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Review

Materiality in community energy innovation: A systematic literature review of hands-on material engagement in energy transition

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A R T I C L E I N F O

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A B S T R A C T

Collective and citizen-driven activities for energy transition have been thriving globally in recent decades. Community energy innovation (CEI) developed through hands-on engagement with materials has garnered increasing attention from the interdisciplinary energy research community. The recent scholarly discussion has highlighted the role of materiality and its relation to collective agency, inclusion, and approaches to participation. Accordingly, paying attention to materiality in CEI can clarify sociotechnical aspects of energy innovation which have been commonly understood through either solely a social or technical view. Furthermore, fostering citizens' take-up of renewable energy in more democratic ways is a prerequisite for accelerating the energy transition and is arguably best done via material, hands-on engagement. However, the focus on materiality, particularly hands-on material engagement, in research on community energy appears to be fragmented. Therefore, we conducted a systematic literature review to better understand how researchers understand and approach materiality and material engagement in CEI. The results of analyzing 36 papers highlight that materiality in CEI has been studied in interdisciplinary fields through diverse methods, and we identify four types of networks in which such innovation emerges. We also identify geographically dispersed and Do-It-Yourself enthusiast-led energy innovations which go beyond the existing understanding of CEI. More importantly, a network may change over time and place because of the configurational material nature of decentralized small-scale renewable energy technologies. However, studying materially-engaged CEI needs further efforts to integrate empirical data more centrally with the existing knowledge base and concretely define how materiality plays out in collective energy innovation.

1. Introduction

Citizens are no longer mere individual customers. Increasing access to technology allows us to not only adapt, adjust, and adopt diverse technologies, but also interact, share, and support others' innovative activities. Renewable energy technology (RET) is no exception. A wide range of citizen-led renewable energy (RE) projects have recently emerged around the world [1], and a considerable number of these citizen activities and projects are done by collective and participatory efforts to meet community needs for RE. Community energy innovations (CEI) have attracted increasing academic attention as a prerequisite for accelerating inclusive and democratic energy transition [2–9]. Additionally, new political efforts have been made to foster CEI in Europe. For instance, the European Commission recently included the concept of community energy in regulatory frameworks [10], and some authorities in e.g., northern Europe and the UK have adopted community energy as a new policy tool for clean energy transition [11,12].

Despite the increasing interest and emergence of CEIs, the current discussion has primarily been occupied with matters of organizational and financial attributes, e.g., decision-making processes, ownership, organizational types, and financial structures or new business models. More importantly, the discussion has largely neglected the material

Abbreviations: CE, community energy; CEI, community energy innovation; DIY, do-it-yourself; ICT, Information and Communications Technologies; MECEI, materially-engaged community energy innovation; NGO, non-governmental organization; RE, renewable energy; RET, renewable energy technology; RQ, research question; STS, Science and Technology Studies.

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dimensions of CEI, i.e., how communities develop their own renewable energy solutions hands-on, and how such hands-on engagement with materials mediates collective participation in energy transition. According to recent scholarly discussion on materiality [6,13,14], however, focusing on the material dimension is significant to understanding how the public is currently participating in energy transition. It is not simply because energy innovations take a physical and technical form. Rather, material engagement is arguably an effective and democratic way to foster citizens' take-up of RETs in current society.

According to recent inquiries into innovative public participation in energy transition, CEI is contrary to large-scale state- or market-led RE development in many ways. For instance, in a large-scale approach, the public is given roles mainly as consumers in consumption, via self-monitoring, time shifting, and altering consumption habits [15]. However, CEI frequently requires communities to directly engage with materials in the construction and installation phases [4,16,17] as co-creators [18]. Examples explored in these studies include the solar collector do-it-yourself (DIY) movement [3,17], wind turbine development led by DIY enthusiasts [19], and emergence of Internet forums for exchanging DIY ideas around RETs [20]. In addition, these researchers argue that micro-scale decentralized RETs are accessible to ordinary people because they can be manufactured using basic workshop tools, techniques, and materials. Furthermore, involving communities in the designing, building, advancing, and diffusing phases increases not only the possibility of successful RE innovations, but also citizen participation in energy transition. Participants' roles in materially-engaged CEI go beyond the definition of consumers and even energy prosumers, which recognize user activities only through the energy value chain, such as production, consumption, and distribution [21].

However, the current understanding of energy communities is still largely limited to what Walker and Devine-Wright's concept map suggested in 2008, focusing on local processes and outcomes (without consideration of material aspects) [9]. Moreover, research to understand material-driven CEIs appears to be scarce and too scattered to build a more concrete discussion [22]. Therefore, the authors of this paper conducted a systematic literature review to clarify how scholars understand, approach, conduct, and evaluate materially-engaged CEI. For this paper, we tentatively define a self-building, DIY type of CEI as materially-engaged community energy innovation (MECEI) by focusing on their material engagement and materiality. This review addresses a primary research question (RQ) and four sub-RQs as follows:

RQ. How has materiality been explored in materially-engaged community energy innovation, and what avenues exist for future research?

1. How are MECEI studied in academic research: research field, type of research, focus, method, and research position?
2. How and where are MECEIs emerging?
3. How is MECEI best understood? What are its differentiating characteristics?
4. What is the potential research agenda for future MECEI studies?

We address these questions in the following way. We start by outlining our research topic, conceptualizing materiality in community energy innovation and outlining high level perspectives taken by the extant research (Section 2). We then move to a basic overview of the main trends, outlets, citation connection, and topical categories of the papers reviewed (Sections 4.1–4.2). We then identify types of communities to understand how and where MECEIs are emerging (Section 4.3) and describe the characteristics of the material innovations that are common across the communities (Section 4.4). We offer an alternative concept map to embrace the emerging MECEIs (Section 5). Lastly, we summarize our findings and their implications and provide a future research agenda (Section 6).

2. Material engagement in CEI

MECEI in this review refers to community RE innovation developed through hands-on engagement with materials. The term "material" typically refers to physical things as prevailing in the realm of science and engineering. In this understanding, tangibility is a key feature of materiality, for example, whether it can be touched and where it is located. There has been a strong dichotomy between the material thing and the social thing [23]. However, the current scholarly discussion expands its meaning to non-physical and conceptual things that consist of matter by looking more closely at how materials construct our way of doing. For example, through an empirical case, Orlikowski [24] illustrates how we cannot interact with or experience data or electricity through touch, but rather how we do so through materials such as paper and screens. Ashcraft et al. [25] further argue that material entails institutional facts, which inform how we work in organizations. This sense of material, which is multivalent and negotiable, often accompanied by the word "materiality", prevails in social science disciplines, e.g., Science and Technology Studies (STS), anthropology, organizational studies, and human geography, to name a few [26–30].

Academic research recently published in the field of public participation in energy transition tends to embrace these senses using the term sociomateriality [31–33]. The majority of studies in the field tend to define physical and social material and materiality as things engaged in and supporting the process of RE innovations – energy resources, devices, infrastructures, material setting, and landscapes [34,35]. Hence, a constructivist and relational understanding emerges by arguing that materials should not be understood as inert, fixed, and discrete entities, but as a social outcome which is constructed through the collective process of social, economic, political, and cultural elements [33]. For instance, some empirical case studies demonstrate how non-linear and heterogeneous material dimensions of CE have affected regional RE uptake [35] and potentially RE related policies [34].

Furthermore, this discussion on material and materiality has been expanded towards its political and moral matters of concern by STS scholars such as Noortje Marres and Bruno Latour. In his highly influential book *Making Things Public*, Latour [14] calls for 'object-oriented democracy' by exploring how objects mediate issues of public concern and identify multiple assemblages with agency. By coining the concept of material participation, Marres [13,36] develops the discussion and demonstrates that materials have a political and experimental capacity to foster public engagement in more mundane and domestic sites, rather than discursive political sites. Some studies adopt the concept of material participation and explore how introducing and using energy technologies, e.g., solar PV [6,37] and battery storage [38], may foster new energy practices and material-based public participation. However, Ryghaug et al. [6] stress that energy citizenship is not given by these technologies by default, but through certain practices related to technology such as localization, integration, and diversification.

While such research has actively contributed to the discussion on a material-driven energy transition, the analytic focus of the research is mainly on citizen activities in the phases of planning and consuming RETs. Although some studies give a glimpse into collective engagement in designing, building, modifying, and advancing RETs, they tend to conflate it with a mere development process. Consequently, the scale and implications of citizens' hands-on and material approach to RETs have been largely underestimated. Considering the common material feature of community energy innovations which are small-scale, off-grid, and easy to assemble, we argue that a community's hands-on engagement in the construction and installation phases is more *material* [13].

Recent user innovation studies, for example, consistently argue that opening up materiality for community engagement plays a pivotal role in the motivation and success of community's efforts to take deep ownership of their own energy. Such studies report a successful shift from grassroots and DIY oriented energy innovations to national and international scale projects [3,20,39,40]. The most salient examples are the Danish bottom-up wind turbine development and the establishment of the Wind Empowerment association. The most promising technological development of the Danish wind turbine has been realized through the 'practical hands-on approach' of skilled workers and DIY builders [41–44]. Wind Empowerment, in turn, is an international association of DIY enthusiasts for a locally manufacturable small-scale wind turbine which can be constructed by local people with minimum tools and techniques [45–47]. Nevertheless, in engineering driven projects such as Wind Empowerment, the potential for empowerment is strongly implied, but the materialities involved are not conceptualized further. There are also various grassroots and transition studies that similarly stress the sociomaterial character of technology and the potential that engagement with the materials holds for adjusting and improving technology so that it can spread more widely and yield critical scrutiny of technological options [11,48].

Conceptualizing materiality in technology development, including RE, is taken furthest in STS and anthropology related works [49,50]. These articles conceptualize the sociomaterial make-up of community innovations as seldom being comprised of either discrete objects or systems, and as being formed of locally assembled parts, components, practices, and knowledge, which may vary from one site to another.

Given this background, and the fragmented nature of the research landscape on community energy innovation and how materiality is conceptualized, we thereby undertook a literature search to examine how materiality and material engagement by energy communities are addressed. Focusing on how CEIs are materially realized by a community's hands-on engagement can unfold how networks connecting between sociomaterial elements are being shaped and changed, and how innovative and experimental energy publics are created.

3. Material and methods

To understand how MECEI is studied and what avenues exist for future research, we conducted a systematic review of academic literature [51,52]. As described above, since MECEI is a nascent topic in academia, there was a need to design a search protocol flexible enough to embrace wide research areas and at the same time rigorous enough to filter out irrelevant papers and allow other researchers to replicate the process [51]. To serve both goals, a four-step research protocol was developed and, as a result, 36 papers were selected for this review as presented in Fig. 2.

3.1. Literature search

3.1.1. Step 1. Finding search keywords through a scoping study

The first step was to conduct a preliminary scoping study to identify appropriate keywords for finding studies related to MECEI [52]. As illustrated in Fig. 1, the three search terms "renewable energy" (RE), "community innovation," and "materially-engaged" are the phrases that represent the topic and our research question. However, since the field of RE is well established, we identified that the search terms, particularly "RE", were too vague and broad resulting in an unmanageable number of papers that focus on technical aspects. Therefore, as seen in Fig. 2, "RE" was divided into specific keywords referring to types of RETs such as "wind", "solar", "bio", etc., and the sub-keyword was also further delineated into several, more specific terms. For instance, "wind" was divided into "wind energy" and "wind turbine." For the same reason, other search terms, "community innovation" and "materially-engaged" and their sub-keywords were divided into several synonyms.

The preliminary review provided the justification for the inclusion and exclusion of some sub-keywords. For example, the term "bottom-up" under "community innovation" was excluded because it captured few papers focusing on social material aspects but too many engineering or technical papers in which the term is used to describe bottom-up energy production models. In contrast, the terms "user innovation" and "open innovation" under "materially-engaged" were identified as valid keywords as they enabled us to identify numerous papers of interesting citizen-led, open innovation cases where communities collaborate with different actors on RE developments and entail material engagement. Likewise, although "hands-on," especially when combined with keywords related to RE, also returned a large share of irrelevant results, we decided to keep it in our search net and manually discard irrelevant papers, since it unexpectedly enabled us to find articles with educational implications of MECEI.

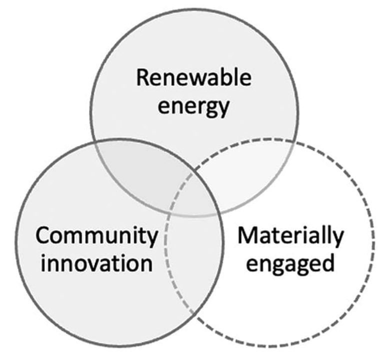

Fig. 1. Three relevant academic topics of MECEI.

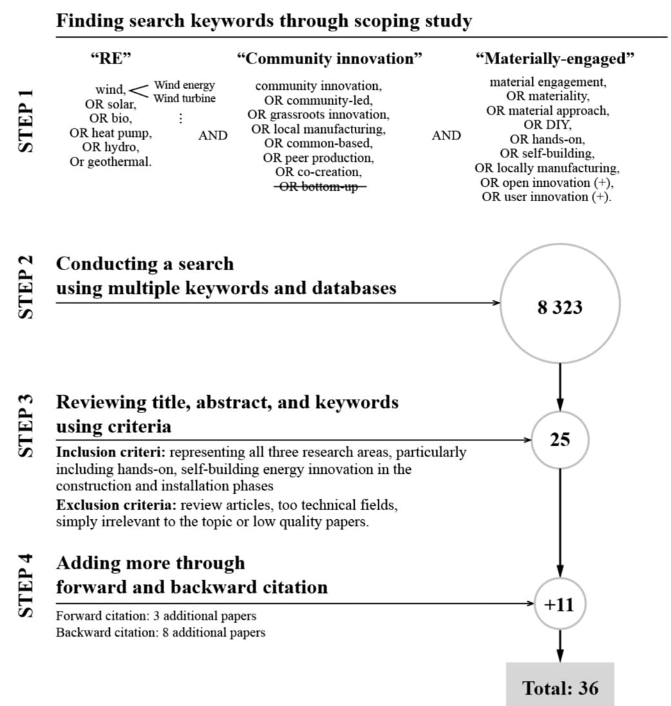

Fig. 2. Steps in selecting publications and the resulting numbers of articles at each step.

3.1.2. Step 2. Conducting a search using multiple keywords and databases

The second step was to conduct the search using the combinations of the search terms. Three electronic databases were used, namely Scopus, Web of Science, and EBSCO Academic Search Elite, limited to title, abstract, and keywords. Additionally, the search was limited to peer-reviewed journal articles to ensure the quality of papers. The keywords identified in step 1 were combined using a boolean operator AND and OR and entered in the three databases in October 2023. As a result of this, 8323 papers were initially identified in this step.

3.1.3. Step 3. Reviewing titles, abstracts, and keywords using criteria

The next step was examining article titles, abstracts, and keywords using the exclusion and inclusion criteria. The full text was reviewed for some articles with insufficient information in their title, abstract, and keywords particularly related to "materially-engaged". If the papers did not include hands-on, self-building energy innovation in detail, they were excluded. In addition, 62 articles, out of 89, were found in more than one database, and hence the overlapping articles were consolidated. Two papers related to educational aspects were also ruled out based on evaluation of their quality. This process resulted in 25 papers.

3.1.4. Step 4. Adding more through backward and forward citation check

The last step included articles yielded by forward and backward citation of papers selected in step 3. This step resulted in 11 additional articles after applying the same inclusion and exclusion criteria as step 3. The overall search resulted in 36 papers.

3.2. Synthesis

The synthesis of the data was done using qualitative content analysis [53] with several supportive tools such as ATLAS.ti, spreadsheet software, and citation analysis. ATLAS.ti was employed to derive critical themes and insights related to materiality from the selected literature. In using the tool, both directed codes related to our research question and emerging codes that arose during the coding process were considered. Next, a spreadsheet was used to systematically document basic information of the studies as well as sociomaterial aspects, e.g., research type, methods, type of community, and RET involved. Last, to examine how scholarly discussion takes place, we also analyzed the 1822 citations of the 36 papers selected for this review manually.

4. Findings of the systematic literature review

This section presents the findings of the analysis of 36 articles on MECEI selected through the systematic process described in the previous section. This section is divided into four subsections. Section 4.1 provides a general summary of the results focusing on year of publication, journal type, location of study, research methods, and citations. Section 4.2 identifies four key topical categories discussed in the papers. These subsections address sub-RQ1. Section 4.3 identifies four community types wherein MECEI emerges in consideration of sub-RQ2. Section 4.4 addresses sub-RQ3 by identifying three material characteristics of community material innovations that were common in all community types.

4.1. General result

4.1.1. Research type – year, journal, method, and geographical location

The data shows that MECEI is a new and emerging topic in academia with roots across different disciplines. As shown in Fig. 3, before 2013, there was at most only one publication on MECEI per year. However, there was growing interest in the topic from 2013 on, with four or five articles published between 2013 and 2015, and four in 2018. Yet, the number of articles have decreased somewhat from their height in the early 2010s. The main academic journals are *Energy Policy* ($n = 5$), *Energy Research and Social Science* ($n = 3$), *Energies* (n = 3), and *Science & Technology Studies* (n = 3). The other 25 articles are evenly distributed across 18 journals that cover a broad range of subjects, according to Web of Science categories, e.g., environmental studies and science, engineering and mechanics, anthropology, and education.

Despite the various disciplines and subjects involved, generally the research is dominated by two methods. First, more than half of the papers use ethnographic methods combining participatory observation, field visits, and interviews. Second, the rest of the studies are based on a practice-based approach where researchers are engaged in the research outcome as project managers and engineers. Only three papers employ mixed methods, using both qualitative and quantitative research techniques. It is notable that four papers use historical narrative. Two/thirds of the papers are real-life based, single case studies focusing on a regional ($n = 9$), national ($n = 7$), and project case ($n = 8$) while 13 papers used multi-cases and a comparative approach.

The number of cases in Europe far exceeds those in other continents. More than 70 % of the scholars are based in Europe such as the UK, Finland, and Denmark, and European cases account for around 65 % of the articles. Particularly, Finland shows the highest interest in terms of the number of scholars (18 out of 90) and study sites (8 out of 45). As Hyysalo et al. [54] describe, Finland is a culturally and educationally promising place to nurture DIY innovations. This distribution also suggests that there are many compelling collective energy innovations even in a single country that could attract the attention of several scholars. On the contrary, the number of papers dealing with cases in continents such as Asia, Africa, and Central and South America account for only one/third: these articles were even rarely written by scholars based in those regions. Meanwhile, two papers present no geographical site of study but state their focus is on an online community [55,56].

4.1.2. Type of RETs

RETs in the review are mostly small-scale, off-grid technology except for large-scale wind turbines discussed in comparison with hand-made wind turbines [57] or showing development of wind turbines from the grassroots to a national scale [58,59]. According to the conventional categories of RET, solar energy, wind turbines, and biomass ($n = 4$) are

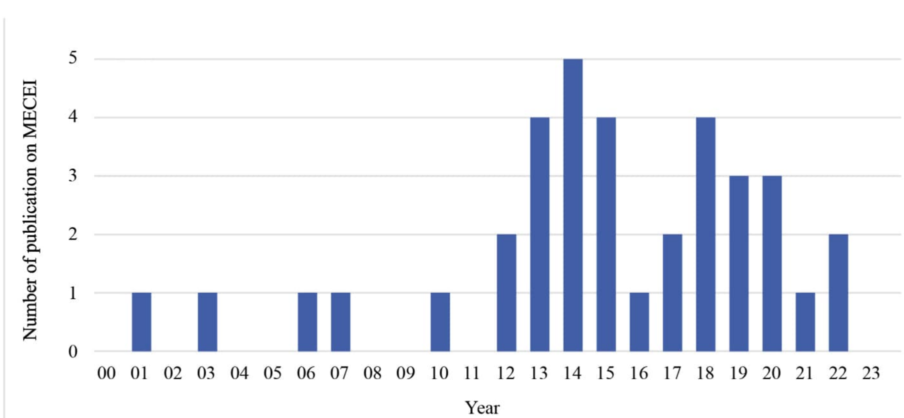

Fig. 3. Temporal trend in the number of reviewed publications by October 2023.

the most popular technologies employed by communities. However, the RETs presented by most of the papers are not a single technology standing alone. From a relational view, the papers directly and indirectly portray it as complex and hybrid technology - a large set of heterogeneous energy systems combined with various components (e.g., batteries and charge controller), locally available materials (e.g., wood and plastic), surrounding environment (e.g., rooftop and existing infrastructures), and even different types of RETs (e.g., solar PVs with hydro power and a windmill pump used for irrigation). In addition, the RETs are deployed not only for energy provision and consumption. As the recent decade has seen, in our review Information and Communications Technology (ICT) is increasingly integrated with RETs for energy monitoring ($n = 8$), storage ($n = 2$), governance through a smart grid ($n = 2$), and efficiency such as when retrofitting ($n = 3$).

4.1.3. *Citation connection*

This section presents the results of the citation analysis to disclose how the scholarly discussion on MECEI takes place and what the most referenced articles are in the field of research related to MECEI. The citation analysis identifies one well-connected cluster consisting of 18 papers as seen in the blue cloud in Fig. 4. In this cluster, three papers in bold boxes which are cited by approximately 10 papers are identified as the key articles. In 2006, Ornetzeder and Rohracher [3] explored how bottom-up self-building solar collectors and sustainable building technologies have grown at regional and national scales in Austria. Seven years later, Hyysalo, Juntunen, and Freeman published two papers [20,60] that delineate and analyze around two hundred user innovations with heat pump technologies that were discussed on Finnish online forums. Both papers analyze compelling bottom-up RE innovations and their diffusion process through the lens of user and grassroots innovations. However, they also differ in several ways. The notable difference is whereas the focus of paper [3] is the vertical dissemination of the innovation from local to national scales, the two Hyysalo et al. papers [20,60] reveal horizontal collaboration and diffusion between heterogeneous and anonymous individuals, which better reflects the current dynamic of user innovations.

In contrast, the other half of the papers are loosely connected or entirely disconnected from each other, as seen in pink, yellow, and green clouds in Fig. 4. This implies that in this relatively young field of research related to MECEI, article output seems to revolve around a small set of scholars or still rests on unsolid scholarly discussion. This discussion continues in the following Section 4.2.

4.2. *Topical categories of reviewed papers*

This section describes the four main research topics that emerged in the selected papers. These topics were identified by examining common topics with regard to the research field, focus, and reference of the reviewed papers. The most prominent topics that carried across the papers reviewed are collective user innovation, energy justice, mechanical and technical solution, and educational tool for sustainability. While most of the publications belong to one topic, five publications [46,56,61–63] addressed two topics (as seen in Fig. 4). Two papers [64,65] are outliers that address MECEI in terms of life skills and everyday activism in ways that neither align with the four main topics above nor present enough similarity to form a fifth topic. Fig. 4 shows the reviewed articles according to the topical categories which will be discussed in detail next.

4.2.1. *Collective user innovation*

The first and most consistent topic is collective user innovation for low-carbon energy transition. Eighteen papers, out of 36, understand MECEI as energy innovation led by diverse user groups: civic energy communities [66,67]; online user communities [20,54,55,60,68–70]; RE self-building community [3,5,17,71]; and user community at a national level [58,59,71,72]. In the papers, a wide range of research methods were used, such as interviews, document analysis, participatory observation, and historical narrative.

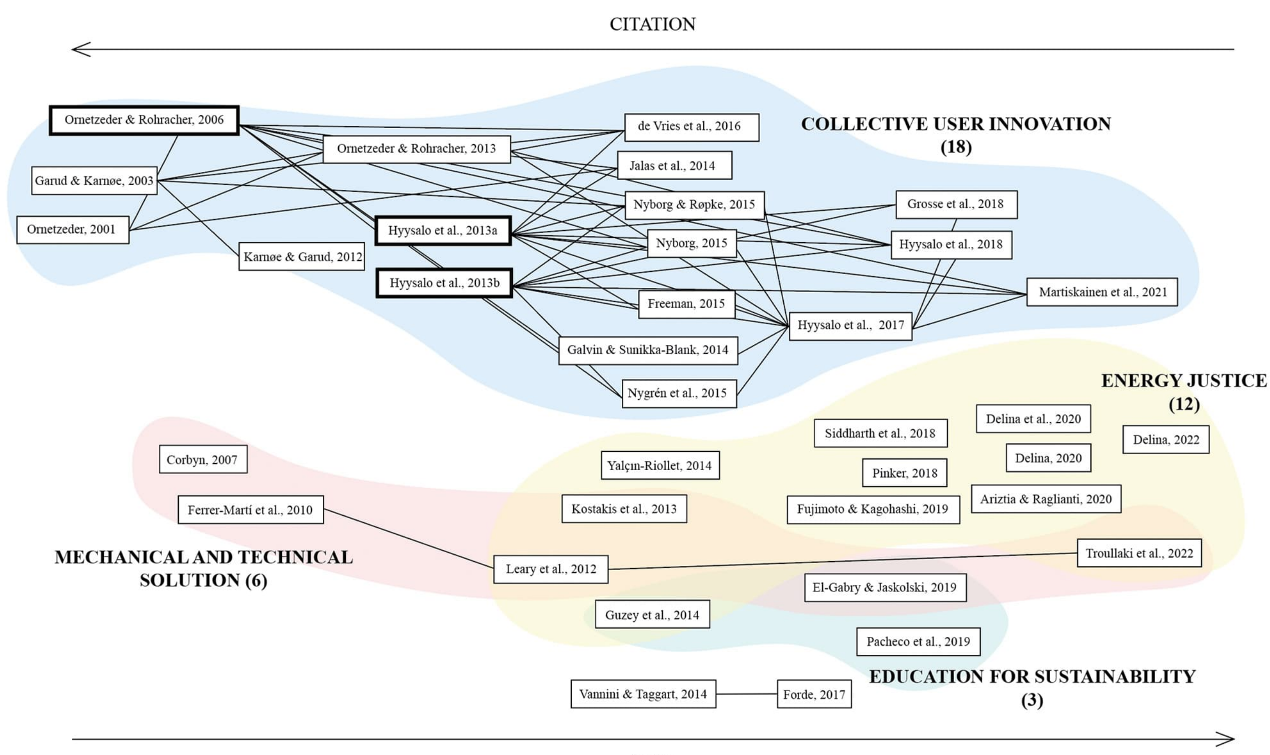

Fig. 4. Visual presentation of citation connections within the literature. This figure presents papers in time order, and the line between papers stands for a citation connection. The color clouds represent four topical categories: collective user innovation (blue), energy justice (yellow), mechanical and technical solution (pink), and education for sustainability (green). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

The focus in the papers is how communities are collectively involved in RET innovations and how this innovation is disseminated as a form of knowledge. While most of the papers focus activities within contemporary communities such as online communities, Garud and Karnøe's two papers [58,59] demonstrate how a community can be involved in a collective yet distributed manner over time, as seen in the modern design of Danish wind turbines. With examples of heat pump technologies and domestic thermal retrofit respectively, Hyysalo et al. [54] and Galvin and Sunikka-Blank [67] demonstrate that innovations made by user communities can even be technically superior to commercial solutions by firms or professionals. However, there is also a contradiction, for example, in how the relation between the complexity of RETs involved in the innovations and the emergence of collective participation is understood [3,20,56,60]. In addition, a few papers, in particular Jalas et al. [17] and Ornetzeder and Rohracher [3], share the concern that collective user innovations depend on too few inventive users, and this may be a bottleneck to dissemination.

This understanding of MECEI as collective user innovation is theoretically based not only on user innovation studies [73,74], but also grassroots innovations [7,39,48,75]. Diverse literature written by von Hippel [76–78], particularly the book entitled *Democratizing Innovation* [79], are the most mentioned by the papers. However, de Vries et al. [66] argue that seeing MECEI through the lens of grassroots innovation is also important to reveal how communities collectively create knowledge in response to local problems and how such knowledge informs paths of technological change. In a similar vein, social practice theories [80], community studies [81], and communities of practice [82] are all frequently cited by the papers to emphasize the sociomaterial aspect of RE innovations.

4.2.2. Local solution for energy justice

The second evident topic is about energy justice for inclusive energy transition. Twelve papers approach MECEI as a local solution for energy justice, energy democracy, and the Sustainable Development Goals (SDGs), and the main method used for data collection is ethnography, such as participatory observation, field visits, and interviews. As energy justice has gained interest as a new topic in energy transition studies [83], the papers have also been published in relatively recent years as shown in the yellow cluster in Fig. 4.

The authors of the papers argue for the importance of the participation of climate vulnerable communities in energy transition, e.g., off-grid communities located on islands in the Philippines [84], in mountains in Peru [85], and in national parks in Thailand [86]. Incorporating their local knowledge and locally available materials into RET innovation is crucial to meet their conditions and disseminate their solutions more widely. Furthermore, cases of energy injustice are not restricted to low-income regions: communities in affluent countries that are neglected in regional and national energy systems are also struggling to gain access to energy and participate in the energy transition. Examples in our review are an Indian community in the USA [62], an island in the UK [57], and a remote community in France [87].

In the communities, access to the national grid is seemingly prevented by environmental constraints alone. However, a few cases show that energy scarcity is also caused by social and political decisions that result in excluding the communities in regional and national energy systems. For example, access to the national grid for a community is forbidden by law [86] or absent due to the decreasing population of a rural community caused by low employment prospects and urban growth [57].

The theoretical link between the papers is weak compared to the previous topic. Walker et al. [88], which was one of the first articles that clarified the term community energy, is the only mutually cited article.

4.2.3. Mechanical and technical solution

Generally, a problem-solving approach is widespread across all the papers in our review. Particularly, six papers explicitly explore mechanical and technical solutions through practice-based methods where the authors of the papers participate in the development as project managers or engineers.

Interestingly, the wind turbine is the only RET seen in this topic. The wind turbine the papers explore is small/scale and locally manufacturable with varying capacity between 7 and 100 kW. The papers explored diverse technical issues related to wind turbines, e.g., how to measure wind speed for a wind turbine [63,85], a cost-effective wind turbine solution [56,89], and the process of manufacturing wind turbines with locally available materials [63].

Most of the inventions are led by non-profit organizations. The importance of local participation in maintaining wind turbines installed is also acknowledged by the papers. However, only two papers address the importance of local manufacturing and maintenance in depth. For instance, Troullaki et al. [61] compare four different conditions of local manufacture and maintenance, and Leary et al. [46] claim that sustainable and reliable energy systems require local participation in repairing and producing spare components.

There is no reference or theoretical foundation commonly shared among the papers except Hugh Piggott's wind turbine manual [90], and materiality is narrowed down to a technical and mechanical understanding of material.

4.2.4. Educational tool for sustainability

The last topic discussed across the papers pertains to educational implications. Particularly, three papers appear to understand MECEI as an educational opportunity, e.g., situated learning and STEAM, that combines science, technology, engineering, the arts, and math, to teach sustainability and collaboration simultaneously in a hands-on manner. All papers in this topic argue that hands-on and practice-based learning can stimulate better learning experience related to RETs for students of different ages from undergraduate [63,91] to 4–8 graders [62]. More importantly, this type of education provides context-specific knowledge which is different from theoretical knowledge that only models an ideal situation [63]. In addition, besides these papers, in our review, there is wide acknowledgement of the importance of engaging local schools in initiating local energy innovations as a key partner [5], encouraging local engagement [61,85], and facilitating follow-up activities such as maintenance [85].

Akin to the previous themes, wind turbines are also the only RET explored, and data was collected mainly through practice-based methods. In addition, most of the argument relies on pedagogy literature (e.g., engineering, science, sustainability education) and rarely conceptualizes materiality.

4.3. Community types

Analysis of the literature revealed different community types in which MECEIs emerge or can be emerging. Therefore RQ2 was not a focal point from the outset but rather emerged from examination of the reviewed papers. Aligning with STS understandings of groupings, configurations and networks to sensitize our analysis, as discussed in Section 2, we examined diverse sociomaterial elements presented in the papers, such as the motivation to initiate RE innovations, key actors, involved RETs, and the material conditions upon which communities collaborate; the connections among actors and networks; and how networks or communities changed. We thereby use the terms ‘community’ and ‘network’ interchangeably here to highlight both human and non-human elements constituting the sociomaterial configurations [8]. It is important to note that there is no clear boundary between the types of communities, and our final categories are based on a judgment of what perspective is most dominant in the paper in consideration of our second RQ. As a result, one paper [64] remains outside of the categories. Table 1 summarizes the community types, and Appendix A lists the reviewed articles according to the community types.

4.3.1. Locality-based community

The first and most notable community type is one based in a particular locality. Overall, 12 papers present how MECEI emerges around a local community with a clear historical and geographical boundary. The whole process of the RET development in this community is strongly under local control. Although collaboration with external actors such as neighboring communities are occasionally observed, key decisions in relation to the RET development are made through local practices, e.g., neighborhood meetings [57,84].

Material engagement in this community appears not to be optional, but to a certain degree inevitable. For the local communities, a lack of resources, both energy and finance, is a key motivation to initiate their own RE project. With the example of rural communities in Thailand, Delina and his colleagues [84,86,92] show that material engagement is one of the most accessible and practical options for local communities to improve their basic living such as for cooking and schooling. Even rural communities in wealthy countries, for example, Japan, Austria, and the UK, also recognize the importance of MECEI for increasing energy supply and community wellbeing [3,57,93].

While the lack of resources is portrayed as troublesome in the beginning, this becomes a blessing in disguise throughout the process of materializing RE innovations. The inaccessibility to high tech, off-the-shelf components and expertise forces the communities to revalue locally available materials and develop an ability to create a local solution, as seen in the examples of a plastic balloon biogas digester [86] and a hand-crafted wind turbine with scrap materials [37]. In turning the gaps into creative innovations, volunteer-based, skillful members of the community play a key role. They also help unskillful members to be competent with RETs by sharing their knowledge and skills. Consequently, most innovations in the community appear low-tech and easy to assemble, and as local context-specific systems.

However, locality-based communities do not necessarily remain small and local. Six out of the 13 papers demonstrate how small-scale RE innovations initiated by local communities have developed at regional and national scale, which we have identified as the Institutionalizing community type [3,5,71,72,94,95]. Such development brings institutionalization in many layers of the network, from the motivation for RE innovation and tasks required for the community, to technical characteristics of the RE involved.

4.3.2. Institutionalizing community

The second type of community arises around emerging, expanding, and institutionalizing communities with a wider vision associated with sustainability. Eight papers in our review show how MECEI emerges in diverse organizational forms: citizen-led organizations committed to diffusion of a specific type of RE [3,5,67]; vocational schools providing an RE self-building course [17]; and a local or international community committed to self-sufficiency and energy saving, e.g., eco-villages [65,87]. In this community type, RE innovations tend to serve as a means of accomplishing their communal vision.

Collaboration inside a community is also central to RE innovations in this network. However, they also actively expand their network by embracing diverse outside actors with different backgrounds and skills. For instance, the communities intentionally invite outsiders with specific competencies to aid their experiments with RE [87,96]. Jalas et al. [17] show that self-building movements in other countries can be initiated by people with different nationalities and languages. The external collaboration brings not only new expertise on how to use and build RETs in novel and effective ways but it also channels new and high technologies, for example, computer simulations and ICT components [66], and new software [67]. This may explain why this community type is only observed in European cases in this review.

As the community expands in scale, the tasks required for community members to accomplish are multiple. Along with technical development of RE, communities take managerial jobs for effective communications among members and paperwork, e.g., for funding or government subsidies [66,71]. Likewise, some members become 'accidental entrepreneurs' [67] and educators [17].

RE innovations are also systematically implemented in this community type. Some innovations are mainly conducted by a technical team responsible for the RE projects [66]. Knowledge and skill dissemination is also done in a more coordinated manner, e.g., self-building courses, a hands-on week, scheduled collective site visits, and public meetings. With the example showing the growth of the self-building RE movement on a national scale, Ornetzeder and Rohracher [3,5] argue that the organizational unit enables long-term learning processes between different user groups and between users and professional producers. In Garud and Kanøe's papers [58,59], the users' contributions to the modern design of Danish wind turbines are distributed over time. At the same time, RE innovations in this community type have become products simply assembled from prefabricated components and more sustainable and effective technologies.

4.3.3. Project-based community

The third type of community emerges as an engineering project led by an international alliance. The international alliance is temporarily shaped to provide a locally manufacturable RE solution to an off-grid community and consists of local communities, educational institutions, enterprises, regional governments, international non-governmental organizations (NGOs), and research institutions. Seven papers in our review are related to project-based networks.

The wind turbine is the only RET seen in this community, and the projects' primary aim is the local manufacture of wind turbines. Therefore, the wind turbines developed should be simple and straightforward to be built by the local population with minimum tools and techniques. However, in the planning and evaluation phases, diverse sophisticated technologies are also used, e.g., a computer aided design program, SolidWorks, and Google data, for measuring wind speed, modeling wind

Table 1
Summary of the four types of communities where MECEIs are emerging.

	Locality-based community	Institutionalizing community	Project-based community	Online community
Feature	Geographically and historically bound	Expanding and institutionalizing	International and project-oriented	Geographically dispersed and interest-driven
Site	Around the world	Only Europe	Mainly Africa, Asia, Central and South America	Online
Key actors	Members of local communities	Members of local communities and diverse external actors	An international alliance and DIY oriented experts in NGOs	Heterogenous individuals
Aim	To solve a local problem, i.e., energy poverty	To achieve a shared vision, i.e., sustainability	To solve a local problem, i.e., energy poverty	To gain information about RE innovations and peer support
RET	Mainly communal projects combined with low tech and local materials	Both communal and individual projects with high and low tech	Mainly communal projects with high and low tech, particularly wind turbines	Individual project combining high and low tech
Material engagement	- Inevitable option - Strong local control - Importance of alternative, local material provisions	- Collaboration-driven innovation with external actors - Inclusion of prefabricated components	- RE solutions led by external actors with passive involvement of local people - Relatively short term	- Dispersed engagement - Peer support and knowledge sharing

turbine ideas, and evaluating the wind turbine built.

In the development process, DIY/oriented experts play a key role. The papers reveal that most of the technical innovations are led by experts of non-profit organizations (e.g., Wind Empowerment and Practical Action) or educational institutions (e.g., universities). However, they explicitly and implicitly indicate that the wind turbines they develop are open source designs. Leary et al. [46] explain that 'any successful generic design modifications they make can then be fed back into the open-source design, thus ensuring its continual development' (p. 174).

In the project descriptions of the papers, the importance of collaboration with the local community is recognized. For example, Ferrer-Martí et al. [85] conducted interviews with local people to understand the socioeconomic context of the community before embarking on the project, and Troullaki et al. [61] and El-Gabry and Jaskolski [63] involved a local vocational school in the project for better engagement with local people. However, key decisions regarding technical features of the wind turbines are left in the hands of the experts. Furthermore, a clear role division between experts and lay people continues throughout the projects as the local community is passively engaged in the projects as either helpers or recipients; local engagement is largely absent in the core process of technical development.

4.3.4. Online community

The fourth type of community pertains to geographically dispersed, interest-driven, and online user communities where anonymous individuals freely exchange information and skills related to RETs without time-space constraints. Eight papers in our review present this community by focusing on national (e.g., a Finnish heat pump forums) and transnational online networks (e.g., Thingiverse, Instructables and OpenEnergyMonitoring).

In this community, RE innovation starts as an individual project. Each member of the community carries out their own RE project that produces, monitors, and analyzes energy in their home sector. Freeman's study [69], where face-to-face interviews with the members of an online community were conducted, indicates that although members share the same interest regarding RET and seemingly join the communities mainly to acquire information required for their individual project, the reasons to initiate the projects are multiple and sometimes ambivalent, e.g., personal rewards, environmental concerns, and reducing energy costs.

In addition, although starting individually, the interactions and activities in online communities encourage collective innovations through peer support. Through the example of Finnish online forums, Hyysalo et al. [60] demonstrate that technical problems of an individual project are solved by volunteer-based peer support through threads, pictures, and comments. Grosse et al. [55] also highlight that providing feedback and calling for actions most increases the probability of collaborative innovations in online communities. Furthermore, with their own wind turbine project, Kostakis et al. [56] also show that the open-source software and hardware shared in the online community enable uninformed users to build a wind turbine from scratch.

The RE innovations developed by a group of heterogeneous users are also diffused through online communities. Hyysalo et al. [54] identify that while few innovations are copied as is, one third of user innovations are adapted by using different and cheaper materials. Additionally, RE innovations collectively developed by communities combine low tech (e.g., locally available materials) and high tech (e.g., ICT). Due to the language skills needed, the papers also indicate that this type of network seems available only to people with English skills, and Finnish in some cases.

4.4. Differentiated material characteristics

In this section, we examine material characteristics of the innovations that were commonly shared across all community types in consideration of RQ3. These characteristics differentiate these CEIs from large-scale RE development and thus have implications for how energy transitions unfold. They also have implications for how RETs become embedded in local practices, as we will discuss further in Sections 5 and 6.

4.4.1. Configurational MECEI

The first common material characteristic is that energy innovations developed through hands-on engagement with materials easily travel and reconfigure their materials, forms, and functions differently according to the context in which they relocate and operate. There are several concepts developed in STS that clarify the transferability of technology, such as plasticity [97] and fluid object [98]. However, we rather draw on the concept of configurational technology [99–101] that enables us to focus on when and how technological innovation is being transferred and implemented in different settings through installation, test, and use by users [102].

Almost all papers in our review detail the process of implementation of RE innovation in different local settings. In these cases, the origin of the innovations mostly comes from elsewhere, e.g., neighboring communities, like-minded people in online communities, books, or research papers. As argued by de Vries et al. [66], however, mere knowledge sharing is insufficient to build successful RE innovations. Grosse et al. [55] also highlight that disseminating information triggers collective and collaborative innovations the least, even in online communities where knowledge sharing is a fundamental function. Instead, they emphasize that '(the) most valuable and efficient learning has taken place in the communities' direct efforts to implement new specific projects' [55,66].

Configurational RE innovation appears not only within the papers, but also across the papers selected for this review. The most prominent example is Hugh Piggott's hand-made wind turbine model [90]. Four papers in our review demonstrate how Piggott's model is implemented and modified in rural areas in different countries, such as Ethiopia [61], Peru [46,85], and the Philippines [89]. Leary et al. [46] highlight how modification requires not only technical but also economic, social, and ecological consideration of the new local contexts in which the wind turbine operates. Another notable example is the Austrian self-building movement. The papers on the movement [3,5,71] have theoretically and practically influenced other cases, e.g., the solar heat collector self-building movement in Finland [17].

4.4.2. Learning by trial-and-error

Second, most of the innovations discussed in the papers are not done at once. Instead, they have gone and are still going through successive trial-and-error processes to work readily. Most authors in our review describe failures as part of an active learning process as seen in their own phrases: gradually accumulated knowledge [58,59,67], learning-while-implementing [66], feedback loops [46], and experimental learning [63]. This iterative learning process relates to the aim to optimize the output and efficiency of RETs (e.g., adjusting the height of a wind turbine to optimize electricity generation), revalue and recycle materials (e.g., using wood and plastics instead of imported and expensive materials), or find adequate places to install RETs (e.g., in communal spaces or on individual roofs).

Additionally, the learning by trial-and-error process provides more supporting evidence of the first material characteristic, configurational innovation. As Fleck [99] emphasizes, the implementation of configurational technology inevitably involves iterative trial-and-error processes to make the technology suitable for new locations. For instance, in de Vries et al. [66], the results of several real-life tests and computer simulations are applied to designing an engine system suitable for a new location. In addition, the trial-and-error cycle also takes place during the period of use as seen in the case of Leary et al. [46], where user feedback leads to redesign of the blades and bearings of the wind turbine which was a fault.

4.4.3. Locally available materials

The last common characteristic is that the locally suitable designs are accomplished through material selection. Some cases modify forms and structures of RETs according to local contexts. However, most of the modifications start from revaluing and recycling materials that are readily available around the local communities. The most typical examples are wood and abandoned industrial products. Hyysalo et al. [60] report that although user-innovators begin their innovation with a ready-made product, locally available materials are easily added to their innovations and eventually makes them different in form and structure. However, it does not necessarily mean locally available materials are always low tech and natural materials. RE innovations in all community types tend to be rather hybrid, combining low and high tech, and natural and industrial materials.

5. An alternative concept map of MECEI

In the previous section, we identified four community types of materially-engaged community energy innovation (MECEI) and three material characteristics that were common across the communities. Inspired by scholarly efforts to visually conceptualize energy communities [4,9,103], we offer an alternative concept map to synthesize these key findings [104]. As shown in Fig. 5, this map consists of two important sociomaterial elements of community energy innovation (CEI) explored in this review: collaboration and material engagement. The x-axis represents the range between two material conditions within which people collaborate: at one end, dispersed and individual projects, and at the other end physically working for a communal project. The y-axis represents the level of the communities' material engagement: strong local control or driven by technical expertise.

The map we offer provides the sociomaterial layers that recognize a wider range of emerging energy communities. In the field of community energy (CE), the most well-known concept map is one suggested by Walker and Devine-Wright in 2008 [9]. Their map suggests that a social and institutional aspect is a necessary condition to recognize 'ideal' (emphasis in the original) CE. The Locality-based community identified in our review and located in the top right (Fig. 5) is the 'ideal' case and the majority in our review. However, as Walker and Devine-Wright clearly concede, their map excludes the material aspect [9]. More importantly, it is in line with the prevailing assumption that collective and local communities are undoubtedly just and sustainable (see the discussion on the local trap: [105,106]). This limited understanding of CE results in a failure to embrace contemporary emerging and materially innovative CE [4,103].

However, our analysis identifies various CEIs that sit outside the 'ideal' frameworks yet actively contribute to energy transition. A notable example is the Online community at the top right in our map where individual and private renewable energy (RE) projects are developed by geographically dispersed collective efforts, for instance user-run online communities. Hyysalo [4] clarifies that although these online and dispersed communities are distanced and private in output, they are open and collaborative in terms of participation, action, learning, and cooperation.

Another conspicuous example is the Project-based community located at the bottom right in the map. In our review, the Project-based community is the case where RE projects are led by an international association of DIY enthusiasts and experts, such as the Wind Empowerment association. Since 2009 when Hugh Piggott, who is widely known as a small wind turbine expert, shared the open-source design, over a thousand DIY makers have adopted and adapted it for off-grid communities all round the world [45]. This collective interest and effort resulted in establishing the international association, and members of the association have started to publish journal papers regarding the small wind turbines they develop and their broad social and political implications [46,47].

In fact, this and other cases of the Project-based community type have rarely been recognized by social science research as an energy community perhaps due to surface characteristics related to being engineering-oriented and temporary. However, the reviewed papers provide enough supporting evidence to perceive it as CE. These projects are driven by strong DIY ethics and open source principles, and the results of their activities contribute to building communities united by a

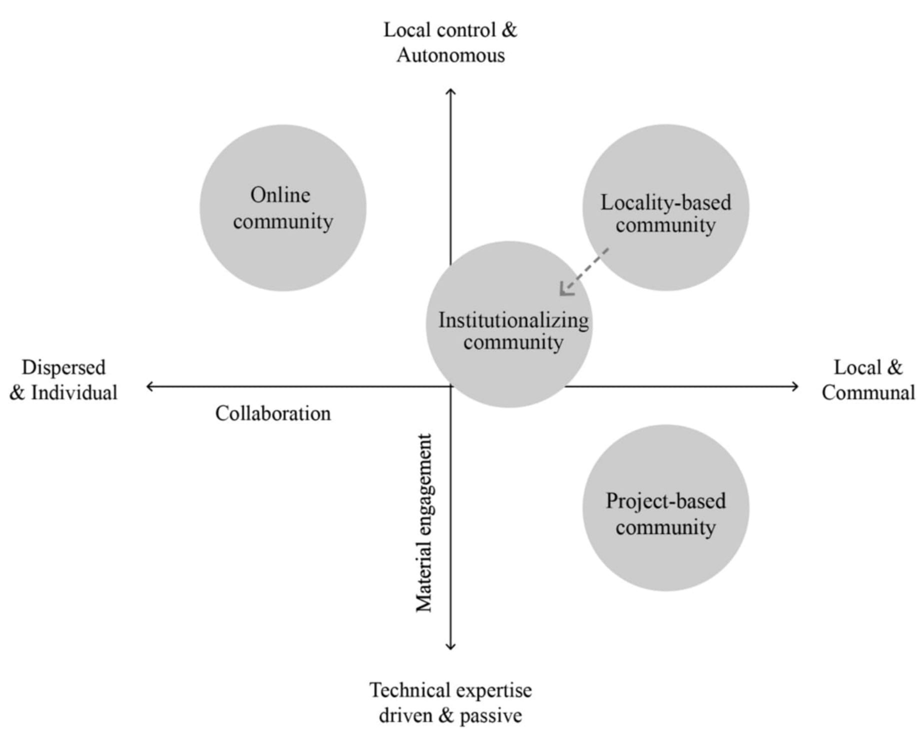

Fig. 5. Concept map in relation to collaboration and material engagement (adapted from [9,103]). The circles in gray represent the four communities identified in this review and the arrow shows transformation.

strong interest in the social value of RETs. In addition, slowly but surely, the researcher-practitioners of the papers in the Project-based community category have also perceived their activities as socially embedded innovations that require a variety of local knowledge, skills, equipment, and materials to construct and maintain the sustainability of wind turbines [46].

Last but certainly not least, using a dotted arrow [103], our map reflects that community types can change. Our review has demonstrated that the Locality-based community, which is a local network, can alter towards an Institutionalizing community type, which extends outside of the local communities and is open to collaborate with outsiders in an institutionalizing process. Interesting cases in our review are the wind turbines in Denmark and solar water heaters in Austria, which were both grown from small-scale and grassroots innovation to national scale. However, our review does not identify CEs located in the bottom left of the map. In addition, the map and axes require further research to be validated.

6. Discussion and future research agenda

The primary aim of this review is to provide the scientific community with a better understanding of materially-engaged community energy innovation (MECEI) and to show how and when community energy is materialized through hands-on material engagement. In this section, we discuss the key points of our findings illustrated above by reflecting on the four RQs.

Regarding RQ1 of how MECEIs are studied in academic research, our findings are threefold. Firstly, in the stage of article selection, we found a considerable number of articles from diverse disciplines presenting obvious evidence of material engagement in vignettes or texts. However, most of these papers were excluded from this review because material engagement was rarely mentioned further in the article. As shown in this review, however, communities' hands-on engagement with energy materials clearly exists and is, in some places, prevalent. Therefore, the lack of focus on a community's material engagement can prevent us from fully grasping how sociomaterial relationships are shaped, how innovative and experimental energy publics are created, and how this can transform the congifuration of energy system. Secondly, although two methods (i.e., ethnographic methods and practice-based approaches) are conspicuous in the selected literature, this review identifies four notable approaches to generate knowledge on MECEI: 1) engineering studies with project organizers' self-description and participant feedback, 2) interview studies of project organizers and participants, 3) ethnographic studies of MECEI in different settings, and 4) historical narratives relying on expert interviews and available documents. These diverse knowledge generation approaches have clear merits of enabling us to have a broad view on MECEI by complementarities. Practitioner reflections, participant feedback, and ethnographic studies can zoom into the intricacies of hands-on energy innovation practices, while interview studies and historical narrative can zoom out to the contexts, organization and evolution of MECEI initiatives. However, thirdly, it is notable that half of the reviewed studies, especially from engineering and education disciplines, prioritize empirical data and barely link to further academic discussions while the other half engages with community energy literature [9,88], user innovation studies [74,79], and grassroots innovation literature [7,39,75]. Although differences between disciplines are acknowledged, empirical evidence alone is not enough to build the knowledge base about how and why RE innovations are realized and its potential values and challenges. Furthermore, scholars should articulate the distinct contributions of hands-on material community innovations to inclusive and democratic energy transition compared to prevailing approaches such as “large-scale industrial solutions”, “plug-and-play”, and “one-size-fit-all”.

For the RQ2 of how and where MECEIs are emerging, our review categorizes four community types and offers an alternative concept map that embraces them: locality-based community, institutionalizing community, project-based community, and online community. The key finding here is that MECEI emerges not only in local communities by local control. Geographically dispersed, individual RE projects may also produce collective materially-engaged innovations through knowledge and information sharing. Cohorts of DIY enthusiasts are also a place where voluntary and professional RE innovations evolve. However, these community types do not necessarily remain exclusive and fixed. The communities, more specifically sociomaterial configurations, may shift and interplay with each other over time and place through the transferability of decentralized small-scale RETs, as we have seen in several examples in our review. Therefore, we argue that we need to enhance our understanding of community energy innovation extended in space and time, beyond geographically bound group activities that can appear rather static, to a view of how new energy communities can emerge and how they can change and evolve over time.

The transferable and configurational nature of MECEI technologies and practices can answer our RQ3 of how MECEI should be understood. Throughout the review, decentralized small-scale RETs are found to be versatile, flexible, and transformable, and this characteristic enables energy innovations to travel and reconfigure their materials, forms, and functions differently according to the context in which they relocate and operate. The *configurational materiality* that is predominant in MECEI enables (and often requires) several cycles of a trial-and-error process from designing, building, using, to modifying, in turn fostering learning in and across installation sites. In the many studies from the open and user innovation field that study materiality, there are competencies in user domain knowledge, technical skills, and sharing of knowledge and solutions among peers that are taken as pivotal, implying that the materialities are knowledge- and community anchored [3,54]. The resulting ‘configurational’ or ‘fluid’ nature of materialities in community energy is a key characteristic in achieving locally adequate solutions that can be designed, built, maintained and upgraded, and decommissioned by local resources and solutions [4,98,99,107,108].

Taken together, these arguments imply CEIs should be understood through a broader sociomaterial lens including diverse types of human and nonhuman actors [14,26,109,110]. Developing CEIs are more than planning and installing RETs in communities; installing RETs is merely the entry point. Rather, developing CEI should be understood as collective efforts for fostering energy innovations based on learning on RETs and interaction with internal and external actors and materials. Such a view reveals a complex sociomaterial networking process, through, for example, how human activities, such as interacting, supporting, and sharing, can be enacted, refused, and reshaped through exchange of non-human agency, and how this eventually influences collective actions around RETs. This view also reveals how communities and collective actions change over time and place. Exploring various types of material energy innovations reveals various venues which embody great potential to become new types of energy communities, but it also fosters a better understanding of how RE innovations can be fostered by reflecting its collective and configurational nature.

These core findings of our review translate to a future research agenda, which is our last RQ. Firstly, research on CEI should more duly address material engagement in CE research beyond simply verifying its existence and importance. Secondly, in describing material engagement, researchers and researcher-practitioners ought to link their findings to the body of research and theoretizations on MECEI that is already established to further, cumulate, and extend the knowledge base. Third, while different forms of knowledge generation on MECEI complement each other, when possible, it would be desirable to utilize the complementarities more extensively and rigorously in research designs [111,112]. Fourth, materialities of MECEI deserve an explicit focus both empirically and theoretically. Even as MECEI in general has configurational materialities, the four community types where MECEI emerges hold different materialities, and there are equally important differences in different renewable technologies as well. Fifth and finally, as seen in our review, the current studies in the field of CE tend to explore community energy with short-term, intermittent site visits. Instead, there is a need for long-term investigation and follow-up research to gain more reflection on not only how the RE innovations are in practice being used or modified according to local contexts, but also how those are transformed and relocated in different settings [4].

We acknowledge several limitations of our study. First, the article search, which was narrowed down to English, may have led to the suggestion that MECEI is more prominent in European countries and our limited scope possibly reduced access to case studies in non-English speaking regions. This view is consistent with the ongoing argument for inclusion of non-English language studies in the field of CE [113]. Second, with regard to the quality criteria, this review exclusively focuses on peer-reviewed articles, which had the downside of excluding compelling book chapters. One example is the above-mentioned Danish wind turbine development. Such limitations related to language and types of articles are indeed common issues in systematic literature reviews [51,114]. Nevertheless, further systematic literature research can address these limitations in advance through co-authorship with non-European scholars or broadening the scope of article selections.

7. Conclusion

This systematic literature review explores research on community energy innovation developed through hands-on engagement with materials. Although the scholarly discussion on this topic is still in its infancy, the current literature has explored diverse types of community innovations through various methods and disciplines and consequently provides us with a broad view on community energy innovations. Our first key contribution to energy research is identifying geographically dispersed and DIY enthusiast-led energy innovations which go beyond existing understanding of community energy innovation. Our second key contribution identifies a distinct configurational materiality of renewable energy technologies. Unlike "plug-and play", this materiality is based on continuous learning through trial-and-error processes and continuous interaction with internal and external actors and materials. Our third key contribution points to the enhanced understanding of community energy innovation extended in space and time, beyond geographically bound group activities that can appear rather static, to a view of how communities change and evolve over time due to configurational materiality. Based on these contributions, we argue that researchers and practitioner-researchers interested in community energy innovations should understand community innovations, not as mere development projects with aims to implement RETs in local communities. Instead, they need to approach it as fostering collective efforts over energy innovations in a longer time frame and through flexible approaches. However, studying materially-engaged community energy innovations needs further efforts to integrate empirical data more centrally with the existing knowledge base and concretely and rigorously define how materiality plays out in collective energy innovation and eventually energy transition.

CRediT authorship contribution statement

Goeun Kuu-Park: Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization, Writing – original draft, Writing – review & editing. **Cindy Kohtala:** Conceptualization, Data curation, Formal analysis, Methodology, Supervision, Validation, Writing – original draft, Writing – review & editing. **Jouni K. Juntunen:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Project administration, Supervision, Writing – review & editing. **Sampsa Hyysalo:** Writing – review & editing, Validation, Supervision, Conceptualization, Data curation, Formal analysis, Funding acquisition, Project administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

This is a literature review and all data is available from the selected journals

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Appendix A. List of the articles reviewed according to four network types

Locality based network (6)	Institutionalizing network (8)	Project-based network (7)	Online network (8)
Ariztia & Raglianti, 2020	de Vries et al., 2016	Corbyn, 2007	Freeman, 2015
Delina, 2020	Galvin and Sunikka-Blank, 2014	El-Gabry and Jaskolski, 2019	Grosse et al., 2018
Delina, 2022	Jalas et al., 2014	Ferrer-Martí et al., 2010	Hyysalo et al., 2013a
Delina et al., 2020	Siddharth et al., 2018	Guzey et al., 2014	Hyysalo et al., 2013b
Fujimoto and Kagohashi, 2019	Yalçin-Riollet et al., 2014	Leary et al., 2012	Hyysalo et al., 2017
Pinker, 2018	Forde, 2017	Pacheco et al., 2019	Hyysalo et al., 2018
	Garud and Karnøe, 2003	Troullaki et al., 2022	Kostakis et al., 2013
	Karnøe and Garud, 2012		Nyborg, 2015
Cases grown from locally based network to institutionalizing network (6)			
Nyborg & Røpke, 2015			
Martiskainen et al., 2021			
Nygrén et al., 2015			
Ornetzeder, 2001			
Ornetzeder & Rohracher, 2006			
Ornetzeder & Rohracher, 2013			

* Vannini and Taggart, 2014 is excluded.

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