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Analysing community-based initiatives for heating and cooling: A systematic and critical review

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ABSTRACT

Energy communities are decentralized socio-technical systems where energy is jointly generated and distributed among a community of households locally. As the energy that is shared among the community is commonly electricity, the energy community's literature is dominated by electricity-systems and mostly neglects collective thermal energy as an alternative energy carrier for heating and cooling. Our goal in this article is to organise the existing research on "community-based initiatives for heating and cooling " by using the Institutional Analysis and Development (IAD) framework, and based on this analysis, identify a future research agenda. Our analysis reveals that the number of publications in this area has been growing fast recently, focusing on technological challenges. Fewer papers take an institutional point of view, in which they cover policies, price reforms and values. The institutionally oriented papers focus on solar thermal energy and bio-based thermal energy. Other thermal technologies, such as geothermal wells, are largely neglected in the literature, but are known to have different institutional constraints. Informal rules and values are mainly researched from a consumer perspective. Since energy communities often consist of consumers and prosumers, additional research is warranted into this area. Evaluative criteria for such communities are limited to economic aspects and greenhouse gas emissions, while indicators such as soil pollution and spatial planning that may play an equally important role are neglected. We recommend studying thermal energy communities as distinctive entities with their own unique characteristics, and we develop a research agenda for this purpose.

1. Introduction

The effects of the global temperature rise on human and natural systems, such as the sea-level rise and the increase of the intensity and frequency of extreme weather events like droughts and floods, are well recognised [1]. According to the IPCC report, "worldwide, numerous ecosystems are at risk of severe impacts" [2]. Greenhouse gases (GHG) mitigation is essential in order to limit the consequences of these impacts [3], and special attention is being placed on transition in the energy sector since it is one of the main sources of GHG emissions worldwide [4]. The energy transition is executed at different scales: international, national, regional and local [5]. Energy communities (interchangeably also used as community energy systems (CES) in the literature) are considered key elements of the energy transition at the local level as they aim to locally generate and distribute renewable energy resources in order to meet the demands of local stakeholders [6].

Although there are many different definitions for CES in the literature (e.g. [7], [8], [9], [10], [11], [12], [13], [14]), in a broad sense, CES are defined as a community of actors in a local area, with renewable energy technologies that they have jointly invested on to generate, consume and/or sell renewable energy [15]. CES promote collective citizen action to address various aspects of the transition to a low carbon energy sector [16].

CES can be based on the generation of renewable electricity (e.g. [17], [18]), the generation of renewable heat (e.g. [19], [20]) or on a combination of the two energy carriers (e.g. [21], [22], [23]). However, the literature on CES does not address how differences in the energy carrier and the technologies that accompany them, impact the social,

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institutional and economic attributes of such collective energy communities. As electricity-generating communities seem to be currently mainstream in many countries (e.g. [14], [17], [18], [24]), this leads to more publications of often case-driven research. Despite the importance of heating and cooling [25], which covers approximately 75% of the non-transport related energy consumption among households [26], [27], community-based initiatives for heating and cooling, namely thermal energy communities (TEC), have received less attention in the literature.

In TEC, households collectively invest in renewable thermal energy systems (e.g. geothermal, bio-energy, heat pumps or solar thermal) to jointly generate and consume thermal energy [19]. Many of these thermal technologies are quite mature but are different from electricity-generating technologies [28], which leads to differences in the distribution and storage infrastructure (e.g. district heating instead of micro-grids [29], [30], and thermal storage systems instead of electrical batteries), consumption patterns [26], [27], initial investment costs [31], behavioural characteristics and collective arrangements [32], [33], among many other differences. For example, indoor air quality [34], and thermal comfort level [35], [36], along with specific biophysical characteristics of the community (e.g. ambient temperature, geographical place, level of urbanization, building characteristics and insulations) [35], [37], are issues unique to TEC initiative.

Our goal in this paper is to outline the existing research on TEC initiatives in order to identify distinctive features of TEC initiatives that distinguish them from their electricity-generating counterparts, and propose areas for further research that require specific attention for this type of energy community. We do this by reviewing the existing body of literature on TEC initiatives. TEC initiatives can theoretically be seen as a form of collective action where actors join efforts to achieve shared goals on a common-pool resource dilemma [38]. Therefore, to provide a theoretical basis to analyse the existing literature and to be able to identify aspects that have not yet been addressed systematically, we use the Institutional Analysis and Development (IAD) framework of Ostrom [39]. The IAD framework is specifically designed for collective action problems [39] and has already been applied to study CES (e.g. [40], [41]). It has proven to be highly instrumental in this domain in particular because it explicitly addresses the formal and informal institutional challenges for such collective initiatives [42].

The structure of the paper is as follow. The next section presents the theoretical background. Section 3 presents the methods that were used in this research. Section 4 discusses the literature. The literature analysis using the IAD framework is presented in Section 5. Further analysis and discussions are elaborated in Section 6. Finally, conclusions and research agenda are presented in Section 7.

2. Theoretical background: Institutional Analysis and Development (IAD) framework

The IAD framework (Fig. 1) was specifically developed to study collective action in socio-ecological systems [39], particularly their related institutions. Institutions are human-constructed rules which shape social, political and economic interactions [43] or, more loosely, rules that govern the system [44], in this case, the (thermal) energy communities. Institutions can be discerned into formal and informal rules [39].

At the centre of the IAD framework is the "action situation" building block, where participants' actions take place [44]. The action situation is "a conceptual space in which actors inform themselves, consider alternative courses of action, make decisions, take action, and experience the consequences of these actions" [39]. The action situation is described by variables such as the characteristics of the individual actors, their roles (position), the range of actions they can take and the potential outcomes, the cost and benefits of those actions and outcomes, the available information they have, the level of control over their decisions and choice/participation mechanisms [43].

What happens in the action situation is influenced by a series of exogenous variables (biophysical conditions, community attributes and rules) and leads to patterns of interactions and outcomes that can be assessed on the basis of evaluative criteria [45]. In the end, there is feedback connecting the outcome of the action situation to the exogenous variables. The description of each exogenous variable is as follow:

- ❖ Biophysical conditions: natural surrounding and human-made infrastructure [41], including the physical and material resources and capabilities available within the system's boundaries [46];
- ❖ Attributes of community: informal rules and public perception [47], including the cultural norms accepted by the community. In other words, the values, beliefs and preferences about the potential outcomes of the action situation [44];
- ❖ Rules in use: formal rules and policies [47] that define what actions are allowed and which are not in an action situation [44].

Even though the IAD framework has conventionally been used to study traditional common pool resource management (e.g., irrigation and fishery), it has lately been applied to energy systems (e.g. [48], [49], [40]) and especially to CES (e.g. [41], [47], [50]).

Since the framework is specifically aimed at analysing collective action settings such as those found in TEC initiatives, we also use it to analyse the literature in this research. By basing our analysis on this framework, we aim to address the literature with a focus on the social and institutional settings for these systems, given their highlighted importance [7], [20], [37]. Furthermore, using the IAD framework also adds value to studies such as [4] and [51], which studied CES literature from integration and sustainability angles.

3. Research methods

An extensive literature search was conducted on thermal energy communities (TEC). This literature review was based on material collected from www.webofknowledge.com and www.scopus.com that are published until the end of 2020, using combinations of keywords as

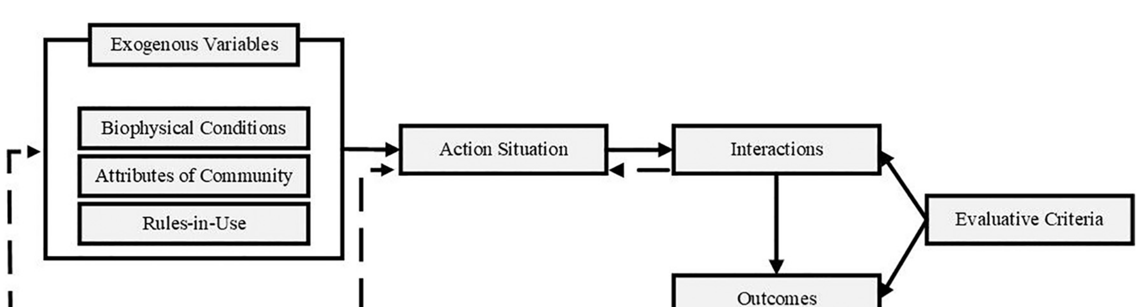

Fig. 1. IAD framework [39].

follows:

As the goal of the current study is to provide a critical overview and propose a research agenda for studying TEC initiatives (and as the literature on TEC initiatives is relatively small), the collected materials cover all different types of documents, including peer-reviewed articles and conference proceedings. The choice of keywords is to cover all research about thermal energy applications ("heating", "thermal" and "cooling") with collective action and bottom-up organizational structures ("energy initiative", "energy community", and "energy cooperative"). Since the goal of this study is to provide an overview of research on community-based initiatives that collectively invest in thermal technologies rather than thermal technologies themselves, we deliberately left out research that does not address the bottom-up and collective nature of these systems or only focus on specific technologies (e.g. solar energy, geothermal, and district heating).

The keywords in Table 1 appeared in 410 documents. However, only 134 of them actually referred to the energy community as a local scale, collective action and bottom-up energy system. For instance, in some of these 410 documents, "energy initiative" referred to an official part of the government (energy initiative office/ plan), but not to the community-based energy initiatives (e.g. [52], [53], [54]). "EU energy community", "international energy community", "atomic energy community", and "East Asia energy community" are other examples of using the "energy community" keyword with a different meaning. Fig. 2 elaborates on the processes of including and selecting documents.

Next, in order to provide a descriptive analysis of this literature, the dominating topics (i.e. common repeating words) in these 134 documents were explored using Vosviewer [55] with co-occurrence analysis of all keywords with minimum co-occurrence of 5. Vosviewer is a software tool for creating, visualizing and exploring maps based on network data (e.g. scientific publications and scientific journals), where these networks can be connected by co-authorship, co-occurrence, citation, bibliographic coupling, or co-citation links [55]. Therefore, in our study, any word in the abstracts, titles, and articles' suggested keywords, that has been repeated in at least five different articles is reported.

Lastly, we analysed and structured the literature in detail using the IAD framework. In order to do so, along with using the Vosviewer (i.e. common repeating words) for this purpose, careful discussion and extraction of the topics studied in each of the 134 documents also contributed. Therefore, all the topics that are discussed in the TEC initiatives literature are aligned with different building blocks of the IAD framework.

4. Overview of the TEC initiatives' literature

This section presents an overview of articles on TEC initiatives (details of these 134 articles are presented in the Appendix). The number of studies related to TEC initiatives has grown rapidly in recent years. As Fig. 3 demonstrates, around 50% of all studies (66 studies) were published in the last 4 years from 2017 onwards.

Although the focus of this study is limited to TEC initiatives and thermal applications, only 53 solely focus on heating and cooling energy generation. The other 81 studies also consider electricity generation in addition to thermal energy. These articles can be further divided into two categories: (i) those where electricity is generated and then used for thermal application purposes, such as for heat pumps (e.g. [56]), and (ii) the energy generation for both thermal energy and electricity, such as community-based (bio-)gas combined heat and power systems (e.g. [57]). Even in communities with both generation of heat and electricity (which is for thermal purposes), district heating remains the main technology for distributing the thermal energy among the households. Different thermal energy storage systems (e.g. thermal buffers), built environment efficiency (e.g. buildings' energy label) and thermal energy applications (e.g. space heating, air-conditioning and hot water) are also studied in the literature. These are unique topics for TEC initiatives and are discussed in detail in Section 5.

Concerning the scientific discipline of these existing studies, following [4], five groups have been identified: technical, economic, environmental, behavioural/institutional, and literature reviews. The technical discipline with 55% of the total share of these studies is the dominant discipline, including topics such as the technical design of renewable heat generation and distribution (e.g. district heating systems), optimization of heating energy systems, and integration of different renewable heating systems. For instance, [58], [59], [60], and [61] study different types of smart systems and their influence on thermal energy consumption at the community level. The relation between increasing domestic energy efficiency and thermal energy consumption in energy communities is presented in [62] and [63].

The second-largest discipline is the economic discipline (16%). Articles with a purely economic focus (e.g. [64], [65]), including topics such as market design, economic feasibility and cost-benefit analysis, cover 12% of the studies. Also, broader topics are addressed, such as [66], which explores socio-economic factors for small rural communities, while [67] studies technical and economic factors for renewable energy technology retrofits to single-family homes.

Environmental studies cover 14% of the literature. Different topics such as the influence of climate change on buildings' thermal energy consumption (e.g. [68], [69]) and the environmental sustainability of thermal energy systems (e.g. [70]) are related to this category.

9% of studies focus on behavioural and institutional aspects (e.g. stakeholder analysis, policy analysis and consumer behaviour). Bioenergy policy in Finland [71], the influence of institutional reforms on environmental aspects related to both the heating and electricity sector in Montenegro [72] and bio-energy policy in Chile [73] are examples of such studies. Lastly, 6% of studies provide a literature analysis, review, or opinion about a particular topic (e.g., thermal technology, policy, or economic consideration). Fig. 4 illustrates the overview of research disciplines and approaches in the TEC initiatives literature.

Before going into the analysis, we first look at the geographical location of the studies. The geographical location of the studies can influence the research results, as different regions have their own background and exogenous variables (i.e. biophysical conditions, attributes of community and rules in use in the IAD framework). As Fig. 5 shows, in the TEC context, most case studies are conducted in Asian and European countries, whilst the literature offers only a relatively small number of case studies in North America. This is relatively similar to the CES literature, dominated by studies focusing on European countries [24]. Fig. 5 demonstrates the percentages of worldwide distribution of the case studies present in the literature.

Given the important level of geographical urbanization, namely differences between rural and urban settings (e.g. space availability) [50], we also investigate the distribution of the studies with this categorization. For instance, [66], [74] show that rural TEC initiatives have less (thermal) energy demand and make a smaller investment in comparison with urban TEC initiatives. However, 39% of the TEC initiatives' literature (52 studies) does not clearly distinguish between the urban and rural contexts. As Fig. 6 shows, more studies investigated TEC initiatives in an urban context than in a rural context.

As a final part of the overview, we extracted the commonly repeated

Table 1
Used keywords.

Combination of the keywords	Number of articles
"heating" AND "energy community"	55
"heating" AND "energy cooperative"	7
"heating" AND "energy initiative"	110
"thermal" AND "energy community"	65
"thermal" AND "energy cooperative"	7
"thermal" AND "energy initiative"	106
"cooling" AND "energy community"	25
"cooling" AND "energy cooperative"	6
"cooling" AND "energy initiative"	29

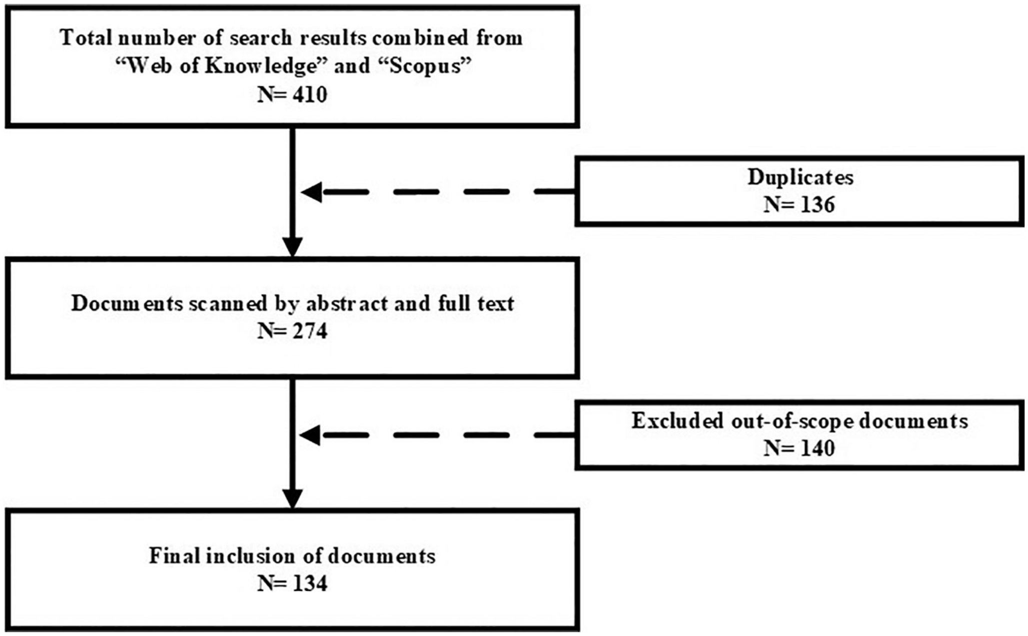

Fig. 2. Prisma Flow diagram literature search.

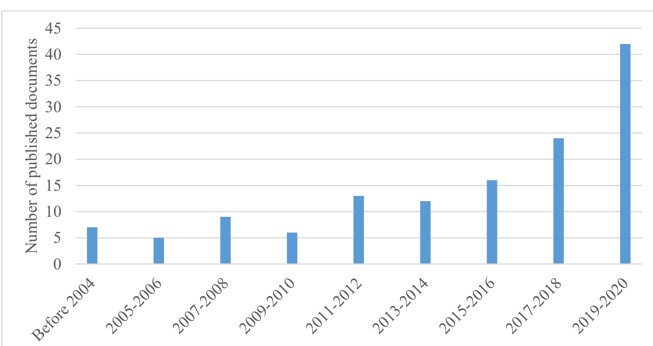

Fig. 3. Timeline of published documents.

words of these research articles using Vosviewer [55], meaning words with minimum co-occurrence of 5 in all articles (more detail can be found in Appendix A, Fig. A.1. and Table A.2.). In total, the results of analysis by Vosviewer showed 91 common repeated words, where we grouped them in suggested categories presented in Table 1 to provide a more abstract overview. The suggested categories have emerged from commonly repeated word themselves while considering studies such as [4] [75]. These commonly repeated words and their overarching suggested categories could be used in organizing and analysing the literature further. Moreover, they bring more context to the literature disciplines (see Fig. 4), as the repeated words are related to a certain discipline. For instance, the following five categories are associated with the technical discipline: (i) energy resources, (ii) energy generation technology, (iii) energy storage technology, (iv) energy distribution technology, and (v) final energy application. Besides providing an abstract overview of the ongoing discussions in the literature, Table 2 would potentially help the next steps of analysing and organizing the literature.

5. Organizing the literature using the IAD framework

As elaborated in Sections 2 and 3, we use the IAD framework to analyse the current literature on TEC initiatives. Along with studying the documents, we also use the keyword categories in Table 2 to determine which papers focus on which building block of the IAD framework.

5.1. Biophysical conditions

For this building block of the IAD framework, we address the biophysical attributes of these systems and the technological and infrastructure attributes [76]. Therefore, the keywords related to energy resource, energy generation, energy storage and energy distribution technology fall within this building block of the IAD framework. This covers 40 out of 91 of all keywords identified and presented in Table 2, which shows the domination of this building block in the TEC initiatives' literature. Fig. 7 illustrates the distribution of energy resources and technologies for heating purposes within the 134 documents.

Among the resources and generation technologies, solar energy plays a major role. Topics related to design of solar energy communities (e.g. [77], [78], [79], [80], [81], [23], [82]) and (technical, economical) feasibility study of solar energy communities (e.g. [83], [84], [85], [86], [87], [88]) are researched extensively. Both types of solar energy technologies, i.e., solar photovoltaic systems (e.g. [89]) and solar collectors (e.g. [78]), are explored in the TEC literature. However, unlike the mainstream CES literature, which is focused on available solar irradiation as a determining factor for solar photovoltaic electricity communities (e.g. [90], [91], [92]), TEC initiatives' literature also considers environmental surrounding factors such as ambient environment and seasonal temperature (e.g. [77], [78]), as these determine the performance of solar heating technologies, such as solar collectors.

In addition to solar energy, various studies (including [93], [94], [95], [96], [97], [98], [99], [100], [101], [102], [103], [104]) address bio energy. [94], [96], [97], provide technical designs and models for bio-based energy communities. Studies such as [104], [103] and [100] study domestic availability of bio-energy (e.g. fuel wood and wood chips) and environmental surroundings (e.g. climate and temperature) as crucial factors for bio-based TEC initiatives.

These two specific RETs, solar and bio-energy, are by far the most studied sources of heat-generation in the literature, which is probably due to their considerable share in local renewable energy generation overall (see articles such as [12], [105]). Although there are few studies in our set (e.g. [106], [107], [108]) that perform research on geothermal energy, all of them also study other RETs in that same study (except [107] that only focuses on geothermal energy). For both solar and bio

Fig. 4. Overview of research disciplines and approaches in the TEC initiatives literature.

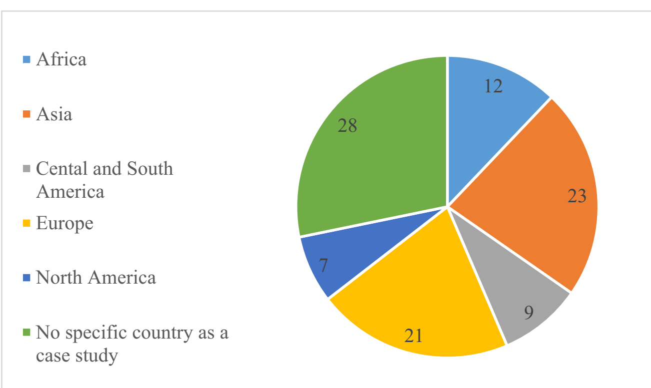

Fig. 5. The percentages of worldwide distribution of case studies of articles.

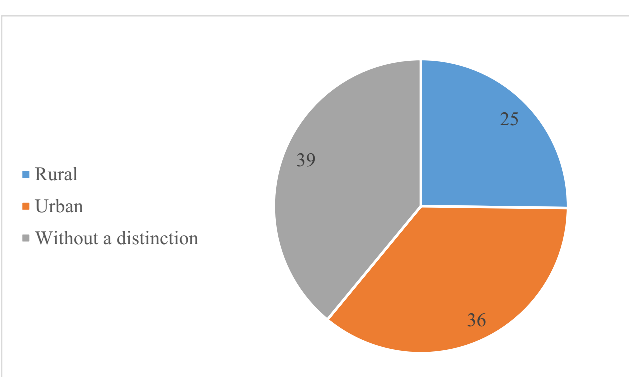

Fig. 6. The distinguish of the level of geographical urbanization of study in percentages.

Table 2
Overview of topics in the studied literature.

Suggested category	Keywords
Energy resource	Solar power, Renewable energy resources, Biomass, Solar energy, Renewable energy, Fuels, Fossil fuels, Biogas, Solar radiation, Renewable energy source, Energy resource, Natural gas, Natural resources, Energy resources, Renewable resource, Alternative energy
Energy generation technology	Electricity generation, Solar water heaters, Photovoltaic system, Water heaters, Solar heating, Renewable energy technologies, Solar water heating, Power generation, Combustion, Photovoltaic cells, Heat pump systems, Solar collectors, Combined heat and power, Solar power generation, Electric power generation
Energy storage technology	Energy storage, Heat storage, Electric energy storages, Energy conservation
Energy distribution technology	District heating, Hot water distribution systems, Electric power transmission network, Smart power grids, Smart grid
Final energy applications	Cooking appliance, Air conditioning, Domestic Hot water, Heating equipment, Heating, Cooling
Formal institutions	Energy market, Energy policy
Environmental aspects	Water, Atmospheric pollution, Greenhouse gas, Carbon emission, Carbon dioxide, Gas emissions, Emission control, Greenhouse gases, Environmental impact
Buildings	Housing, Residential energy, Buildings, Residential building, Intelligent buildings
Research Approach	Design, Integer programming, Modelling, Cost benefit analysis, Optimization, Economic analysis
Economic and financial	Economics, Commerce, Costs, Investments
General keywords	Energy systems, Multi-energy systems, Multi energy, Thermal energy, Thermal power, Energy efficiency, Energy utilization, Heating system, Cooling systems, Sustainability, Sustainable development, Digital storage, Climate change, Energy use, Household energy

TEC initiatives, institutional design and economic topics, including market design, [109], [110], business models, [111], [112], [113], and socio-economic aspects [99], [66], [114], [115] are studied in the literature (elaborated in Section 5.2 and 5.3). As presented in Fig. 7, other energy technologies, such as heat pumps (5% of studies),

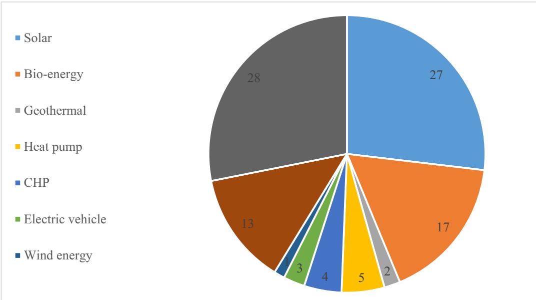

Fig. 7. The percentages of distribution of energy sources and carriers in the body of literature.

electricity (13% for both conventional and renewable electricity) and wind turbines (1% of studies), are also studied in the literature.

There are also a considerable number of articles (30% of the literature approximately) that study TEC initiatives without specifying the energy source or carrier. In these studies, the main focus is on district heating, as the distribution system (e.g. [116], [117], [118]) or on thermal applications (e.g. [119], [120]). District heating design is the focal point of many articles such as [107], [121], [122], [123], [124]. The influence of storage systems on TEC initiatives is studied in [74], [77], [125], [126], [127], [78], [23].

[116] and [118] study integration of energy systems (e.g. electricity, heating, and cooling) for TEC initiatives, while [117] focuses on developing an integrated design approach for sustainable energy communities. [119] explores thermal applications (e.g. chillers, boilers and heat pipes) within TEC initiatives, and [59] studies monitoring households' energy consumption as an essential factor for TEC initiatives establishment. These topics, particularly district heating and thermal storage design, are only specific to TEC initiatives.

Regarding energy consumption technologies specifically, the TEC initiatives literature elaborates mainly on the optimal design and consumer interaction/ behaviour with the consumption technologies (e.g. [63], [128], [70]). In line with this, the literature's focus could be divided in three groups: (i) final consumption, such as providing hot water, air conditioning, and cooking ([128], [129]), (ii) control systems (e.g. [59], [60]), and (iii) efficiency and insulation (e.g. [63], [67], [130], [131], [132]). These consumption technologies are studied within the context of different kinds of buildings (e.g. residential, commercial, social, intelligent buildings, and smart homes). These applications and technologies are also specific to TEC initiatives and are different from the CES main body of literature that mainly focuses on electrical applications, such as lighting and household appliances.

Finally, it is worth highlighting that many biophysical and environmental surrounding attributes are specific to TEC initiatives and have been extensively studied in the literature. These include indoor air quality (e.g. [34]), and ambient temperature (e.g. [77], [78], [119], [133]). Specifically, studies such as [11], [94], [134], [56] focus on analysing the impact of climate, temperature, or location on TEC initiative establishment. These factors are important conditions for TEC initiatives' performance, as they influence system design, thermal efficiency, and indoor comfort.They also influence TEC initiatives institutional settings [135], [136], as we will study further in Sections 5.4, 6, and 7.

5.2. Attributes of communities

The ‘attributes of communities’ is one of the main building blocks of the IAD framework as it greatly influences the behaviour of the actors and, therefore, the action situations [44]. In this context, community attributes (such as norms, values and culture) influence motivations and behaviour towards the (thermal) energy communities. However, as it appears in the literature, minimal attention is given to this part of collective action in TEC initiatives (14 articles out of 134). Although there are no identified keywords related to this building block of the IAD framework in Table 2, a number of articles have studied some aspects related to the community attribute.

In this building block, two main lines of research stand out: 1) norms and values 2) community behaviour. Norms and values (e.g. environmental concerns and lifestyle) are mainly studied in relation to the final application and consumption side of TEC initiatives such as the ones related to cooking stoves and indoor air pollution [34], norms related to income level and energy consumption [137], and norms of single-family homes and relation to energy demand [67]. This is different from the mainstream literature of CES, where norms and values are commonly studied in relation to general motivations such as environmental concerns and financial benefits for participating and investing in CES initiatives (e.g. [138], [139]). Therefore, the norms and values of prosumers that received considerable attention in CES literature are missing from TEC initiatives' literature.

Secondly, the users' common behaviour in a specific community has been highlighted by several studies (e.g. [56]). The influence of users' behaviour on biogas generation (e.g. [99], [140]) and the impact of home efficiency upgrades on residents and tenants (e.g. [63]) are studied in the TEC literature. These studies explore the behaviour of households related to thermal energy applications. Furthermore, [141] observed and modelled social dynamics to explain uptake in energy-saving measures. This research line is similar to the CES body of literature, where studies such as [142], [92], [139], [143] also explore the overall behaviour and attributes of actors in CES initiatives.

In addition to the specific characteristics of TEC initiatives, other overall behavioural attributes of a community have also been studied in our TEC body of literature. Particularly [137] is focused on environmental and social impacts of solar water heaters in South Africa, and [144] dived into the influence of housing cooperatives and households attributes on buildings' heating systems and their costs. These attributes and the approach for studying them are similar to the ones studied in CES literature, such as willingness to pay (e.g. [145], [146]), awareness (e.g. [147], [148]) and trust (e.g. [149], [150]).

5.3. Rules-in-use

In this building block of the IAD framework, we address the formal institutions (i.e., policies, regulations) that influence TEC initiatives [46]. Informal institutions (i.e. norms) were already discussed in Section 5.2. Within this building block, studies are mainly dominated by TEC initiatives' energy market and energy policy. Studies such as [109], [110], and [112] performed market analyses on solar and biomass energy resources. [109] specifically focused on solar water heaters, while [110] explores the biomass market. [64] also explored market diffusion of solar photovoltaic systems. Furthermore, [134] researched the influence of residential aggregators on market flexibility.

Price reforms [71], [72], bio-energy policy [114], [71], [73], and cost reduction [102], are examples of studies on energy policies related to TEC initiatives. [71] extensively elaborated on bio-energy in Finland and how policies and regulations evolve in this regard. Furthermore, studies such as [114], [73], and [102] also focus on policies related to bio-energy in other countries. Assessment of related energy policies is also studied in different researches (e.g. [115], [123]).

Another line of research, in addition to the ones that are mainly technology-driven, is about the relationship between policies, social and environmental aspects. For instance, [72] explains the environmental impacts of energy price reforms, and [151] studied the impact of energy exchange cost on TEC initiatives. [101] explored the role of institutional entrepreneurship in emerging TEC initiatives. However, these studies can be generalized to CES research, as they do not have dived into specificities of thermal energy applications of these communities.

The overall number of studies covering institutions is limited in our studied TEC literature (15 articles out of 134). However, we conjecture that the technological specificities of thermal energy may require specific institutional arrangements and regulations (such as institutions for district heating and underground thermal storage to avoid environmental impacts, including soil pollution) other than the ones that are extensively studied in CES literature. Examples of institutional research in CES include regulations and policies (e.g. [37]), (self) governance (e.g. [152], [153]) and ownership (e.g. [154], [155]).

5.4. Action situation

In the action situation building block, the focus is on the participants, their positions, responsibilities, possible actions, trade-offs and participation rules [44]. Nevertheless, it has not received much attention in the CES literature as a whole, and particularly within TEC initiatives literature. There are only a few studies that are specifically related to this building block, and they can be divided into two main groups (i) participants, their roles and the participation rules (e.g. [104], [156], [157]), and (ii) trade-offs and decision-making processes (e.g. [107], [102]) in TEC initiatives.

For instance, [157] investigated sustainable energy project development (waste-to-energy initiative) with a public-private partnership organizational form in Nigeria. Along with the position of participants and their responsibilities, the study elaborates on technological, economic and environmental factors as well as the project's financial and work schedule data, which are related to the trade-offs and participation of actors. Social, economic and environmental aspects related to the fuelwood value chain in Burkina Faso are elaborated extensively in [104], as well as responsibilities and participation rules.

Regarding the trade-offs and decision-making processes, [34] focuses on trade-offs between human health and biomass usage for households. Therefore, health consideration-heating energy trade-offs are particularly related to TEC initiatives, as the households burn biomass (e.g. wood) indoors for heating and cooking purposes in their accommodation, which is different from electricity-driven communities. Studies about the trade-offs and decision-making processes related to living conditions, energy access and economic aspects are elaborated in [158]. Users' behaviour on biogas production through a technical and a social approach is the focus of [99]. Furthermore, [66] elaborately studied the influence of socio-economic profiles and level of development on energy consumption.

The current body of literature on TEC initiatives is limited to either households (as participants and prosumer/ consumer) or policy-makers (as government/ municipality who execute formal institutions). In contrast, in CES literature, the importance of other actors, such as prosumers, energy companies and community leaders/ cooperative committees, and their roles are highlighted. In addition to such actors, waste companies, farmers (i.e. manure production) [140] and building insulation companies [159] are also important actors that need further inclusion in TEC initiatives analysis given their importance in thermal energy provision. On top of this, further research on other topics in the action situation building block, such as possible actions (e.g. dropping-out process based on the participants' satisfaction), need to be studied.

5.5. Interactions and outcomes

In the IAD framework, the “Action situation” leads to “Interactions” and “Outcomes” building blocks [39]. Considering the thermal technology specifications, topics discussed in these two building blocks have the most similarities with the main CES body of literature. In our literature on TEC initiatives, we found that interactions are diverse and include the ones that take place when developing a new energy community (e.g. [133], [160]), member and board settings (e.g. [161], [162]), and general participation in TEC initiatives (e.g. [134]). [133] is focused explicitly on geometric variables correlated with energy performance and providing guidelines for buildings in hot climates. It also explores the possible impacts and outcomes of such buildings and communities. An optimization model for home energy management systems focusing on internal interactions of energy technologies and users is presented from an aggregator's standpoint [134]. [119] explored the network synergies within energy communities and [160] developed a method to explore the energy cooperatives networks. Studies such as [20], [163], suggest that there are 4 phases for (thermal) energy communities' establishment (namely: idea phase, feasibility phase, procurement and construction phase and expansion phase), where each phase has its own specific interactions and outcomes. These topics are similar to discussions within CES' literature.

The TEC initiatives' literature discussed that possible outcomes of TEC initiatives could be reduction of CO_2 emission (e.g. [164], [11]), more supportive structured policies for thermal energy transition (e.g. [71], [73]) and sustainable and healthy life-style (e.g. [137]). There are other studies, such as [115], [107] and [157], that took an integrated assessment approach (with emphasis on environmental impact) for measuring outcomes of energy communities in developing countries. Key performance indicators for energy communities and TEC initiatives in particular are addressed in most literature, but hardly systematically and explicitly. These indicators are input to the evaluative criteria to assess the performance of TEC initiatives, which will be elaborated on next.

5.6. Evaluative criteria

Evaluative criteria for TEC initiatives include technical feasibility measures, environmental performance measures, individual consumer satisfaction and economic benefit measures. Although various studies could potentially be related to evaluative criteria, 27 articles particularly explore and assess the performance of TEC initiatives. In this part of the literature, studies with a focus on measuring the environmental performance of TEC initiatives stand out (e.g. [157], [165], [11], [123]). These studies focus specifically on the greenhouse gas emission reduction by the establishment of TEC initiatives. [123], [157], and [165] used greenhouse gas emission reduction as the main indicator for analysing infrastructure for (thermal) energy communities, while [11] explored the greenhouse gas emission reduction potential for TEC initiatives. However, the environmental evaluation performance is more inclusive in the CES literature . In addition to greenhouse gas emission, the CES literature also evaluates CES based on community's waste and spatial issues [4], [18]. This is an essential consideration in the context of TEC initiatives as they could potentially have more significant environmental impacts due to their larger consumption share [6], [26], [27] in comparison with electric-generating communities. Furthermore, due to the technical design of TEC initiatives (e.g. district heating as distribution system, and geothermal energy and ground-source heat pump as generation systems), topics related to water and soil pollution could also become relevant.

In addition to the environmental oriented evaluation, there are also other ongoing discussions in the literature for evaluating TEC initiatives. Studies such as [85], [108], [117], and [166], investigate the energy performance of TEC initiatives. [108] specifically studies the energy performance of buildings within energy communities. The study presented an approach to achieve a nearly zero-energy community by assessing the energy performance of building design solutions and renewable energy systems. The literature also conducts various feasibility studies, which can be divided into 2 main categories, (i) technical and environmental feasibility measures (e.g. [85], [68]), and technical and economic feasibility measures (e.g. [83], [84]). Furthermore, [110] evaluated and explored the economic feasibility and market opportunities for thermal energy technologies. [151] studied the impact of internal energy exchange cost on TEC initiatives, while [70] and [167] assessed the techno-economic and economic-environmental performance of TEC initiatives. Finally, studies such as [115], [107], [116], and [168] have an integrated approach for evaluating TEC initiatives. Social, economic and environmental impacts of small scale bio-energy systems are elaborated in [115]. [107] developed a dashboard to support the decision making processes regarding the implementation of (thermal) energy communities.

6. Analysis and discussion

Energy communities or community energy systems (CES) are key entities in the energy transition. The body of literature on CES is dominated by electricity-based technologies, such as solar PV and wind turbines, but since thermal energy consumption in the built environment makes up a large portion of the transition challenge, thermal communities were the topic of our study. Given the technological differences between thermal energy and electricity, energy communities established on either of the two energy carriers are also expected to be different in institutional and social design. Hence in this study, a systematic literature review and analysis was conducted in order (i) to make a comprehensive overview of research on TEC initiatives and (ii) to identify key differences of TEC initiatives and electricity-based energy communities in order to build a research agenda for the future of TEC initiatives.

The literature review revealed that most of the papers in the TEC literature had been published within the last few years. The majority of articles in this literature (72 articles) focus on technical topics, with design, optimization and system integration approaches. District heating is the main distribution technology discussed in the literature. Renewable gas, a micro grid for direct electrical heating and individual renewable thermal energy systems are the alternatives that need further studies. Furthermore, in TEC initiatives' literature, considerable attention is given to the energy consumption of different types of buildings. This is particularly contextual in the TEC initiatives' literature, as different studies discuss how different building' types influence the thermal demand (e.g. heating, cooling and cooking).

In contrast, few studies on actor/ participants' analysis and institutional design. It can be concluded that institutions (both formal and informal rules) are largely neglected in this body of literature. Apart from providing a systematic literature review and a research agenda, this study provided an opportunity to dive into details of TEC initiatives based on the different building blocks of the IAD framework. Using the IAD framework for our literature review analysis revealed that, among exogenous variables, “Attribute of community” is neglected the most, in contrast to general CES literature, where “Attributes of community” gets relatively more considerable attention. This is problematic as TEC initiatives are formed when individuals act collectively, and therefore their attributes (e.g. values and norms) are influential in how TECs form and function. Thus, this hinders the deployment and implementation of TEC initiatives which may consequently hamper the energy transition as a whole. The literature on policies and regulations is dominated by research on specific technologies and resources (namely solar energy and bio-energy), focusing on pricing as an incentive mechanism. As discussed, research on policies and regulations that specifically address TEC initiatives needs to be expanded as they are substantially different from electricity-based communities in terms of land usage, investment, technology, building efficiency, among other factors.

Although the literature on “evaluative criteria” is well developed, it is dominated by technical and economic analyses and CO_2 emission reduction assessments. However, other important topics (e.g. soil pollution and public welfare) need to be included as evaluative criteria for TECs. The literature on building blocks “action situation”, “interactions” and “outcomes” is relatively limited (and also different from mainstream literature on CES), and there is a need for further research on topics related to these building blocks in TEC initiatives context. For further elaboration. see Sections 5.4, 5.5, and 7.

The current study sheds light on the TEC literature; however, it does not address certain technologies, locations or system designs. We deliberately excluded keywords related to specific thermal energy technologies (e.g. geothermal and district heating). For further work, as our analysis showed, there is considerable attention to particular technologies, such as solar energy, bio-energy and district heating. This is probably due to the historical maturity of such renewable thermal energy technologies, compared to relatively new technologies such as geothermal wells and heat pumps. However, it would also be meaningful to focus on the literature of specific thermal energy technology, and while considering the collective nature of TEC initiatives, investigate the new insights, if any. Furthermore, the results showed that the number of studies focusing on TEC initiatives is increasing fast; therefore, it is also meaningful to add more recent studies (e.g. published 2021 onwards) in future reviews. It would also be meaningful to consider other keywords, such as thermal energy system, renewable thermal energy, collective action and collective decision-making in order to collect a larger number of documents to validate and generalize current findings.

As TEC initiatives are based on the collective action of individuals, the collective action perspective and the IAD framework that we used in our analysis were highly instrumental in mapping out the current research and identifying gaps. As a future research avenue, it is meaningful to investigate the relationships and interactions between the building blocks of the IAD framework in the TEC initiatives context. Studies such as [169] hired such an approach. Other lenses (e.g. urban resilience) and other frameworks (e.g. innovation management and multi-level perspective) may provide additional insights related to resilience and different stages of technological diffusion of TEC initiatives.

7. Research agenda and future work

This research aimed to study the body of literature on Thermal Energy Communities (TEC) to highlight state of the art and propose areas for further research. By taking a collective action perspective in our literature analysis, we paid special attention to the institutional and community attributes of these community-based initiatives. This perspective is less highlighted in the general body of literature on CES and even more so in the TEC literature. We used the IAD framework to map out areas of research that are relevant in the study of TEC initiatives from a collective action point of view. This is yet another contribution of the current study, as despite the IAD framework's proven instrumental analytical power for studying collective action resources and systems, this framework has not been used previously to analyse and structure energy communities' literature. Fig. 8 summarizes the current, published, state-of-the-art in TEC initiatives research. We conjecture, in addition, that TEC initiatives have several unique characteristics, suggesting that these initiatives need to be studied specifically in addition to the general CES studies. These differences stem from the technological and infrastructure differences but are also related to differences in consumption behaviour of consumers and prosumers in addition to other types of institutions and behavioural attributes.

Below we discuss areas for future research in TEC:

- ❖ Solar and bio energy are the main energy resources for TEC initiatives; however, several other heat resources can be shared and used on a community level and are worth further investigation. These include resources and technologies such as geothermal, heat pumps, and waste heat. Furthermore, different thermal energy applications (e.g. space heating and hot tap water) needs further investigation. Therefore, technical design and feasibility studies of other thermal technologies and resources are required.
- ❖ Unlike electricity-generating communities, biophysical conditions such as ambient temperature and indoor air quality in the context of TEC initiatives are essential factors influencing the establishment of these communities and their success (see Section 5.1.). Specific thermal energy technologies such as geothermal energy and ground heat pumps influence the soil and ground water quality and would therefore need to be included in environmental assessments of TEC initiatives. Although there are a limited number of studies addressing

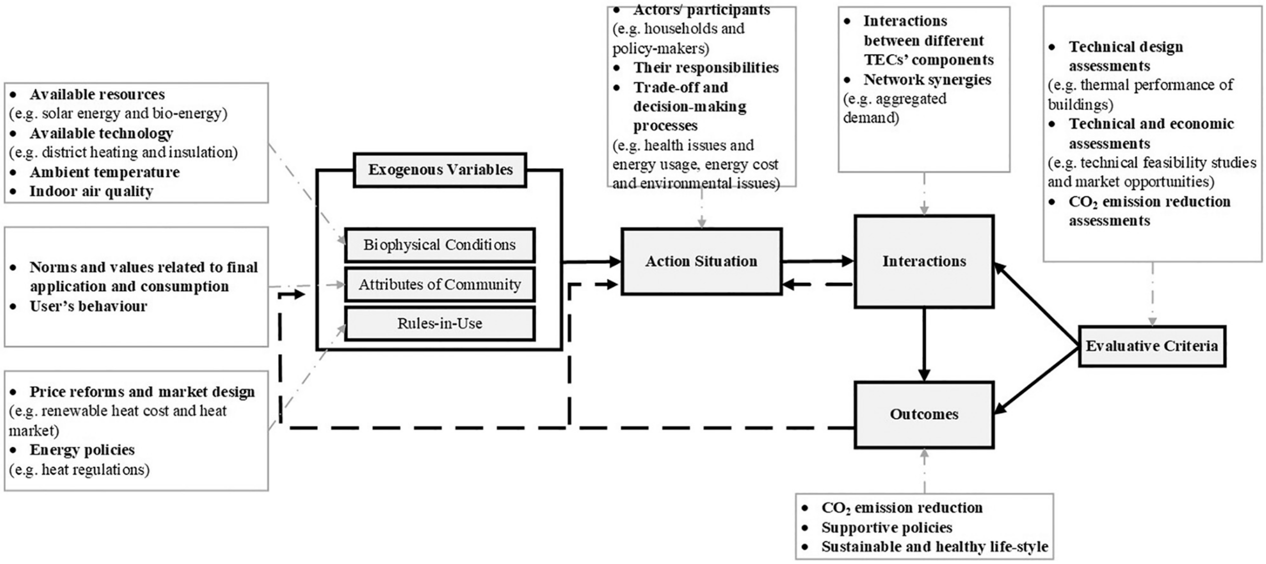

Fig. 8. Overview of findings by applying IAD framework on TEC initiatives literature.

these factors, more substantial inclusion in TEC research is needed. Performing life cycle assessments(e.g. [170], [171], [172]) could be useful in this regard.

❖ Institutions are essential in studying TEC initiatives to allow these community-based initiatives to flourish to the extent of their electricity-based counterparts. The institutional factors are both high level and formal such as the ones related to market mechanisms, but also informal, such as the ones that determine the internal functioning mechanisms of these initiatives and influence the type of interaction among community members. Particularly in TEC initiatives literature, there are few studies in this field. Conducting surveys and interviews with the assist of computer modelling (e.g. agent-based modelling [173]) could be helpful further to investigate institutions, both formal and informal rules. For instance, studies such as [135] that use behavioural attributes data to populate an agent-based model for studying the establishment of electricity-based energy communities could be an example for studying institutions in the TEC initiatives' context.

❖ The interactions' network (e.g. interactions between different actors), internal dynamics (e.g. dynamics and information exchange between households), desirable and possible outcomes (e.g. the number of participants) need to be explored for TEC initiatives. As presented in Section 5.4. it is also critical to study other actors. In this regard, as studies such as [174] and [175] suggest, approaches such as studying focused groups and organizing workshops of involved actors would bring new insights. Q-methodology [176] and serious gaming [177] would benefit such approaches.

❖ A methodological observation from this literature review was that the papers reported mainly mono-disciplinary studies focusing on the technical design or economic assessment. However, in order to facilitate TEC initiatives establishment, there is a need for multi-disciplinary research. Studies such as [20] and [178] also argued for the need for multi-disciplinary in the heat energy transition as a whole.

In conclusion, substantial differences were identified between the TEC initiatives literature and electricity-generating energy communities. Their differences are in generation sources, distribution systems and consumption applications from a technological standpoint. Furthermore, unlike the CES mainstream literature, studies related to attributes of community do not play a significant role in TEC literature, and the few studies in this regard are mainly focused on attributes related to thermal consumption applications. Due to all the differences and the identified literature gaps, we recommend studying thermal energy communities as distinctive socio-technical entities with their own unique characteristics.

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.

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Appendix A

Table A.1
Thermal energy community literature.

Study	Year	Publication	Energy focus Heating (H)/ Electricity (E)	Approach[a]			Source
				D	F	C	
[58]	2020	Journal of Cleaner Production	H/E	X			SET

(continued on next page)

Table A.1 (*continued*)

Study	Year	Publication	Energy focus Heating (H)/ Electricity (E)	Approach[a] D	F	C	Source
[179]	2020	Sustainable Energy, Grids and Networks	H			X	SET
[134]	2020	IEEE Transactions on Smart Grid	H/E		X	X	Electricity, PV, storage
[128]	2020	Energies	H	X	X	X	Electricity/ air conditioning
[106]	2020	Green Energy and Technology (book chapter)/ 7th Global Conference on Global Warming	H/E	X		X	RET, geo, PVT, wind
[8]	2020	Green Energy and Technology (book chapter)	H	X			RET
[180]	2020	Energy for Sustainable Development	H		X		All
[107]	2020	Energies	H		X	X	Geothermal
[74]	2020	Renewable Energy	H/E		X	X	RETs
[64]	2020	Energy for Sustainable Development	H/E	X		X	PV and collector
[137]	2020	Physics and Chemistry of the Earth	H		X		Solar
[129]	2020	Energy for Sustainable Development	H		X	X	Technical
[181]	2020	Energy	H/E	X	X	X	Sustainable
[100]	2020	Energy for Sustainable Development	H		X	X	Bio
[156]	2019	IEEE conference on Energy Internet and Energy System Integration	H/E	X		X	All
[119]	2019	Applied Energy	H/E	X	X	X	Everything
[11]	2019	Energies	H/E	X		X	Electricity, PV, electric vehicle, heat pump, storage
[83]	2019	Energy	H/E?		X	X	Solar, HP, storage, district heating
[59]	2019	IEEE Transactions on Industry Applications	H/E			X	Electricity
[77]	2019	Solar Energy	H/E	X		X	Solar, storage, PV, collector
[182]	2019	Energy Conversion and Management	H/E	X		X	Electricity, solar, electric vehicles, storage
[60]	2019	2019 IEEE Energy Conversion Congress and Exposition	H/E	X		X	Solar, electricity
[101]	2019	Renewable and Sustainable Energy Reviews	H	X	X		Biomass district heating
[84]	2019	ASME 2019 13th International Conference on Energy Sustainability	H		X	X	Solar thermal
[89]	2019	IEEE Transactions on Industry Applications	H/E	X	X	X	Solar, heat pump, storage
[151]	2019	IEEE Sustainable Power and Energy Conference: Grid Modernization for Energy Revolution	H/E		X	X	HP, storage, electricity
[125]	2019	Applied Energy	H/E	X		X	PV, HP, gas
[126]	2019	IEEE Transactions on Smart Grid	H/E			X	PV, HP, electricity, storage
[108]	2019	Sustainable Cities and Society	H/E		X	X	PV, solar thermal, geothermal, storage
[111]	2019	Renewable and Sustainable Energy Reviews	H/E		X	X	Solar, HP
[102]	2019	Energy Policy	H		X	X	Bio
[85]	2019	Energy for Sustainable Development	H			X	Solar
[183]	2019	Energy for Sustainable Development	H		X		Bio
[157]	2019	International Journal of Critical Infrastructures	H/E	X	X		Waste to energy
[62]	2019	Dianli Xitong Zidonghua/Automation of Electric Power Systems	H/E		X	X	Efficiency and all together
[184]	2019	Dianwang Jishu/Power System Technology	H/E	X		X	All system
[116]	2019	Innovative Smart Grid Technologies Asia	H/E			X	all
[121]	2019	Energy for Sustainable Development	H	X	X	X	Bio
[103]	2019	Energy for Sustainable Development	H	X	X	X	inside
[122]	2019	Energy for Sustainable Development	H/E			X	Electricity
[185]	2019	Energy for Sustainable Development	H/E		X	X	Electricity / solar
[86]	2019	Sustainable Energy Technologies and Assessments	H/E		X	X	Solar + gas/CHP
[63]	2018	Energy Efficiency	H	X	X	X	Energy efficiency
[118]	2018	2018 IEEE International Conference on Environment and Electrical Engineering	H/E	X		X	SET
[70]	2018	2018 IEEE International Conference on Environment and Electrical Engineering	H/E	X		X	SET
[186]	2018	ASHRAE Conference-Papers	H/E	X	X		SET
[164]	2018	Energy Procedia	H/E	X	X	X	SET
[141]	2018	Energy Research and Social Science	H/E?!	X	X		Electricity
[69]	2018	Energy for Sustainable Development	H	X		X	RET and efficiency
[67]	2018	Energy for Sustainable Development	H/E		X	X	RET
[187]	2018	Energy for Sustainable Development	H/E	X		X	Electricity
[188]	2018	Energy	H/E		X	X	seawater Pumped Hydro Storage system
[189]	2018	Dianli Xitong Zidonghua/Automation of Electric Power Systems	H/E			X	Integrated, probably solar
[133]	2018	Energy for Sustainable Development	H/E	X		X	All
[127]	2018	Energy for Sustainable Development	H/E			X	RET/Battery/ vehicle
[190]	2017	IOP Conference Series: Earth and Environmental Science	H/E	X			All
[167]	2017	2017 IEEE Manchester PowerTech	H/E	X		X	hot water, base electricity, space heating/cooling), thermal and electrical energy storage, and solar photo-voltaic generation
[78]	2017	Computers and Chemical Engineering	H	X		X	Solar, storage
[191]	2017	IEEE Technology and Society Magazine	H/E		X		RET
[104]	2017	Energy for Sustainable Development	H	X	X		Bio
[130]	2017	Energy for Sustainable Development	H		X	X	Efficiency, RET
[168]	2017	Energy for Sustainable Development	H	X	X		F.F.
[79]	2017	Energy for Sustainable Development	H			X	Solar
[87]	2017	ISES Solar World Congress 2017	H/E		X		Solar
[93]	2017	Energy for Sustainable Development	H	X	X		Bio, waste

(*continued on next page*)

Table A.1 (*continued*)

Study	Year	Publication	Energy focus Heating (H)/ Electricity (E)	Approach[a]			Source
				D	F	C	
[61]	2017	World Sustainability Series (book chapter)	H/E		X	X	Electricity
[73]	2016	Energy for Sustainable Development	H		X	X	Bio
[56]	2016	Energy for Sustainable Development	H/E		X		Electrical heating
[80]	2016	Energy for Sustainable Development	H	X			Solar
[131]	2016	Energy for Sustainable Development	H		X	X	Solar, efficiency
[123]	2016	Journal of Settlements and Spatial Planning	H	X	X		District heating
[192]	2016	Progress in Photovoltaics: Research and Applications	H/E		X	X	Solar PV
[94]	2015	5th International Conference on Industrial Engineering and Operations Management	H		X	X	Biogas
[160]	2015	Applied Energy	H/E	X		X	PV, collector, fuel cell
[144]	2015	Conference on Human Factors in Computing Systems	H/E	X	X		Building consumption
[193]	2015	2015 European Control Conference	H/E		X	X	Electricity
[34]	2015	Energy for Sustainable Development	H		X	X	Bio
[112]	2015	Energy for Sustainable Development	H/E			X	Solar, CHP
[65]	2015	IEEE Innovative Smart Grid Technologies	H/E			X	Electricity from grid
[95]	2015	Energy for Sustainable Development	H	X			Bio
[99]	2015	Energy for Sustainable Development	H		X		Bio
[57]	2015	Energy for Sustainable Development	H/E		X	X	Electricity, gas
[194]	2014	Applied Energy	H/E		X	X	CHP
[195]	2014	ASHRAE Transactions	H/E		X		RET
[196]	2014	Energy for Sustainable Development	H/E	X		X	All
[88]	2014	Energy for Sustainable Development	H		X	X	Technical design
[197]	2014	ASHRAE Transactions	H		X	X	biomass-fired boiler and a number of decentralized solar thermal facilities, district heating
[22]	2014	Applied Energy	H/E		X	X	Solar PV
[166]	2014	Fusion Engineering and Design	H			X	Pure technical
[96]	2013	International Journal of Thermodynamics	H			X	Bio, waste, CHP, solar
[109]	2013	Energy for Sustainable Development	H	X	X		Solar
[198]	2013	Energy for Sustainable Development	H/E	X			RETs
[199]	2013	Transactions of the Korean Institute of Electrical Engineers	E			X	Pure electricity
[66]	2013	Energy for Sustainable Development	H		X		All
[81]	2012	Energy for Sustainable Development	H		X	X	Solar
[97]	2012	Energy for Sustainable Development	H/E	X	X		Bio with CHP
[120]	2012	11th International Conference on Environment and Electrical Engineering	H/E		X	X	RET
[200]	2012	11th International Conference on Environment and Electrical Engineering	H/E		X	X	RET
[23]	2012	Energy Procedia	H			X	Solar, storage
[98]	2012	25th International Conference on Efficiency, Cost, Optimization and Simulation of Energy Conversion Systems and Processes	H			X	Bio, waste, CHP, solar
[165]	2012	ASME Design Engineering Technical Conference	H/E			X	All
[82]	2011	Journal of Solar Energy Engineering, Transactions of the ASME	H/E		X	X	Solar
[114]	2011	Energy for Sustainable Development	H		X		Bio
[68]	2011	Energy for Sustainable Development	H/E	X		X	All
[201]	2011	2011 Conference on Smart Materials, Adaptive Structures and Intelligent Systems	H/E	X			RET
[113]	2011	24th International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems	H	X			Solar
[202]	2011	Energy for Sustainable Development	H/E	X		X	RETs for Electricity, wind, PV, Solar thermal
[203]	2010	4th International Conference on Energy Sustainability	H		X	X	Wastewater, HP,
[204]	2009	3rd International Conference on Energy Sustainability	H		X	X	RET
[72]	2009	Utilities Policy	H/E		X	X	Electricity
[205]	2009	Energy for Sustainable Development	H/E	X	X		Solar
[206]	2009	Biomass and Bioenergy	H		X	X	Bio
[117]	2009	42nd Annual Hawaii International Conference on System Sciences	H/E		X	X	Solar, electric vehicle, storage
[207]	2008	Solar Hydrogen Generation: Towards a Renewable Energy Future	H/E	X			?!
[208]	2008	Towards Zero Energy Building: 25th PLEA International Conference on Passive and Low Energy Architecture	H		X	X	Sustainable sewage system, a waste treatment and food production systems
[209]	2008	Energy for Sustainable Development	H			X	heating
[110]	2008	Energy for Sustainable Development	H	X			Bio
[158]	2008	Energy for Sustainable Development	H/E		X		All
[210]	2008	Building and Environment	H	X			Heating systems inside the buildings
[124]	2008	25th PLEA International Conference on Passive and Low Energy Architecture	H		X	X	RET
[211]	2008	25th PLEA International Conference on Passive and Low Energy Architecture	H	X	X		RET and district
[132]	2007	36th ASES Annual Conf.	H/E		X	X	Solar, efficiency
[212]	2006	Energy for Sustainable Development	H/E	X	X		All
[213]	2006	World Energy Engineering Congress	H/E	X	X		All

(*continued on next page*)

Table A.1 (*continued*)

Study	Year	Publication	Energy focus Heating (H)/ Electricity (E)	Approach[a] D	F	C	Source
[214]	2005	World Energy Engineering Congress	H/E	X	X		All
[115]	2005	Energy for Sustainable Development			X		Bio
[215]	2005	Refocus	H/E	X			RET
[216]	2004	The International Society for Optical Engineering	H/E	X		X	Solar
[217]	2004	VTT Symposium (Valtion Teknillinen Tutkimuskeskus)	H	X		X	Bio
[71]	2004	Energy for Sustainable Development	H/E	X	X		Bio
[218]	2003	Energy for Sustainable Development	H/E	X	X		RETS
[219]	2001	Energy for Sustainable Development	H/E	X	X		Electricity
[220]	2000	Energy for Sustainable Development	H/E			X	Bio/CHP
[221]	1974	energy Symp, Energy Delta/Supply vs Demand, 140th Annu Meet of Am Assoc for Adv of Sci	H/E	X		X	Solar

[a] D; (Desk research approach): includes studies with desk research methods (e.g. literature reviews, conceptual development, collecting data based on documents).
F; (Field research approach): includes studies which conduct data collecting besides of desk research (e.g. case study, interviews, survey).
C; (Computer modelling approach): includes studies which develop a computer model (e.g. optimization, agent-based).

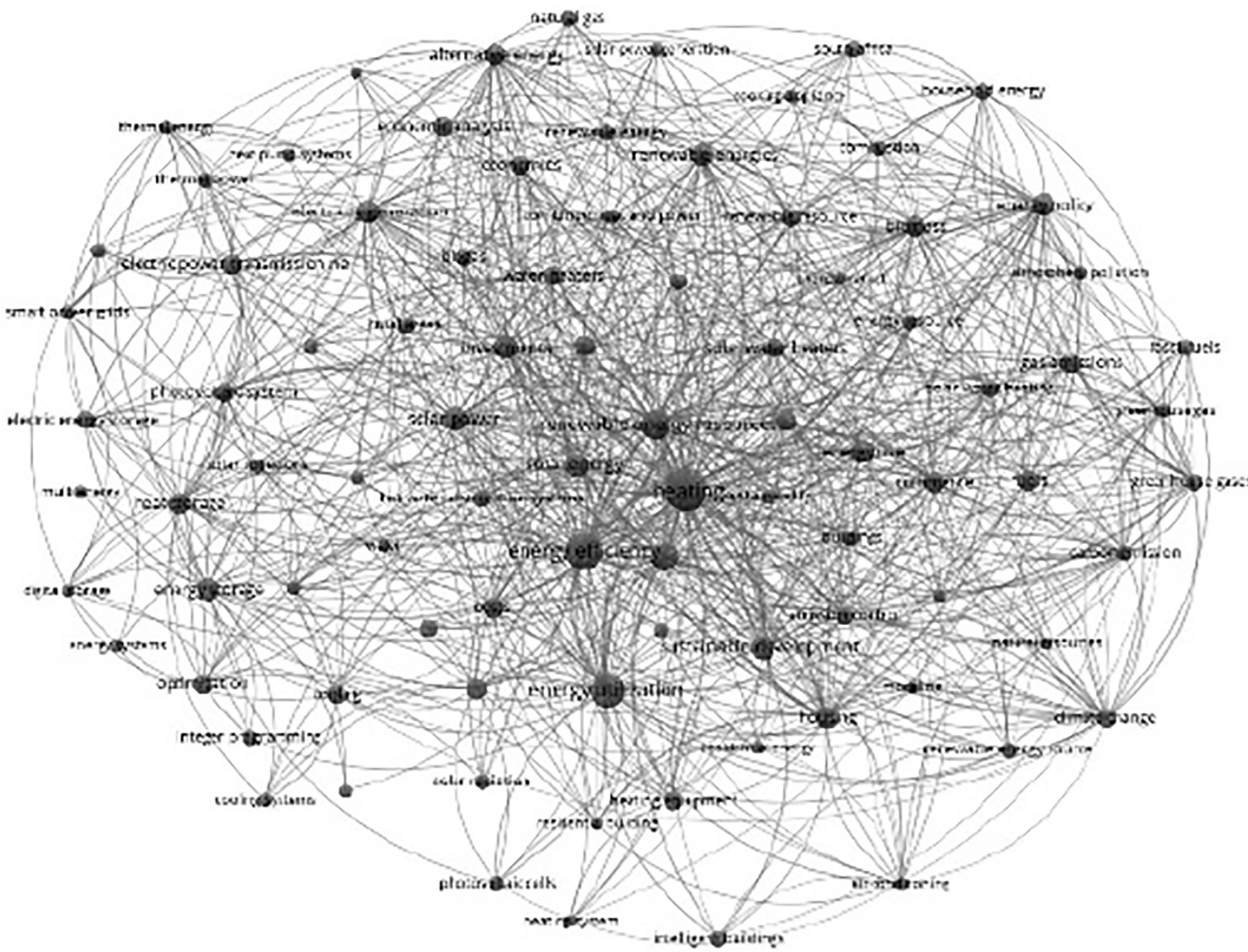

Fig. A.1. Dominating topics of 134 documents.

Table A.2
The list of dominating topics of 134 documents.

Dominating topics: "common repeated words" Vosviewer results (Fig. A.1.)	Occurrences	Total link strength
Heating	45	351
Energy efficiency	33	248
Energy utilization	28	206

(*continued on next page*)

Table A.2 (*continued*)

Dominating topics: "common repeated words" Vosviewer results (Fig. A.1.)	Occurrences	Total link strength
Renewable energy resources	23	194
Energy conservation	20	163
Solar power	16	154
Energy policy	13	142
Electricity generation	14	138
Housing	13	124
Sustainable development	15	124
Renewable energies	13	121
Investments	14	119
Photovoltaic system	10	107
Alternative energy	11	106
Energy storage	14	103
Solar water heaters	10	103
Biomass	11	102
Carbon dioxide	9	100
Gas emissions	9	98
Emission control	7	97
Heat storage	13	95
Greenhouse gases	7	94
Energy use	13	92
Commerce	10	90
Costs	12	90
Solar heating	10	89
Solar energy	15	88
Water heaters	9	84
Climate change	8	81
Renewable resource	8	81
Economics	10	80
District heating	10	78
Solar water heating	7	77
Hot water distribution systems	7	76
Renewable energy technologies	7	72
Carbon emission	6	71
Electric power transmission network	10	68
Greenhouse gas	5	68
Economic analysis	9	67
Fuels	9	66
Household energy	7	66
Energy resource	7	64
Electric energy storage	8	61
Cooling	8	60
Heating equipment	8	59
Renewable energy	6	59
Thermal power	6	58
Combined heat and power	6	56
Optimization	9	56
Buildings	6	55
Energy market	5	55
Thermal energy	5	55
Sustainability	7	54
Combustion	6	53
Power generation	5	53
Fossil fuels	6	52
South Africa	6	52
Natural gas	6	51
Domestic hot water	5	50
Rural areas	7	50
Smart grid	6	49
Smart power grids	6	47
Digital storage	5	46
Renewable energy source	6	46
Residential energy	5	45
Solar collectors	6	45
Environmental impact	8	44
Residential building	5	44
Solar power generation	5	44
Electric power generation	5	42
Energy resources	5	41
Natural resources	5	41
Atmospheric pollution	5	40
Cost benefit analysis	6	38
Intelligent buildings	6	38
Modelling	5	37
Photovoltaic cells	6	37
Water	5	37

(*continued on next page*)

Table A.2 (*continued*)

Dominating topics: "common repeated words" Vosviewer results (Fig. A.1.)	Occurrences	Total link strength
Cooling systems	5	35
Solar radiation	6	32
Air conditioning	5	31
Integer programming	7	29
Cooking appliance	5	28
Biogas	6	26
Design	6	26
Energy systems	5	25
Heat pump systems	5	25
Multi-energy systems	5	25
Multi energy	5	23
Heating system	5	18

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