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Learning and diffusion of knowledge in clean energy communities

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A B S T R A C T

Clean energy communities (CEC) represent emerging socio-technical systems that offer a suitable alternative to non-sustainable energy production and consumption. Thus, CECs cultivate new knowledge of clean energy use and diffuse it among their members as well as interested publics outside the CECs. This paper aims to contribute to the rather limited literature on the role of learning and knowledge in energy transitions in general and CECs' knowledge circulation and learning in particular. The paper presents findings about the knowledge development and learning settings within CECs that provide the ways of cultivating knowledge within CECs and ways of disseminating this knowledge outside the CECs for potentially influencing wider social change. This research contributes to the energy transition literature by focusing on the overlooked perspective of learning and knowledge dissemination as an important part of a niche-innovation setting.

1. Introduction

Scientists and policymakers have now firmly established that a clean and renewable energy transition is one of the most crucial processes that can mitigate climate change and its consequences. Currently, quite a lot is known about energy transition itself and the factors that could promote, hinder or shape the energy transition (Neofytou et al., 2020). Yet there has been much less emphasis on the roles of multiple actors involved in these radical shifts. In particular, the literature does not tell us a lot about the agents in the energy transition, their roles and the actual activities that can potentially lead to the transition (Dóci et al., 2015), including the importance of learning for fostering the transition (Van Poeck & Östman, 2021).

Among these agents are renewable or clean energy communities (CECs) that can be important drivers and carriers of energy transitions (Dóci et al., 2015). CECs have several synonyms and definitions. They revolve around 'green energy grassroots initiatives' that produce or invest in the production of renewable energy (Dóci et al., 2015); 'sustainable energy communities' whose members are strongly involved in the planning and implementation of measures aimed at the rational use of energy and the introduction of renewable energy sources in the production, consumption and/or supply of electricity (Romero-Rubio & de Andrés Díaz, 2015; Schweizer-Ries, 2011); 'clean energy communities' formed to achieve specific goals for cleaner energy production, consumption, supply and distribution (Gui & MacGill, 2018); and 'community initiatives for renewable energy' manifested as decentralised, non-governmental initiatives of local communities and citizens to promote the production and consumption of renewable energy (Oteman et al., 2014). Finally, one of the most recent definitions frames 'energy communities' as 'associations of actors engaged in energy system transformation through collective, participatory and engaging processes, seeking collective outcomes' (Blasch et al., 2021, p. 3). CECs can assume various forms, as 'communities of place' within a limited local area (e.g. village or urban district, thus

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place-based CECs) or as 'virtual networks' – 'communities of interest' which are not confined to a specific geographical area (Bauwens & Devine-Wright, 2018), also called virtual CECs.

Although diverse, these definitions continuously put forward the social aspects of energy transition often overshadowed by technological perspectives (Dóci et al., 2015). In this vein, CECs could be perceived as social innovations that comprehend new energy-related solutions that lead to new or enhanced capabilities (Gui & MacGill, 2018) and can offer an alternative for non-sustainable energy systems. However, to achieve this, CECs must not only cultivate new knowledge of energy use (and ways of reducing carbon footprint) but also be effective in circulating information about energy among their members and outside their communities (Catney et al., 2013). Thus, the acquisition of knowledge and skills is considered crucial (Kamp et al., 2004). Yet empirical evidence in the literature about the role of learning and knowledge in energy transitions in general and CECs' knowledge circulation and learning in particular is rare (Van Poeck & Östman, 2021).

Thus, the aim of this paper is to address this gap, first, by researching the knowledge-building and learning settings that enable learning within CECs and, second, by exploring how the knowledge cultivated within CECs is then spread outside these communities to potentially influence wider social change. Thereby, our study contributes to the energy transition literature by focusing on an often neglected angle of learning and knowledge dissemination as an important part of niche-innovation.

In this paper, two theories are used tentatively to inform our study by providing guidance for developing research questions and enhancing the interpretation of our findings (Collins & Stockton, 2018): the multi-level perspective (MLP) framework and transactional learning theory (TLT). MLP provides a useful lens to understand how CECs as niche-innovations can build up internal momentum through learning, influence changes by disseminating new knowledge and consequently diffuse CEC experiences and models to contribute to substantial transformation (Geels, 2020). In contrast, TLT delves deeper and unpacks the 'black box' of learning and its outcomes within the CECs – in our case we focus on what CEC members learn (Van Poeck & Östman, 2021) and what are the learning settings that may help to facilitate how people learn (Van Poeck et al., 2020). These frameworks guided our empirical study that addresses three research questions: (1) What kinds of knowledge and skills have CEC members acquired in the learning process; (2) What are the settings and objects that enable learning within CECs; and (3) How is the knowledge accumulated in CECs and then shared outside the CECs?

The remainder of the paper is structured as follows. First, we elaborate the theoretical background. This is followed by the methodology section and then the results, where we present the main findings regarding the CEC members' perspectives on learning and diffusion of knowledge. We then discuss the implications of our findings and present the conclusions.

2. Theoretical background

2.1. MLP framework

In the sustainability literature, MLP has been established as a useful framework for explaining socio-technical transitions concerning sustainability in general (e.g. Geels, 2020) and clean energy transitions in particular (e.g. Dóci et al., 2015). Regarding clean energy transitions, CECs seem to have great potential for developing innovations and shifting the current regime towards sustainability (Dóci et al., 2015). MLP distinguishes three inter-reliant system levels through which (energy) transition emerges: landscape (macro level), regime (meso level) and niche (micro level) (Geels, 2004). Landscape represents the wide-ranging cultural patterns, macro-economics, macropolitics and socio-spatial structures which define the regime and create specific environmental settings for niche-innovations. The latter could potentially influence or even displace the regime (Seyfang & Longhurst, 2016). Regime symbolises the current dominant structures and practices – self-reinforcing rules, institutions and technologies (Smith, 2003). From the energy system optics, the predominant regime is still mostly reliant on fossil energy sources. Regimes usually renovate incrementally, but more radical innovations could materialise at the niche level. A niche is a protected space that shields radical innovations from the regime's selection pressures (Geels, 2004; Geels & Schot, 2007; Smith & Raven, 2012). A CEC represents a good example of a niche, where special conditions for experimentation with new clean energy approaches are enabled and supported. Niches provide space for learning processes and building support for innovation (Geels, 2004), and the MLP framework, through its 'multidimensional model of agency', gives grounds for studying how actors within CECs use their cognition in learning, decision-making and actions (Geels, 2020). Niches help to set in motion interactive learning processes and adaptations in management, organisation and the institutional context that are important for the wider diffusion and development of the new technology (Kemp et al., 1998).

The information flow (within and outside CECs) through innovative sharing practices represents an essential empowerment process for CEC members and influences the smooth functioning of CEC systems. It also provides grounds for negotiating, learning and adopting new meanings of new clean energy technologies and their use, which essentially leads to a more or less unified and shared frame for new clean energy in CECs (Geels, 2020). Therefore, it is crucial to focus on the information flow dynamism and meaning-making processes within CECs (as well as interactions between empowered niches and regimes) to unlock the potential for upscaling and making a change at the regime level. As Van Poeck and Östman (2021) argued, while it is almost impossible to investigate how learning processes directly affect energy transition, all transitions (even major) are made 'in action, in people's day-to-day practices' (p. 156). Niche actors, such as CECs, are assumed to develop innovations with the intention that they will be used in the regime or even that they will become the dominant technologies in the regime (Dóci et al., 2015). Naber et al. (2017) identified four patterns of upscaling sustainable energy innovations: growing (participation of more actors), replication (model reproduction in new locations or contexts), accumulation (linking with/to other initiatives) and transformation (shaping wider institutional change/regime). For CECs to break through, grow, multiply and take advantage of the 'window of opportunity' to trigger adjustment in a socio-technical regime (Geels, 2020), it is firstly necessary that the information about the existence of a CEC, its benefits and the

established dominant design of how to approach the socio-technological perspective on clean energy are diffused to the broader public. Therefore, the focus is not only on the learning and knowledge building among actors inside CECs but also on how the CECs disseminate and promote knowledge to the wider society.

Network building, vision formulation and learning are internal niche processes that have been analysed and described under the concept of strategic niche management (SNM), which is derived from MLP (Geels, 2006). Kemp et al. (1998: 186) define strategic niche management (SNM) as: "the creation, development and controlled phase-out of protected spaces for the development and use of promising technologies by means of experimentation, with the aim of (1) learning about the desirability of the new technology and (2) enhancing the further development and the rate of application of the new technology". Strategic niche management (SNM) is a tool to (1) understand and manage radical socio-technical innovations and (2) facilitate their diffusion (Marten et al., 2011). More specifically, the goals of strategic niche management focus primarily on learning processes (e.g. in terms of social desirability, technical and economic feasibility, and environmental benefits of different technology options) and knowledge diffusion (to stimulate further development of these technologies, achieve cost efficiencies in mass production, promote the development of complementary technologies and skills and stimulate changes in social organisation that are important for the further diffusion of the new technology) (Kemp et al., 1998). SNM studies suggest that active interaction in niche networks and accumulative learning are crucial for scaling up experiments (Romijn et al., 2010).

In line with our research objectives and inspired by the SNM and MLP analytical frameworks, we have collected empirical data focusing on two main research pillars: (1) *exploring learning settings in the socio-technical innovation* (CEC) and (2) mapping how accumulated *knowledge within the CEC social networks is diffused to the wider society*.

2.2. Transactional learning theory

As established above, niches, such as CECs, that participate in energy transition differ by their motivation to engage in and contribute to the learning process (van Mierlo & Beers, 2020). Recently, learning has become a salient topic in sustainability transition literature, where it is understood both as a process and an outcome and is, therefore, characterised by both; learning by doing and doing by learning (Plummer & Van Poeck, 2021). Van Mierlo and Beers (2020) maintained that although learning is strongly associated with transitions, there seems to be a lack of clarity regarding the theoretical and conceptual underpinnings of learning.

In the absence of a solid theoretical foundation for learning in sustainability transitions, authors developed a new theoretical approach, transactional learning theory (TLT), inspired by Dewey's pragmatism (Östman et al., 2019a). This theory assumes that individuals in their daily lives function habitually, without much reflection. However, when they encounter problems or novel situations, they can no longer rely on existing habits; they must experiment and use different skills and knowledge to solve problems, which then results in new knowledge, skills, etc. (Plummer & Van Poeck, 2021, p. 421). Relying on a pragmatic approach, TLT focuses on the dynamic interplay between individuals and their social and material surroundings (this interplay is called 'transaction'; Van Poeck & Östman, 2021). Thus, learning is conceptualised as 'a process that takes place through *encounters* between a person and an environment (social and material)' (Van Poeck et al., 2020, p. 306). The learning process is difficult to study without the *in situ* approach (e.g. Van Poeck et al., 2020). However, TLT could also be useful in shedding light on the empirical evidence of *what* CEC members perceive to have learned and which *encounters* in which *learning settings* have, according to their opinion, influenced this (Lidar et al., 2006; Van Poeck et al., 2020).

Although existing knowledge and skills can be useful to tackle new problems, CEC members may be confronted with a situation where their previous knowledge and experience are not sufficient. To this end, Van Poeck and Östman (2021) propose to combine TLT as an analytical framework with practical epistemology analysis (PEA), an analytical method for dealing with empirical data about learning. According to PEA, *gaps* occur in situations where previous knowledge is insufficient (Van Poeck & Östman, 2021). To fill these gaps, members try to use their existing knowledge and skills in the process of *re-actualisation* to find possible ways to act in the future (Plummer & Van Poeck, 2021). However, the TLT tells us that in order to fill the gaps, especially in new situations such as the new energy communities, a new inquiry is needed. To this end, and according to the TLT, learners (i.e. CEC members) need to stage new *encounters* with other CEC members, experts or *learning objects* such as manuals, within specific *learning settings* (i.e. the environment for interactions with community members, experts) (Östman et al., 2019a).

In addition, TLT includes the notion of 'educative capacity' (Plummer & Van Poeck, 2021). Educative capacity encompasses the potential for learning to take place, i.e. the creation of learning opportunities and the possibility for those interested to start investigating and eventually engage in a learning process (Östman et al., 2019b). In this sense, the accumulated knowledge within CECs and the ways in which knowledge and information related to CECs are made available to recipients outside CECs (i.e. through encounters with other people and with the use of learning objects within specific learning settings) can be important in increasing the possibility that learning takes place.

3. Methodology

3.1. Data collection

For the purpose of our study, we used the data collected by qualitative and quantitative methods within the NEWCOMERS research project.[1] The qualitative study was based on 42 interviews with members of 10 different CECs from 6 EU countries. The quantitative study was based on a survey with 123 CEC members from 5 different communities in 5 EU countries. Both studies used convenience samples.

Within the qualitative study, 42 semi-structured, face-to-face interviews with CEC members were carried out between September and October 2020. We designed an interview guide that was used in conducting interviews with selected community members across the studied CECs. The semi-structured interview guide consisted of a set of topics that provided a general guideline for the interviewers, namely (1) CEC members' background and involvement with the CEC; (2) knowledge and skills perceived as necessary for joining the CEC and the process of learning CEC-related knowledge and skills; (3) barriers and incentives related to CEC membership; and (4) everyday life and (social) practices in the CEC. We conducted the majority of interviews via online platforms (e.g. Zoom and Skype) due to Covid-19 pandemic. The interviews lasted for more than one hour, on average. With respondents' written consent, they were audio recorded and later anonymised, transcribed verbatim, and translated to English.

Data within the quantitative study, which followed the qualitative study, were collected with a survey conducted in January to May 2021. Respondents were members of selected CECs of the NEWCOMERS project (n = 123). The survey consisted of 27 sets of questions. In Table 1, we present the distribution of interviews and surveys conducted across CECs.

3.2. Data analysis

Our study is based on quantitative and qualitative data. The procedural diagram in Fig. 1 illustrates the data collection, the convergence of the data in the analysis (the synthesis of the data on learning settings and diffusion) and the interpretation of the findings.

The data collected in a quantitative survey were analysed using the statistical software SPSS 25 on the basis of a descriptive analysis. For this paper, only the data on CEC members' learning settings and objects for learning on energy-related topics were analysed.

The interviews were analysed using thematic analysis according to the guidelines provided by Braun and Clarke (2006). The qualitative data analysis was assisted with MaxQDA2020 software (VERBI Software, 2019). The data analysis was guided by both the research questions and the close reading and interpretation of the raw data with the aim of identifying the existing and newly acquired knowledge and skills of the CEC members. This coding process also aimed to identify the settings and objects that CEC members perceive as enabling learning within the CEC and knowledge sharing with the interested publics outside their CEC. The coding process took place in three stages: open coding, axial coding and selective coding. The first stage of analysis was data-driven and no coding scheme was created prior to data analysis: The analysis process was conducted as an inductive and iterative open coding analysis, starting with the identification of distinct concepts in the data in relation to each research question. The first analytical step was to assign codes to the units of meaning (groups of words or statements that share a common meaning). In this phase of the coding process, mainly descriptive codes with explicit meaning of the data were identified. In the following phase of the analysis, the descriptive codes identified in the previous phase were taken and merged into initial themes with interpretive, broader meaning and implications. In the final phase (selective coding), the analysis revised the initial themes by looking for coherent patterns, defining and naming the themes and their sub-themes, and then determining the meaning and relationships between them.This final stage was guided also by both theories and analytical methods (i.e. SNM and PEA) - they were used in a peripheral way; following the example by Sandelowski (1993), they were 'brushstroked in to enhance the interpretation' (p. 215). Table 2 shows the themes identified and their relationship to the analytical framework used to interpret the results in the later stages of the analysis.

4. Findings

4.1. Past or existing skills and knowledge

When confronted with the possibility of joining a CEC, some participants already had certain knowledge of (clean) energy. Some had an environmental educational background and others had previously gained (clean) energy experience or had 'green' jobs (e.g. environmental science specialist, energy cooperatives consultant, electronic engineer; some were already familiar with the

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[1] The NEWCOMERS (New clean energy communities in a changing European energy system) project aims to explore and evaluate a variety of different new CECs, which have been undertaken in six EU member states (NL, SE, UK, DE, IT, SI). The project assesses the regulatory, institutional and social conditions which support the emergence and operation of CECs as well as their potential for diffusion at the national and local levels. The NEWCOMERS project is providing insights into how new CECs meet their members' (i.e. citizens' and consumers') needs better than more traditional business models and whether they have the potential to increase the affordability of energy, their members' energy literacy and efficient use of energy while enabling participation in clean energy transitions in Europe (for more information about the project, see https://www.newcomersh2020.eu/).

Table 1

Interviewees (for qualitative analysis) and survey respondents (for quantitative analysis) across clean energy communities.

| Clean energy community	Number of interviews	Number of survey respondents
Sonnen Community (Germany)	5	21
Solidarity & Energy (Italy)	5	5
ERiC (Italy)	3	0
Zuiderlicht (The Netherlands)	6	63
Buurtmolen Herbaijum (The Netherlands)	4	0
Buurtmolen Tzum (The Netherlands)	1	0
Soesterwijkwiek (The Netherlands)	2	0
GEN-I Jesenice (Slovenia)	4	6
Dalby Solby (Sweden)	5	28
Energy Local (United Kingdom)	7	0
TOTAL	**42**	**123**
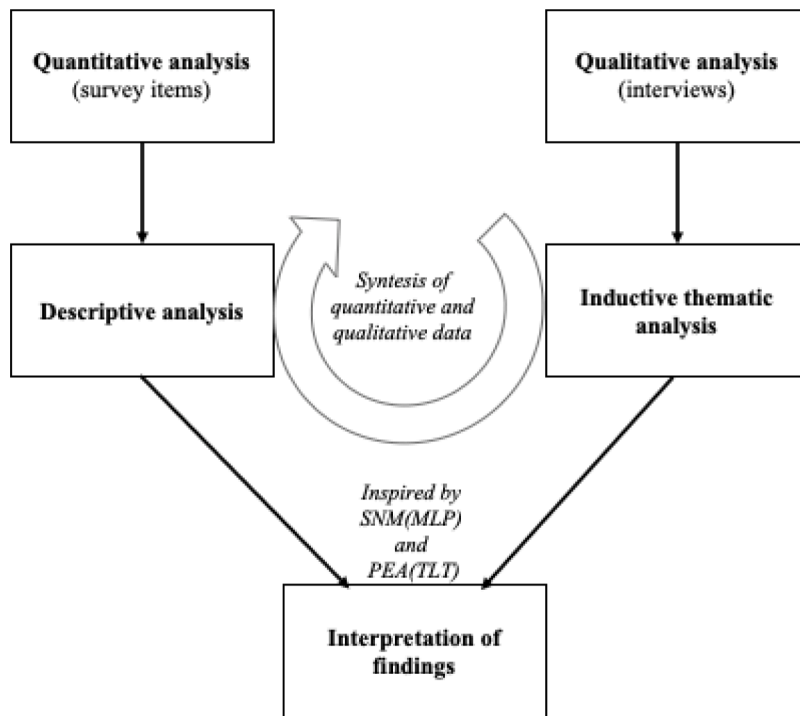
Fig. 1. Procedural diagram illustrating the stages of the study

photovoltaic system, etc.). Yet, some of them felt that one can join a CEC without knowing any specifics about energy provided that one is interested and motivated, as one of the participants said: … *I think it helps if you have the right approach, an attitude to. You do not need to know everything …, you should be interested in it, positive about it* (I3_SE). This implies that it is important that they are willing to engage in specific experiences and interactions to try and learn new things. The voicing of positive motivation and optimism is important for a niche to develop successfully.

The participants had a heterogeneous educational and professional background and found the heterogeneity of their knowledge and skills useful for the work of the CEC. Heterogeneous views and experiences, although sometimes disruptive (… *you may sometimes think a little differently about things, so it can be a little so, a little ugly faces and that you do not completely agree on how something should go or be maintained* (I4_SE)), can have a good impact on learning outcomes.

Participants were able to create relations between what they know and what is new regarding functioning within the CEC. By employing their past skills and knowledge in different areas of CEC development and maintenance, they learned to (collectively) address the problems at hand. One participant mentioned a new situation related to the gap in achieving common goals in the CEC project and the need to work together: *Here was also this new and unexpected component, that is, to be part of a group with objectives that I shared …. I shared the technical choices of the panels that were high efficiency, … with this technology to increase efficiency, also the technical details that I shared and I believe that being part of a group you have the opportunity to improve* (I1_IT).

Building networks and approaching things collectively is also a precondition for niche formation and maintenance. As one of the participants observed: …*it's practical as if so many things are done together so that you do not have to get into everything and do everything*

Table 2
Identified themes and sub-themes.

Inductive themes	Sub-themes, description	Sample quotes	Examples of the reference to the analytical frameworks/methods (with the aim of enhancing the interpretation of findings)
Skills and knowledge	**Existing skills and knowledge** (what participants described they already knew, experienced before joining CEC and how did they describe it as useful in specific circumstances, encounters while being part of CEC)	*No, my background is actually managing nature reserves, but that then moved into some stuff about climate change … But it has often been community-facing work, when I worked in conservation, and a lot of it's the same: trying to convince a farmer to do something for conservation is not dissimilar (I1_UK).*	SNM/MLP: Using existing skills to facilitate the diffusion of CEC as innovation; how the existing skills function in terms of enabling or constraining potential transitions

PEA/TLT: Re-actualisation of past experiences, skills when encountering problematic situation |
| | **Newly acquired skills and knowledge** (what skills and knowledge were developed to overcome new problematic situations within CEC) | *Yeah, because of my climate conversations. I give lectures … I know it's been tough … There are a lot of people who are welcomed at the breakfast. They always say that I'm really good. They learn from me how you can also do it … like the infrared panels I have in my house now (I1_NL).* | PEA/TLT: Gaps open up in relation to practical technical issues. They are filled by the encounter with the expert and _nlnew skills may be learned in the end |
| **Learning settings and objects** (the process of accessing information; gaining and sharing knowledge in specific settings or with particular objects) | **Place based learning settings** (conversations indicating that CEC members attend meetings, engage in people-to-people communication, courses, working groups, informal gatherings …) | *And then we have a big meeting every month, which I think is an important part of how the community works. Then you have the opportunity to come here and discuss big and small things that are going on. You can raise questions or raise anything in a fairly organised way (I1_SE).* | SNM/MLP: Learning settings and objects provide opportunities for learning, networking and articulating problems and expectations

PEA/TLT: Learning takes place 'in action', in communication. Settings offer the opportunity to clearly express different visions and opinions, to open up gaps and possibly fill them through joint efforts |
	Virtual learning settings (conversations indicating that CEC members engage on digital platforms and participate in social media)	*I have contacted someone through the Facebook group, so there is also a value linked to social relationships certainly and that does not stop only at the construction …there will probably be a new initiative to add storage batteries to the plant … (I1_IT).*	PEA/TLT: Objects as learning tools; 'the material for doing things with in order to achieve something' (Östman et al., 2019a, p. 128)
	Learning objects (indication that members use learning materials, such as manuals etc.)	*I am part of the S. editorial (newspaper), we publish a small S. (newspaper) and it is also something related to the community … (I2_SE).*	
Settings and objects for diffusion of knowledge from CECs to the wider society (evidence/examples of sharing information, stories, experiences and good practices with people outside CEC and how this is done)	**Place-based settings for the diffusion of knowledge** (conversations indicating sharing information, experiences or educating face-to-face)	*The way to bring it to the school's … they involve the parents from the children in schools. And then the children ask the parents to join the community. That's the cool thing (I1_NL).*	SNM/MLP: Settings and objects provide an opportunity for the trans-local phase of knowledge sharing (i.e. knowledge begins to circulate more widely; Mirzania et al. (2020))
	Virtual settings for the diffusion of knowledge (indication of virtual sharing of information, experiences)	*And actually I think people may be a little bit scared to ask the questions …. But particularly once when you're in a forum … and you can kind of learn from each other – it's a comfortable place to engage with something like that (I2_UK).*	PEA/TLT: Learning settings offer the opportunity for encounters of people outside CEC with CEC members, ambassadors (and to potentially fill the gaps that may occur)
	Objects for the diffusion of knowledge (indication that learning materials were set up for people outside of CEC to learn)	*And they've created resources, so almost anybody could probably pick up and start .., which I think is really encouraging, and makes me feel like it's going to be replicable. So, I can write a press release, and they've got some advice about press releases, and I can just get on with it (I3_UK).*	PEA/TLT: Objects as learning tools which people outside CEC encounter use to achieve something

Notes: SNM = strategic niche management; MLP = multi-level perspective; PEA = practical epistemology analysis; TLT = transactional learning theory

Acronyms for interviews' quotes: "Interview number in each country_country abbreviation" (SI=Slovenia, DE=Germany, UK=United Kingdom, I=Italy, NL=The Netherlands, SE=Sweden).

from the beginning yourself (I5_SE).

Based on participants' reports, the application of prior knowledge and skills manifests itself in different areas, which can increase the efficiency of a niche. Some examples were finance and law (*We have a very good financial member; he knows everything about taxes and finances* (I2_NL)), information technology (*I do programming and have knowledge of computers … and I'm working on the website* (I6_SE)) and even graphic design *(… because I am a graphic designer, I have developed the style for the website, for the logo and brochures* (I3_NL)).

One participant encountered a situation with other members of the community where a gap arose and the participant tried to continue the activity with the application of past knowledge and skills based on a re-actualised experience of being good at solving other people's problems: *… I have worked as an occupational therapist, it is that I have a habit of spending time with all types of people so to speak. … I have a commitment to solve problems and discuss; I have had to help some people … you help in the association with what you are good at. I'm working on the website for example* (I2_SE).

4.2. Newly acquired skills and knowledge

Participants reported numerous and diverse skills and knowledge that they acquired after joining the CEC, which indicates that learning within niches is essential. They developed technical skills, such as managing solar panels, controlling the functioning and effectiveness of renewable energy installation, optimising energy consumption, handling internet portals, operating specific energy-related apps, controlling energy flows and using energy storage batteries. After becoming CEC members, they felt more capable of identifying technical problems and managing and maintaining specific technological appliances through web portals and energy smart metres apps (*we are able to monitor the appliances and their consumption through [name] website; we are able to track how much we have produced, how much we have consumed* (I2_IT)). As members of a CEC, participants developed specific technical and technological knowledge of energy systems in general and renewable energy installations (e.g. photovoltaic, heat pump, new batteries) in particular (*I learned to exploit the energy produced by photovoltaic panels, and to take care of the maintenance and management of the photovoltaic system* (I2_IT)). This suggests that CEC members recognised the need for adaptive learning when encountering new technologies, which increased the success of niche development. In this regard, one of the participants acknowledged that it was quite difficult for some people without a technological background. When they are confronted with new technologies and new problems, gaps appear and they have to find ways to fill them and find a way out of problematic situations. One of the participants said: *Individuals belonging to the community must obviously understand a little in principle, it is not necessary to go into technical details, but to understand more or less how the system works …* (I3_IT). Encounters with technically skilled people who can help them close the gap are particularly helpful: *… then surely the need for an expert, a technician who has specific skills, in my opinion is absolutely necessary* (I3_IT).

CEC members also reported having acquired other, non-technical types of knowledge and skills. They reported that they had become competent in estimating costs, making agreements, getting permits, constructing a business case; and understanding the public subsidies schemes (*I learned how to manage subsidies scheme* (I4_NL)), energy tax regulation systems and the legislation needed to set up an energy community (*I learned how to set up and run a community energy initiative* (I3_NL)).

Communication skills related to better information exchange on technical knowledge were often mentioned as those that need to be acquired. A conversation in one of the CECs shows how new communication skills were developed. The purpose is to be able to communicate successfully with the people in the community. This opens a gap between what they do (providing digital seminars) and the desired outcomes (I2_NL): *That's what we had a lot of discussion about because you know our digital seminars, we're not very successful.* The gap is closed by the willingness to change the way of communication: *So we conclude it very straight. … you have to communicate directly with people.* A new skill is acquired: *… we try to build up trust and that is also what I learned how to build up trust. We had lectures about it* (I2_NL).

Another frequently mentioned example was marketing skills. One participant explained that sometimes there were problems because the (promotional) emails and phone calls to recruit new members were not thorough enough (a gap): *we need to be very thorough, whereas maybe I'll be in a hurry and go quick ….* Participant was able to solve this by relying on the advice of another member: *From M I learned a lot … You have to do everything right because it's communication and marketing and it's really important that you are really clear and you look professional. So I learned that. That's what I learned from her* (I5_NL).

4.3. Learning settings and objects

Our interview participants were rather elaborate about various settings in which other members, experts and objects influence their learning and encourage them to acquire new skills.

4.3.1. Place based and virtual learning settings

Learning settings that allow *face-to-face* interaction between CEC members seem to be the most valued learning environments in CECs. In such encounters, experts can share their specialised knowledge on practical matters and facilitate processes in which other members can learn new skills or re-actualise previous experiences and invest their previously acquired skills and expertise in envisioning the future development of the CEC. Key persons in interpersonal learning settings seem to be so-called knowledge ambassadors, also referred to as supervisors, knowledge leaders, key interlocutors, community leaders or promoters. In all CECs studied, participants

reported at least one knowledgeable, experienced community member who is a clean energy expert and a point of reference for CEC members (sometimes also for legal, organisational and management issues). Some CEC participants see the community knowledge ambassador as their main source of information and as a trainer.

Settings as *regular formal CEC meetings*, for example, are seen to simplify the information and experience-sharing and learning related to specific issues, like technical features and legal frameworks, as one participant exposed: *we have big meetings (once a month) and then you bring up various current things that need to be done* (I3_SE). Importance of regular face-to-face meetings for sharing experiences between CEC members was elevated also by a participant who said: *… once we've got a club set up then, it's going to be important … to have casual social things or events, where people can get together and compare … or just share experience about what they're doing and how they're finding it* (I4_UK).

In addition to addressing current issues and knowledge and competence gaps, the regular meetings are also seen as an ideal framework for identifying future knowledge and competence gaps by proposing, discussing and developing initiatives for technological or organisational change and investment in future CEC developments, as the following excerpt shows:: *… at the meeting, it is also possible to present ideas about future investments or new projects* (I1_SE).

The data from our survey shows that almost 65% of the CEC participants interviewed have already attended a CEC meeting. The following excerpt from the interviews provides greater insight into why CEC members perceive regular CEC meetings as an important learning setting: *we have meetings every month where we discuss different things that we can develop. We have done this all the time* (I9_SE)*; And then we have a big meeting every month, which I think is an important part of how the [name of the CEC] works. Then you have the opportunity to come here and discuss big and small things that are going on. You can raise questions or raise anything in fairly organised forms anyway* (I7_SE).

Informal community discussions are a more spontaneous type of place-based learning settings that enable face-to-face interactions among CEC members where they can informally discuss, share experiences of their daily practices, share knowledge, and solve problems together. One participant explained: *There is a lot of communication happening when we run into each other in the hallways; we talk about how to continue, where etc* (I1_SI).

Some participants were explaining that their CEC is organised via *working/interest groups* that function as special CEC subdivisions with different purposes – from the organisation and management of different CEC operations to other non-energy-related (communal) practices (e.g. eco-composting group, party group): *And then we also have working groups in [name of the CEC], you have working groups about everything, … we have a purchasing group, root cellar group, land and workshop group, composting toilet group, cultivation/growing/ gardening group, website group, service group, laundry group, party group, flag group, guest room group, home cinema group, sauna group and art group. … Someone who is very interested in something, then it can be a common group of it* (I3_SE).

Members of such groups share knowledge related to specific tasks and learn various skills as they work to solve specific problems. One participant was explaining how their CEC encourages learning processes via rotation of CEC members between different working groups: *We have a system for encouraging people to learn about the different systems that we have by being part of different activities. For example managing different functions in the (earth) cellar, community house, different working groups, different functions in the houses with heat exchangers, and so by taking part in an activity, you come and get familiar with systems* (I7_SE).

Important place-based learning environments also appear to be special CEC events organised by CECs, which tend to be designed to promote empowerment processes within CECs, initiate debate on unusual topics (e.g., new investments), or educate members about specific technical features (e.g. PV system maintenance). Participants were mentioning different forms of such special events, like 'special working days', 'advice sessions', 'breakfast happenings', 'street events', 'annual gatherings' and 'occasional demonstrations'.

Several participants considered CEC's educational offerings, such as trainings, courses, seminars, and lectures on specific energy-related topics, not only an excellent learning environment to become informed and learn about CEC-related topics, but also a crucial environment where knowledgeable individuals, experts in a particular field, can communicate about important CEC-related topics and fill knowledge and information gaps for other CEC members. *It's just to do with communication …. I think education is really important* (I5_UK).

Training on specific energy-related topics can take a variety of forms, which includes a *virtual environment* (e.g. webinar). Participants pointed out that interpersonal learning environments are increasingly taking place in a virtual environment as well, e.g. *web sites, intranet platforms, member portals, on social media platforms*, such as 'CEC dashboard', 'intranet platform with online instructions and literature', 'practitioner forum' and 'village/CEC Facebook page' where people can interact, exchange experience, and discuss. Yet, virtual learning settings don't work for everyone, as one participant pointed out: *Because the population is older, they don't really use the internet for communication; there is still the personal approach, personal contact* (I1_SI).

4.3.2. Learning objects

Various materials play an important role in addressing knowledge and skills gaps related to CEC. Special *mobile apps* with built-in instructions, for example, help members better understand the technological processes involved in CEC by making the steps of the process clearer. As one participant said: *From the beginning, I liked using the … app, how you can see consumption, power produced, battery level, etc. It worked great* (I1_DE).

In the CEC, different materials are used to create formal communication channels that allow clear and constant communication between members. Participants consider *newsletters and/or mailing groups* as one of the most common and efficient communication channels to keep each other informed about various CEC matters. Another useful communication channel, according to some participants, is also a *hotline customer service* that allows members to obtain certain CEC-related information and get help in solving CEC-related problems they encounter in their daily lives. To some extent, hotlines as a communication channel could also be considered a mediated intrapersonal learning environment that is critical for some CEC members, such as older or non-technical populations.

In cases where CECs have their own *websites*, participants view them as advisory portals through which CEC members can obtain the information they need to understand clean energy practices and energy savings. In these cases, the websites are an important tool for CEC members' learning process. Some participants mentioned that they could also learn from the best *case studies* of CECs that record (best) past practices and serve as a source of ideas for CEC development, technical improvements, and problem-solving guidance for interested parties. Regular CEC meetings, as the most common interpersonal learning situations, also provide physical evidence (*meeting minutes*) of key information exchanged and conclusions reached. Some participants mentioned that in some cases CEC *meeting minutes* are also published in the local newspaper so that other members who did not attend the meetings (and the interested local public) can be informed of CEC news.

The analysis showed that members acquired their knowledge simultaneously in more than one learning setting, depending on the type of learning settings and objects available in their CEC. The data from our quantitative study paint a fairly similar picture. CEC members were inclined to share their knowledge with other CEC members. The results show that 39% of the respondents reported that they had already shared their knowledge or experience in the field of energy with other CEC members. In general, CEC members reported learning about energy issues in a variety of learning settings and through a variety of learning objects. Interestingly, traditional media (TV - 78.1%, newspapers - 66.7%, magazines - 40.0%) represent relatively common objects from which respondents learn about energy issues. In addition, a significant proportion of CEC members reported engaging in learning environments that enable meetings with and learning from experts. They cited workshops, webinars, and events organised by their CEC areas as important intrapersonal learning environments for energy issues (22.9%). For some respondents (16.2%), the workplace is also an important environment in which they learn about energy-related issues. (see Table 3).

In search of answers to their energy-related questions, respondents considered a variety of settings and objects. Search engines appear to be the primary starting point for addressing knowledge gaps, but they are not learning objects per se, but rather pathways to other materials (e.g. online manuals) or settings (e.g. online forums) for information and acquisition of new knowledge. In general, governmental, non-governmental organisations and their CECs appear to be the most important sources of information on energy-related topics for respondents (see Table 4).

4.4. Diffusion of knowledge from CECs to the wider society

From the SNM perspective, the idea of sharing the knowledge accumulated within CECs with a wider interested public is seen as crucial for energy transition. Participants perceive that the positive examples their CECs present could serve as a case study and a learning setting for others that could attract more members to existing CECs or encourage the creation of new ones.

Participants mentioned several learning settings that facilitate encounters between CEC members and the interested public, as well as learning objects that can serve as materials for the interested public to support learning about energy-related topics.

4.4.1. Place based and virtual settings for the diffusion of knowledge

Participants often saw themselves as important informal ambassadors for CEC, sharing information, experiences, and knowledge about CEC-related issues in their daily *personal interactions with friends, neighbours, relatives, and colleagues*.

One participant described how he/she talks about his/her CEC membership with colleagues, creating opportunities to spark curiosity, generate interest in new knowledge, and even encourage them to think about how they might do the same: *You say at work, "Yes, we are that block of flats, we are already a bit famous here in town". We are the block with the first solar panels. "So you are the one?" And then you give them a little bit of an idea of how it's done, so that they see it's not so difficult at all* (I2_SI). Another participant seems even convinced that his/her promotion of CEC in his/her personal interactions has a visible impact: *I still promote the project in my community. … We have a community of people who are interested in nature and environmental issues and local issues. So I always promote [name of the CEC]. And I know from our unit that a lot of new members of the [name of the CEC] were gained through my efforts. … I really do feel I'm kind of an ambassador for [name of the CEC]* (I5_NL).

Participants mentioned that their CECs tend to facilitate place-based learning encounters to disseminate knowledge in society. *Informational meetings and special promotional events* (e.g., picnics, parties, practitioner forums, special festivals, energy breakfasts) organised either by local CEC members (grassroots initiatives) and/or by large energy utilities and/or associated partner companies involved in the CEC organisational structure, are usually designed to provide opportunities for communication between CEC members

Table 3
Learning settings and objects for clean energy community members

News or documentary programmes on TV or radio (O)	78.1%
Newspapers (O)	66.7%
Searching on the internet (O)	65.7%
Energy community newsletters (O)	55.2%
Charities and NGOs (S)	49.5%
Information from national government or my local council (O)	41.9%
Energy companies or energy providers' information (O)	40.0%
Magazines (O)	38.1%
Workshop, webinars or other events organised by our energy community (S)	22.9%
My job (S)	16.2%

n = 123; ordered from the most selected option to the least selected option
Note: S = setting; O = object

Table 4
Reference points for addressing knowledge gaps for clean energy community members

Search engines (e.g. Google search)	72%
Government websites (e.g. Department of Energy)	57.9%
My energy community	52.3%
Online or print encyclopaedias (e.g. Wikipedia)	33.6%
Non-profit agencies	32.7%
Industry websites (e.g. utility, gas, renewables)	29.0%
Consumer associations/organisations	28.0%
Social media; professional online profile pages (e.g. industry, non-profit or subject expert)	21.5%
Scholarly research database	19.6%
Blogs or forums	18.7%
Friends or classmates	16.8%
Family	15.0%
Social media feed; non-professional online profile pages (e.g. friends, family)	7.5%
Textbooks	4.7%
A high school teacher	0.9%

n = 123; ordered from the most selected option to the least selected option

and experts on various CEC issues and the interested public, to identify and potentially fill gaps, and thus contribute to the empowerment process of the interested public on energy issues. Such meetings have been perceived as a very important framework for disseminating knowledge to the public interested in the benefits of CEC.

More formal learning environments provide activities that are delivered within the *formal curriculum*. Several participants reported regularly visiting local schools where they gave talks and presentations on sustainable energy and enabled students to learn more about the environment and clean energy. One participant stated: *… education is very important because we are working on new generations. We give lessons at a local school* (I2_NL).

Some participants also reported about *study visits* and described them as unique learning opportunities about innovative CEC design, maintenance, or management. Organised field trips or study visits to CEC communities provided an opportunity for encounters in which visitors - interested external publics, can ask questions and learn about various innovative environmental and technical solutions on sites.

Some CECs studied have an organised *system of formal CEC ambassadors*. Participants in such communities stated that the 'ambassador programme' in their CEC provided a formal learning setting that allowed for personal knowledge sharing and opportunities for interested pulics to learn CEC-related skills. Ambassadors could be viewed as a type of personal trainer or mentor for people who show interest in energy transition solutions. Such ambassadors are able to share their personal experiences, perceived benefits of CEC membership, and motivate and attract new members to join a CEC. Moreover, those CEC members who are accepted into the ambassador program could themselves benefit from improving their knowledge. One participant was quite clear about this: *Due to the fact that I was interested in storage technology as an ambassador for the company [name], I also regularly receive information about new technical advances at [name]. So I'm more or less up to date this way, which is something a normal community member won't be, because this person doesn't get any further information* (I2_DE).

The very existence of CECs can be seen as an *exhibition of good practices* that can arouse the curiosity of neighbours and others in a local community or beyond. In these interpersonal learning environments, people can gain knowledge about the CECs business models and gather advice and guidance for replicating good practices in another community. It is not uncommon for members from different CECs to organise joint meetings and compare practices, discuss problems, and try to find solutions. One participant explained the importance of learning from other CECs: *We've been looking at other cooperatives which were already active /…/ we've been 'stealing' all their knowledge and their smart ways of solving the problems* (I6_NL).

Training on specific energy-related topics for external interested parties can also be conducted in a virtual environment, via webinars, or via social media CEC platforms for example: *on the energy local portal for the advisors I can see loads of literature that they've got … where they've got like instructions when to run your washing machine and they've got loads of advice and information* (I4_UK)

4.4.2. Learning objects for disseminating knowledge

Online promotion via web platforms and social media, for example, was perceived as a fairly common way to communicate about CEC. The importance of online promotion for the dissemination of CEC knowledge is evident in the following observation: *I was certainly lucky … Google helped me a lot because otherwise I wouldn't have known about this project, also because I don't know … how to add people? This is certainly a point to be taken care of because actually apart from word of mouth or now there are Social media, but you should think about how to get this message to as many people as possible, so that those who share these values, those who feel motivated can join and in a second phase try to contact more people still, leveraging other reasons, other aspects* (I1_IT).

Documentaries and books (special technical books, and technical books) on CEC cases were considered by some participants to be important sources of information and materials for learning processes that allow people to get a vivid picture of the nature of CEC, its connection with environmental issues, and technological features. One participant mentioned that some CECs have become internationally known because of their representation in a documentary film: *English filmmaker was here and filmed about environmental protection* (I8_SE).

The media (newspapers; generalists - national, local, and technical newspapers) are perceived not only as a communication channel, but
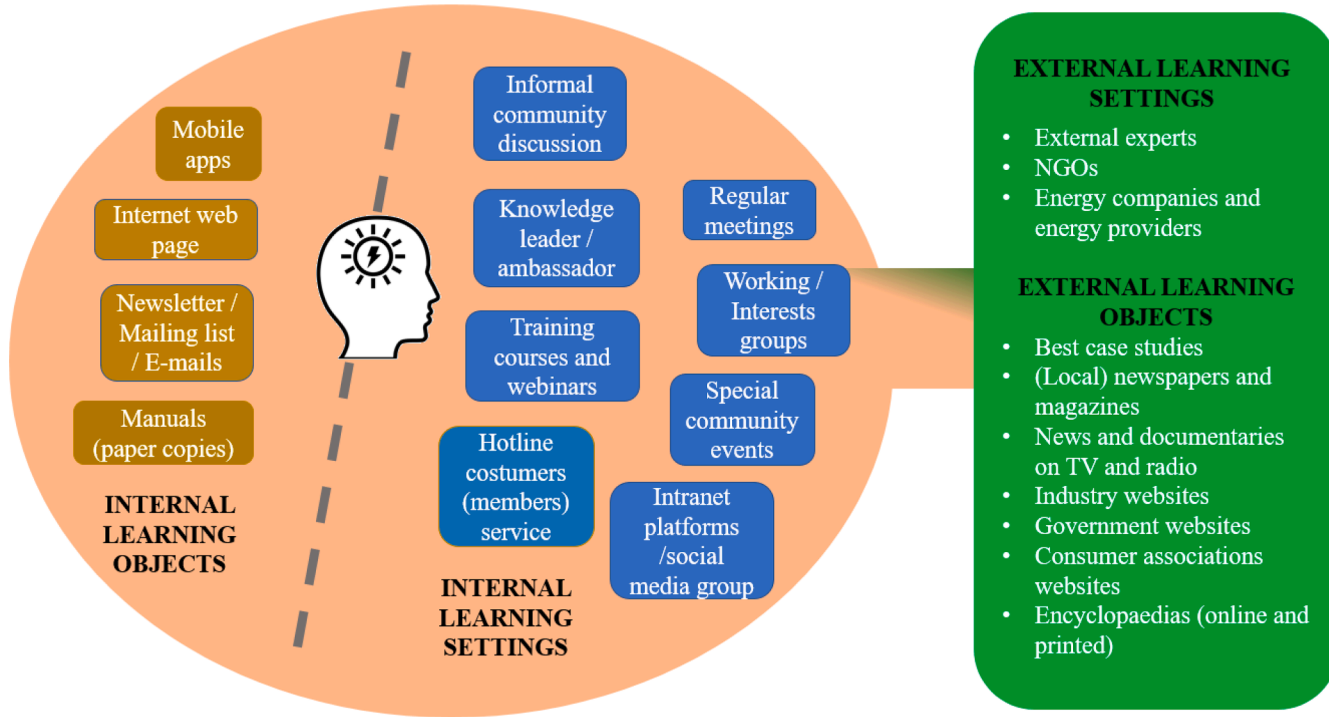
Fig. 2. Learning settings and objects for learning in clean energy communities

also as an important agenda-setting actor with a crucial role in disseminating CEC-related information to a wider public. Some participants stated that before becoming CEC members, they first received information about the existence of CEC through the general national or local newspapers or specialised magazines and newspapers, as noted by one participant: *I came into the project when I read about it in [local newspaper name], when they had started building, and by then, it was something that I had long thought about, that I wanted to invest in* (I7_SE). Some participants obtained initial information about the CEC in a technical weekly magazine and some, who were more interested in investment opportunities, reported that they obtained initial information about the CEC through specialised business newspapers.

In some cases, *energy (distribution) companies* produce promotional materials that can function as objects in learning processes about CEC for broader populations. In some cases (press conferences, PR events that enable face to face interactions) these promotional materials get used as part of interpersonal learning settings for sharing and promoting CEC good practices.

Participants also mentioned *advertising* (e.g., flyers, posters distributed in community locations such as local stores, movie theatres, bus stations, etc.) as a common form of disseminating knowledge about CEC that can reach different audiences and encourage them to learn about the benefits of CEC.

5. Discussion and implications

5.1. General discussion

In this study, the notion of learning in niche-innovations was treated as a purely empirical question, focusing on learning settings and what individuals learn. Furthermore, the study considered not only the interactive learning space within CECs as niches (interlocal phase), but also the potential for broader knowledge diffusion outside the niches (trans-local phase) (Mirzania et al., 2020). In terms of answering the question about skills and knowledge, the findings demonstrate that several skills and knowledge were acquired by CEC members within the identified learning settings. The analysis further shows that often pre-existing skills were re-actualised when dealing with challenges or problematic situations (i.e. gaps) identified by the participants.

In addition to identifying different learning settings within community organising and learning objects that can be used for people's learning, the analysis of participants' views also offers insights into how these settings and objects can help us understand the potential for facilitating learning in CECs. The learning settings we describe can be seen as spaces created for exploring CEC-related issues, as several participants' examples show. Fig. 2 illustrates the learning settings detected among the studied CECs.

The study also shows that certain learning settings created by CECs can be understood as enabling spaces where knowledge can circulate outside CECs thus increasing the transition potential of CECs learning outcomes. CEC members use different ways to share their experiences, practices and relationships with each other and others. The findings reflect that membership in CECs affects members' existing energy-related views, knowledge and skills; it enriches and upgrades them and, thus, provides insight into *what* the participants, as CEC members, learn.

From our analysis, it is important to recognise the diversity of CECs (and their members), which increases the potential for very different learning settings. According to SNM, the heterogeneity of CEC members and the transfer of their (previously acquired) skills is a key factor for CEC development.

CEC members engage in different learning settings in different ways, choosing those settings that are most relevant and effective for the intended inquiry (Östman et al., 2019b). For example, when the majority of CEC members are older, they are more likely to use manual instructions and/or inform themselves with printed media or by talking to other members. In place-based CECs, members can learn more easily in informal settings or face-to-face training seminars. In contrast, in large virtual communities, members can learn through webinars or, if large enough, through the CEC customer hotline and institutionalised CEC knowledge ambassadors. From the SNM perspective, the identified diverse system of learning settings allows for the possibility of an adaptive, customised group of settings that can be configured for each specific stakeholder group and location specificity.

MLP suggests that energy transitions depend on how successfully empowered niches (CECs) can be in interacting with their environment and specifically with regimes (van Mierlo & Beers, 2020). Some authors (e.g. Van Poeck & Östman, 202) have established that it is hard to determine for certain how today's activities affect profound systemic transitions. To grasp the potential of (macro) changes, one can at least observe day-to-day learning and the use of information resources, which represent grounds for any kind of (systemic) transition that may take place in the future. To support this, our study adds important empirical evidence of established learning settings demonstrating that the knowledge is, in different ways and to various degrees, shared with recipients outside the CECs. To a certain extent, such knowledge sharing also embodies the potential to translate the experiences accumulated by CECs into general knowledge.

As can be seen from our study, knowledge diffusion manifests itself mostly spontaneously (especially in place-based CECs) through informal, everyday encounters and is still rather limited to relatively close social circles of members (family and friends). However, there are other, less spontaneous forms of knowledge dissemination that take place for two reasons. The first is to inform the general public about CEC's work in order to raise environmental awareness (e.g. through study visits, books and documentaries, lectures for students in schools, newspaper articles). The second purpose of (planned) activities is to attract new members to join a particular CEC (e.g. through advertising, CEC ambassadors, special promotional events). The SNM perspective suggests that the identified portfolio of settings for knowledge dissemination is particularly relevant for the broader promotion and diffusion of the new socio-technical system - the CEC. Most of the time, there is no single deciding factor that makes someone join a CEC; there is always a combination of reasons (Bomberg and McEwen, 2012; Koirala et al., 2018; Wiersma and Devine-Wright, 2014). Moreover, CECs have different characteristics that require different combinations of knowledge. The settings for the diffusion of accumulated knowledge in CECs with potentially
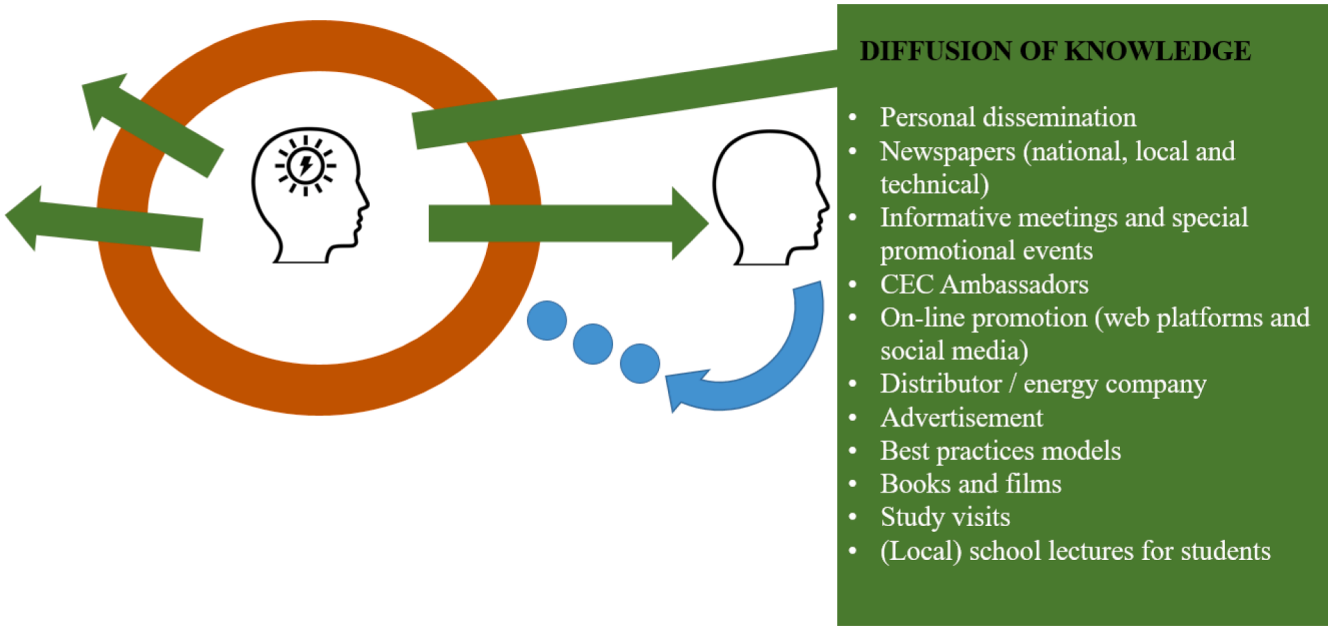
DIFFUSION OF KNOWLEDGE

- Personal dissemination
- Newspapers (national, local and technical)
- Informative meetings and special promotional events
- CEC Ambassadors
- On-line promotion (web platforms and social media)
- Distributor / energy company
- Advertisement
- Best practices models
- Books and films
- Study visits
- (Local) school lectures for students

Fig. 3. Diffusion of knowledge in clean energy communities

interested publics are summarised in Fig. 3.

5.2. Practical implications

CECs are a good example of transdisciplinary co-production of knowledge, where the actors (CEC members) are willing to move beyond the sustainability challenges at hand to co-produce and share new knowledge and learn together how to move forward (Schneider et al., 2019). The identified learning settings cover a wide range of possible arrangements that have been applied in practice (in real CECs) and could facilitate future CECs to develop their own unique CEC learning model.

Systematic and deliberate sharing of accumulated knowledge and information about CECs, maintenance and benefits of CECs for members, the local community and society in general could increase interest in CECs (to organise and establish new CECs) and/or promote the expansion of existing CECs by attracting new CEC members.

Our findings show that there are many relevant learning settings that could help the interested public to engage in the learning process about CECs. However, it was found that effective energy knowledge transfer is not just a matter of sharing information (Catney et al., 2013). Accessibility and recognised personal relevance of information are also important for knowledge transfer. Several actors could contribute to making CEC knowledge more accessible and personally relevant to the interested publics. Universities could develop curricula that present the role of CECs in the energy transition and focus on different aspects of CECs - legal, economic, social and behavioural. Based on the knowledge on CECs' they could develop case studies for students to learn both the theory and practice of setting up and running a CEC. Non-governmental organisations (NGOs) could be very helpful in using CEC learning settings to disseminate energy-related knowledge to their public and encourage people to engage in clean energy production and/or consumption through tailored communication. Local governments in particular could be a very powerful ally in disseminating CEC-related knowledge by establishing an official information centre and department with up-to-date technical, legal and financial information to support the process of establishing and operating a CEC. If governments are seriously committed to the energy transition in the near future, they could assist in the dissemination of energy-related knowledge on a larger scale by helping national energy utilities to inform their customers about the benefits of clean energy and by enabling local government bodies to facilitate the implementation of new CECs.

5.3. Limitations and further research

Our study is not without limitations. Learning in sustainability – and specifically energy – transitions is still a rather under researched area (Van Poek et al., 2020) and many blind spots remain. Our study has focused on learning settings, yet it has not provided an insight into the learning process itself by exemplifying how CEC members learn. To a large extent, this is due to selecting the semi-structured interview as a research method. While generally this method is useful to work with such complex issues as learning (Wilson, 2014), several weaknesses have also been identified in using interviews for assessing sustainability knowledge and competences such as: interpreting statements for evidence of competence is subject to contestation, time consuming to analyse, and responses may be influenced by facilitator, etc. (Redman et al., 2021). Our study was able to overcome certain issues, for example we carefully selected the facilitators – interviewers' who were complete outsiders to the CECs settings and therefore more objective. Yet it should be emphasised that interviews are a typical' self-perceiving-based assessment' procedure and the results can be to a certain degree subjective.

For the future development of this study, it would be advisable to upgrade the 'self-perceiving-based assessment' with 'observation-based assessment' and 'test-based assessment' procedures to better capture the learning process itself. The selection of a different method would require conducting the research *in situ* and thus a different research design. Nevertheless, our study provides valuable insights that point towards interesting new avenues for researching the learning process in CECs in more depth. For example, besides investigating the 'where' of the learning process, it would be interesting to explore 'how' the knowledge expands and evolves across the identified learning settings, in what ways the settings are useful for the inquiries the CEC members start when entering the learning process and how the settings affect their learning outcomes, namely technical and non-technical knowledge and skills, which could be analysed also into greater detail. Additionally, it would be worth exploring in more depth how the learning settings that provide grounds for learning of people outside the communities facilitate their learning process, which then contributes to the outcomes accumulated in the 'general' knowledge about CECs and their functioning.

CECs could be interpreted as agents or 'carriers of energy transitions' (Dóci et al., 2015). In this particular exploratory study, we systematically focus on mapping different learning settings and objects in CEC, which could provide a reference for future agents. In this way, we stimulate and open the door for a possible complementary research that could focus in the future on the specific content, on 'what' members learn in the settings presented. Furthermore, in addition to exploring the 'where' of the learning process, it would be interesting to explore 'how' knowledge expands and develops across the identified learning settings, in what ways the settings are useful for the inquiries CEC members make at the beginning of the learning process, and how the settings influence their learning outcomes, which could also be analysed in more detail. In addition, it would be worthwhile to explore in more detail how the learning settings that provide learning opportunities for people outside the communities facilitate their learning process, which in turn contributes to the findings accumulated in the 'general' knowledge about CECs and how they function.

6. Conclusions

This is the first study to map the different learning environments in CEC contexts. The main contribution of this paper to the energy

transition literature is the comprehensive analysis of learning environments and the mapping of information flow processes - the circulation of clean energy information (inside and outside CEC) - based on empirical data derived from the experiences of CEC members. The research findings are relevant for current and future CECs, as they reveal several valuable learning settings for members and knowledge dissemination in CECs in different European countries.

The analysis highlights the learning settings (summarised in Fig. 2) that enable individuals to acquire various forms of knowledge within niche clean energy systems and the potential for dissemination of that knowledge outside of CECs (Fig. 3), which could lead to improvements in overall clean energy knowledge in the population. An appropriate geographically distributed 'critical mass' of people knowledgeable about clean energy is essential for the development of a more sustainable energy supply with different types of clean energy systems.

Declaration of Competing Interest

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Data availability

Data will be made available on request.

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