thorough comparison of different EU countries can reveal historical evolution pathways and can better understand what factors might trigger ECs exploitation in the EU.
Frieden et al. (2021)	The financial attributes of ECs are among the most representative characteristics and physical parameters of an energy-generating unit in a RES power plant. Subsequently, large-scaled PV power plants imply higher amounts of generated electrical energy with just a small impact on the investment amount, but also an increased domestication capacity of energy users who are interested to contribute at environmental sustainability while lowering their electricity bill at apartment blocks of larger roofs and larger PV units.	This study offered a better understanding and plausible comparability among the emerging regulatory frameworks with those already in place in EU member states. Since some countries already made significant progress in the transposition process of the EU framework, they could comply with the provisions of the European Commissions' Clean Energy Package. However, the majority of EU countries are in an early stage of transposition.	While technology allows for a sufficient amount of storage of electrical energy, it can also contribute to securing supply of larger remote groups of buildings in harsh climate conditions. With proper regulatory frameworks in place, the final consumers can form ECs as one way to participate in collective self-consumption activities.

Table 11. *Cont.*

Reference #	Scopes and Research Objectives	Methodology and Analysis	Research Outcomes and Key Findings
Tangor and Sari (2021)	Recently, there was an organizational transfer from the EU to the Energy Community (EnC) while, at the same time, the transposition of EU law into the contracting parties of southeast Europe and beyond has been also advanced. EnC has been the subject of relatively few theoretical explanations.	The introduction of a new alternative theoretical explanation can holistically conceptualize the role of the EnC, following the compilation and evaluation of the EnC-developed theoretical literature Then, the exploration of rational choice and historical institutionalism's potential can explain the EnC's evolution. Subsequently, EnC's impact on the EU's external energy policy and the Europeanization of energy policies of the contracting parties were studied.	It can be argued that institutional improvements within the EnC they can better drive to implementation results as being foreseen policy implications.
Soeiro and Dias (2020)	Community energy (CE) is a recent concern due to their relevant role in some energy markets and in some cases for their key role in the future of all steps of energy sector: energy production up to energy supply. CE represents a legal form of business that exists worldwide especially among the following sectors: agricultural, financial, general consumption, and industrial contexts, nonetheless on a smaller scale.	In countries where the regulation of public support schemes is inconsistent, then, the development of a sound financing plan and a business model for REC seems to be more difficult. Thus, it is a key role of public authorities to promote and to support the development of RES, the growth of REC, as well as other forms of ECs. In this context national regulations, as transpositions of European directives, they are ruled out by different legal barriers and they may be different according to each one country thus shaping exclusive conditions of Europe expansion.	A comprehensive investigation entails those European level policies and legislation at national level that transposes or complements EU legislation in order to gain a broader perspective on the multiple regulations of European countries concerning REC while considering different law motivations for different evolutionary steps across Europe. While it is fact that laws and regulations raise various restrictions on CE, the development of REC are supported through public policy in most European countries meeting the EU 2030 climate and energy framework and considering the new legislative framework as an undergoing EU energy directive where CE's seem to have a saying at this point in history.
Heaslip et al. (2016)	In the relevant literature, the determination of enablers and barriers towards successful development and assess of successful elements to be implemented by sustainable energy community development methodologies is noteworthy. This research context could be precisely addressed through extensive semi-structured interviews with the managers of the sustainable ECs at both projection level and in-situ visits of each one project conducted.	This study involved fieldwork research of sustainable ECs development and methodologies in the two islands of Denmark and om a rural village in Ireland, respectively. It was proven that social barriers are interconnected and often reinforce each other, thus, it remains crucial to understand how barriers can be transformed into enablers supporting the successful development of sustainable ECs in Europe.	The findings' adaptation to successful tools and methodologies used across all ECs they can illustrate those determining key factors of successful ECs development in Ireland, specifically, and Europe, in general.

Table 11. *Cont.*

Reference #	Scopes and Research Objectives	Methodology and Analysis	Research Outcomes and Key Findings
Prelevic (2016)	The electricity market of southeast Europe (SEE) consists a challenging "experiment" of important electricity reform for the whole world, since the SEE countries have to follow by the EU clear institutional reform models. Subsequently, the key role of the SEE ECs is to extend the EU internal energy market in the SEE. Therefore, the EU has assigned regulators to facilitate infrastructure investment. Therefore, the SEE can testify the transformation of the EU reform model both within the EU and beyond (including plethora of developing countries in the Mediterranean region, Asia, and Africa).	The study determined possible regulatory instruments to attract investment in new electricity infrastructure projects, while recommending possible regulatory support options and investment incentives. It is critical to underline that regional approaches play a decisive role of such a policy and incorporate possible solutions for harmonization of the regulatory regime and its replication outside SEE.	Cross-border cooperation and harmonization of regulators are highly linking the electricity sector with the needful infrastructure investment model applied at regulatory regimes. A failure to generate or design a regulatory asset base and the adequacy of capital costs in revenue requirements could result in either under-investment or over-investment, leading to risks about grid reliability. Failure prevention entails all SEE ECs and the Energy Community Regulatory Board (ECRB) to a widely debated possible regulatory instruments that promote new investment over the past years.

3. Discussion

Based on the literature overview on ECs developed above, it is noteworthy that within the last decade of analysis, an ongoing research interest of ECs in the field of energy poverty emerged, mainly focusing on the topics of European energy policy evolution towards the EU convergence among member states (Poiana 2017), the linkages between energy poverty and the provisional role of European Atomic Energy Community (McKee 2017), as well as the deployment of common energy planning that are directed to foster European neighbourhood policies (Kuhlmann 2014; Petrov 2012), like that of:

- Aviation market in EU (including services, safety, security, air traffic management and environment protection) (Charokopos 2013) and
- Accession countries adopt EU rules as a condition of membership and, in this context, energy interdependence is considered an evaluation criterion regarding the rule transfer effects of EU institutions relative to accession conditionality. In this context external incentives are prone to limit the effectiveness of bilateral accession conditionality, especially for pre-accession European countries with uncertain membership prospects (Padgett 2012).

Moreover, another research focus on ECs has been directed to the role of storage technologies, such as the battery energy storage system, which are expected to shape to future operation of micro-grids. However, current simulation tools underestimate their operating costs, which jeopardises their efficient use and deployment (Korjani et al. 2021).

There is also an increasing interest in multi-energy communities, which could become important sources of demand response flexibility, especially when equipped with storage. while solving local capacity congestions, enabling these ECs ability to partake in energy/reserve markets and subsequently improve their business cases. However, flexibility potentials and provision of multiple services are also prone to uncertain and challenging parameters of ECs modeling (Good and Mancarella 2019), thus, the deployment and the evaluation of KPIs with different generation and energy storage sizes could turn out to be conflicting: i.e., a large PV energy generation increases the self-sufficiency but it also periodically generates an energy surplus that exceeds local storage facilities that has to be sold on the grid. Besides, while a smaller generation can be totally self-consumed, it is not always able to meet ECs needs. Therefore, a totally self-sufficient and self-consuming community is an utopia (Cielo et al. 2021).

The designing steps are as follows: after this selection, an economic evaluation is performed and then the sizing is defined (Cielo et al. 2021). Subsequently, the conduct of a detailed business model supports researchers' understand, given the most competitive sizing, by comparing different models and classifications including (Cielo et al. 2021): community-driven prosumerism, third-party-sponsored communities, a mixed sharing classification related to the previous two models. The research outcomes of the proposed methodology are opt to measurable considerations regarding self-consumption indexes, self-sufficiency levels related to reducing the greenhouse gases emission, while eventually proposing some possible/feasible developments of the proposed methodologies (Cielo et al. 2021). The tasks of ECs locally producing (a) the energy needed for the load, (b) the design of the active part of the REC the are not easy endeavours (Cielo et al. 2021). Therefore, RECs research and their potential impact on the electric distribution grid they have become a necessity (Weckesser et al. 2021).

In this context, the optimal exploitation strategy is further changing and adaptable during the time of the day and through the seasons. For example, in summer the PV output is at its maximum while in winter its contribution can become negligible. Moreover, PVs sizing can trade off between an energy surplus available in summer and an insufficient share in winter, being feasible by key performance indices that balance between generation and loads (Cielo et al. 2021). Similarly, the role of seasonal adaptations to better evaluate the grid impact, minimum and maximum voltage magnitudes observed within the Energy Community (EC) in the simulated weeks-timeplan were extracted, as well as maximum LV line, MV line, and MV/LV transformer loading were investigated by Weckesser et al. (2021).

With the increasing use of RES in power systems, it is also necessary to overcome the limitations of these resources in terms of the supply and demand balance in high-voltage power systems (Jo et al. 2021). In this study, the Customer-owned Energy Storage Systems (CES) was considered, defined as a market model to a scheduling problem. Such an aggregated-CES (ACES) market model was structured as a bilateral contract for fixed payments. This ACES model was designed to change the charged/discharged power of the depending on the SOC. The numerical outcomes of the proposed model revealed the reduction of the MG operator-owned large-scale ESS (LESS) capacity by enabling the consideration of the CES in the microgrid operation (Jo et al. 2021).

Beyond the aforesaid regulatory and legislation aspects, RECs offer the economic incentives for the evaluation of the business models of the REC initiative (Cielo et al. 2021). REC, as a legal entity, aggregates different users sharing their own resources to reduce both electricity bills and CO emissions. REC was deployed as a multi-objective battery sizing optimisation for renewable energy communities with distribution-level constraints, from the prosumer-driven perspective (Secchi et al. 2021). As a consequence, local public sites, such as municipalities, should be in favor of the REC and can support a feasibility study considering the use of part of the municipal buildings roofs (e.g., school, gymnasium and town hall) for hosting PVs (Cielo et al. 2021).

The electrical loads of municipal sites can be estimated on the basis of monthly electrical bills of the municipal loads, and hourly profiles can be obtained by similar standard loads. Similar to this profile, the household loads can be estimated (Cielo et al. 2021). However, in system modeling, the energy supply system that contains three energy storage methods, heat, electricity, and gas storage, is rarely considered. In the process, of modeling, few kinds of literature consider uncertainties on both the source-side and load-side. It is challenging to study an operation mode in a complex energy supply system (especially one containing HES) (Liu et al. 2021).

The economic dimension is also an adhering consideration of all ECs, especially when the environmental dimension becomes widely discussed in alignment with climate changes' mitigation and adaptation. In this context, there is a rich literature concerning those two dimensions of sustainability: environmental and economic (Kyriakopoulos 2021; Streimikiene et al. 2021). It can be also signified that the social dimension is still underrepresented. Indeed, the majority of research studies on assessing energy performance or energy projects that deal with economic or environmental sustainability, without engaging the social inclusion, which is considered a misleading dimension of sustainability (Kluczek and Gladysz 2022). Although social sustainability is the research objective of few studies, incorporation of social and energy sustainability might be a sufficient precondition for a complex energy assessment (Kluczek and Gladysz 2022). In such a study the individually setting goals by EC end-users are related to self-sufficiency, using distributed artificial intelligence and optimization, stating that individual economic goals can negatively impacting on ECs' self-sufficiency (Weckesser et al. 2021).

Within energy circularity indicators (e.g., fossil energy use, total energy use, and CO_2 emission), complementary impact indicators such as waste, materials, pollutants, and toxic emissions might be included. These indicators could be defined to support an effective and sustainable use of energy, thus, leading energy efficiency improvement, energy consumption reduction, and production costs lowering. Such a multi-targeted effect could further minimize climate change in compliance with SDGs (Kluczek and Gladysz 2022). Therefore, research challenges could be referred to (Kluczek and Gladysz 2022):

- The plethora of methods to determine the evaluation framework concerns a wide range of different, occasionally competitive, indicators and measurement units of environmental, economic, and social interest (Kluczek and Gladysz 2022):
    - Results visualization in terms of graphical objects designed to represent the performance of the three aforesaid indicators: environmental, economic, and social.
    - Sustainability valuation regarding the individual energy-side, in alignment with sustainability criteria. Alternatively, an overall criterion should be based on a score regarding the worst/the best energy performance;
    - Trade-off between the sustainability dimensions can be prevented in order to provide equal importance that is plausible for an environmental evaluation.
- Constraints and barriers of applying a feasible energy sustainable performance method could be defined as follows (Kluczek and Gladysz 2022):
    - Boundaries overcoming. Such boundaries are raised from an inadequate design or from a segmented implementation of policies' planned within institutions;
    - Lacking of access to data. These data are related to energy planning and they are proven beneficiary inflows of the method applied.

The aforementioned review study revealed that the main limitation of the ECs, at least in a theoretical-research viewpoint, is their decentralized attributes, having also wide geographical dispersion and covering broad energy-problem solutions, which imply different energy-planning priorities and ECs strategies of deployment to be drawn. The aforementioned research limitation is further making difficult for energy planners to develop proper ECs that are suitable as "all-in" energy solutions for all energy-consuming sectors. For instance, ECs have been commonly designed for specific energy-consuming sectors, such as at meeting household or industrial energy needs, but not for both sectors. In this respect, the emerging research question that was approached in this review study is to understand the logic behind the ECs development as well as to find ways and procedures—not necessarily technological but also procedural, regulatory, and legislative—under which these detached and decentralized ECs could be flexible, synergistic, easily adaptable, adjustable, and shift-transferable from one community to another community, in order to better serve their scoping as solutions to energy poverty, energy safety, energy autonomy and energy alleviation.

For this, the most common and of utmost importance features of all current and future ECs research are those of (a) behind-the-meter energy storage systems and (b) national energy strategic plans which are able to: (a) ensure optimal sizing and operation and (b) improve reliability in local electricity grids. However, relevant research cannot undermine the impact on the power system per se. Indeed, the lack and the constraints of technologically based knowledge commonly refer to (a) comparative research for operational strategies in economics terms (economics dimension), but also (b) investigate the concurring effects of these strategies on distribution grids (technological dimension) (Weckesser et al. 2021). Subsequently, future research should integrate ECs in such a way that can be technologically synergistic and symbiotic while, at the same time, they can be easily adaptable when selected by national energy planners worldwide. Such flexible and transferable ECs can also prioritize the joint functions: being both economic-profitable strategies and technically shifting solutions to support the smooth operation of local energy grids. Otherwise, stressing, instead of relieving, the grid can be at stake/risky. Moreover, future studies should focus on the importance between smart communities and the capability of adapting and adjusting all their (smart communities') components at stable and reliable power supply systems, not compromising power quality.

4. Conclusions

In conclusion, HES-DES is feasible and reliable to provide multiple energy sources for users. The two-layer collaborative optimization method is suitable for the collaborative optimization design of complex energy systems with HES and multiple renewable energy utilization technologies. The thermodynamic performance and comprehensive benefits analysis method in this paper are also applicable to other energy systems (Liu et al. 2021a, 2021b, 2021).

Regarding the REC, these communities can be flexibly considered totally virtual, meaning that all sources and loads are connected to different points of delivery on the grid. In this way, all produced and consumed energy travels on the grid and there is no direct local consumption. Subsequently, all REC-derived revenues have to be shared within EC members on the basis of REC instate phase. In addition to to REC-granted incentives on the energy performance of the REC, another national incentive was introduced to reduce the Capital Expenditure (CAPEX) costs (Cielo et al. 2021). RECs development is also a forecasting and evaluation tool of renewable energy loads of production considering short and long term variations of ECs characteristics. RECs are of paramount importance optimization procedure coupled with real-time energy management (Cielo et al. 2021).

The contribution of this review study is the organization of the wide plethora of ECs-published studies within the last decade of analysis into representative groups of analysis. These groups reflect on the key-determinants of ECs from a research point of view, revealing the multidimensional, geographically dispersed, sectorally scattered, environmentally alarming, and socio-economically sensitive appreciation of energy, regionally and globally. Future research studies should adapt the socio-economic considerations of the future energy provision, confronting energy poverty and directing the energy future at RES-based technologies of low carbon environmental footprint and technologically feasible scale of real world (transferring model approaches in reality) conditions of applicability. In this context, there should be required the development of real-time operation methods and improving proposed ACES (Jo et al. 2021). Future research can also make identifiable the (energy) system sizes and the renewables-infrastructure dispatch strategy from building owners, while minimizing the life cycle cost of energy (Cielo et al. 2021). In implementing such EC solutions and making them easily adaptable for industrialized pilot RECs, the following issues can be considered:

- High specificity of regulation, primarily referring to refund and incentive schemes (Cielo et al. 2021).
- Flexibility of different stakeholders presence in the ECs (Cielo et al. 2021).
- Environmental and social benefits can be further investigated by ECs, along with the already developed research on the economic advantages/dimension (Cielo et al. 2021).

Current EC development is primarily regional-specific (mainly) in European countries. Plentiful initiatives on ECs have been proposed, but more studies could systematically assess the impact of ECs from different perspectives. Future studies could address different impacts if different strategies are to be applied. It is indicatively noted that studies can be used by both policy makers and Distribution System Operators (DSO), showing that slight alteration of incentives offered to ECs can cause significantly different outcomes. Thus, DSOs and policy makers can further use the research findings to create an inclusive framework for ECs that already anticipates the development and impact on the distribution grid (Weckesser et al. 2021). Selected issues of imperative significance emerging at future agendas and multi-criteria approaches are the following (Kluczek and Gladysz 2022):

- Extending the available dataset towards analyzing different numbers of criteria and alternatives, followed by the reproduction of the same assessment for biodigester.
- Similar experimental sessions should be applied using various MCDA methods to gain comparative analysis.
- Considering the MCDA methodology on energy sustainability valuation, future research should focus on those specific uncertainties that consider the various types of biodigesters or similar projects based on biomass/bioresources to obtain reliable results and simultaneously ensuring decision-making design and energy strategic planning at a better and fully informed manner.

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