Knowledge and skills required to set up and operate clean energy communities

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Abstract

An appropriate set of skills and knowledge is required to establish and operate clean energy communities (ECs). In most cases, building an EC is a team effort and it is very important not to neglect or undervalue the skills of the people involved. This paper identifies the knowledge and skills required to create and operate an EC. To this end, ten case studies of clean energy communities in six European countries are examined. The study concludes that skills can be divided into two categories – technical (hard skills) and non-technical (mainly soft skills). Pre-existing technical skills are necessary but not sufficient to create and operate energy communities. The study also focuses on learning and knowledge management and sharing within and outside communities, with an emphasis on learning by doing.

Keywords

Renewable energy; knowledge management; education & training

Introduction

Energy communities (ECs) can be considered technological and social innovations with the potential to contribute to the clean energy transition, whilst placing citizens at the fore (European Commission, 2022). In 2020 there were estimated to be 3,500 renewable energy cooperatives, a particular form of EC, in existence across Europe (Caramizaru and Uihlein, 2020). The true number will be much greater than this, not least because contemporary ECs employ a variety of business models (Reis *et al*., 2021). Contemporary ECs are being developed by community members, by commercial companies, and by municipalities or a combination therein (Barnes and Hansen, 2022). ECs can be spatially limited, e.g. to a building, neighbourhood or village, or they can function as ‘virtual networks’ or ‘communities of interest’, i.e. communities that are not tied to specific geographical areas (Bauwens and Devine-Wright, 2018). As a result, all ECs differ (de São José *et al*., 2022). Following the seminal work of Walker and Devine-Wright (2008) in distinguishing community-led renewable energy projects from their commercial equivalents, this paper defines ECs as ‘associations of actors engaged in energy system transformation through collective, participatory and engaging processes, seeking collective outcomes’ (Blasch *et al*., 2021: 3).

Because ECs involve the active participation of citizens in their design, ownership, or operation (Mihailova *et al*., 2022) the knowledge and skills of members is of vital importance. Skills include the ability to apply knowledge to solve a problem or complete a task; they include ‘knowing how to make something happen; involve cognition, but also other aspects such as manual dexterity or sensory ability’ (Senker, 1995: 427). Thus, for a skill to be demonstrable and observable, a certain knowledge base is required that the individual must be able to access (Peterson and Van Fleet, 2004). Knowledge and skills are thought to drive technological, social and economic aspects of innovation (Blasch *et al*., 2021). A lack of technical and other skills can be one of the main barriers to the diffusion of ECs in society (Ceglia *et al*., 2022). Blasch *et al*. (2021) call for research that critically examines the knowledge and skills required to set up and operate ECs. Following this call, this paper asks: What knowledge and skills are required for ECs to operate? How is knowledge shared within and potentially transmitted outside of communities?

The article is structured as follows: Section 2 reviews the limited body of work on knowledge and skills for ECs and the study of knowledge and skills for sustainable communities, of which there is more; Section 3 introduces the research design and approach taken to studying knowledge and skills in ECs; Section 4 presents the results; Section 5 concludes.

2. Knowledge and skills for energy communities

To date there has been little research on knowledge and skills for ECs. Given this, the following section discusses what little research there has been in dialogue with research on knowledge and skills for sustainable communities, which have received more attention to date (e.g. Franklin *et al*., 2011, Bradbury and Middlemiss, 2015, Turvey *et al*., 2018). Sustainable communities have been defined as communities that 'support the principles and processes of environmental sustainability, economic prosperity (or sustainability), social justice and community well-being' (Turvey et al., 2018: 1175). ECs can be considered as a type of sustainable community that works with renewable energy resources (Østergaard *et al*., 2020). This literature suggests creating and operating sustainable communities depends on how existing knowledge and skills of community members are leveraged; how committed people are to the community; how well they are able to interact with different stakeholders outside the community; how well they are able to plan for and anticipate the current and future needs of citizens in the community (and beyond); and finally, how well they are able to deal with sometimes very complex and challenging issues on the ground (Academy for Sustainable Communities, 2007).

The sparse literature on ECs mentions that professional skills in engineering, technology and science may be required to establish an EC, and that a lack of these skills is seen as an important barrier (Ceglia *et al*., 2022). However, there are other 'soft' skills (communication, organisational skills, teamwork, project management, problem solving, etc.) that are among the important factors for ECs and are also necessary for creating and operating communities on the ground (Hicks and Ison, 2018). Studies on sustainable communities show that skills such as communication, organisation, teamwork, project management and problem solving are particularly important, if not crucial. Following Franklin *et al*. (2011), generic, 'soft' skills – rather than professional, 'hard' skills – could make or break clean energy communities. Generic or soft skills are skills that are transferable between different professions and disciplines and can also be described as 'informal'. They are not necessarily taught, but acquired based on the individual's experiences in daily life (Franklin *et al*., 2011).

The literature on ECs refers to the need to 'upskill' and learn new skills to improve engagement in ECs (e.g. Sareen *et al*., 2018). However, this neglects the fact that people who engage in an EC already have certain valuable skills - either hard or soft (Rogerson *et al*., 2010). Previous studies have shown that skills related to specific technical knowledge are generally required in the energy sector (e.g. electricity, mechanics and engineering), as well as skills related to other professional requirements such as marketing and market research, and general computer knowledge and skills. Soft skills related to interpersonal adaptability and dealing with problems related to behaviours and relationships in specific situations may also be required (Lyu and Liu, 2021).

It is therefore important to know what knowledge and skills can be usefully activated for the EC project. While some ECs rely on top-down planning and professional skills, others emerge from the bottom-up and depend on the skills and knowledge that exist in the communities (Newton *et al*., 2012; Barnes and Hansen, 2022). For an EC to be successfully created and operated, people with different roles need to be involved, and there needs to be a link between the potential contributions of professionals and community members (e.g. Franklin *et al*., 2011). This requires interaction and teamwork - the best community projects are usually the result of dedicated and skilled professionals and community members working together to solve problems and develop solutions.

The literature on ECs emphasises the importance of social motivations for community members (Hicks and Ison, 2018). Similarly, studies on sustainable communities conclude that skills and knowledge are products of social relationships (Bradbury and Middlemiss, 2015). On the one hand, this means that individual engagement in the community is important, which also motivates participants to learn new skills (Franklin *et al*., 2011). On the other hand, it also means that learning has a social dimension that should not be neglected. Knowledge is thus accumulated through social practices in which individuals participate, and this makes individual and collective (community) knowledge highly interdependent (Shin *et al*., 2001). In communities, different types of knowledge are created and shared. The two most common forms of knowledge are explicit and tacit knowledge. Explicit knowledge is anything that can be codified in various material forms (written, drawn...) and easily shared, while tacit knowledge is implicit - it is anchored in the individual and consists of mental models, skills and behaviours, mostly based on experiences and actions (Verburg and Andriessen, 2006).

One of the focal points of learning in communities is the transmission of more implicit knowledge (i.e. tacit, practical knowledge). This knowledge is often passed on through observation, learning by doing and collaboration between individuals (Verburg and Andriessen, 2006). Collaboration can also foster the development of new knowledge by learning to do new things together (e.g. Mittendorff *et al*., 2006; Verburg and Andriessen, 2006). This requires a lot of interaction and a shared understanding of the knowledge to be developed (Mittendorff *et al*., 2006). Essentially, much of the learning and knowledge sharing in ECs is assumed to be social in character, meaning that learning goes beyond the acquisition of abstract knowledge at the individual level (e.g. Darby, 2006). Rather, it is tied to the context of ECs and any practices within those communities for which knowledge has particular meaning (Brown and Duguid, 1991).

3. Research design and approach

To address the research question posed, a case study methodology was employed. Case studies are particularly suited to answering ‘how’ questions - i.e., about processes - where the unit of analysis and the context have unclear boundaries (Yin, 2009). Cases were selected from six European countries - the Netherlands, Sweden, Germany, Italy, Slovenia and the United Kingdom. Each country selected for differing in terms of their share of renewable energy in total energy production, their regulatory environment, the degree to which energy community models are embedded in society, and their economic and social structures. Individual cases were selected for diversity of activity and in order to capture ECs being developed by citizens and by commercial enterprises. The cases are introduced in Table 1.

Table 1. ECs included in this study

Case study	Value proposition	Business activities	Financial model	Governance model
Buurtmolen Herbaijum, The Netherlands	Collective generation and consumption of local wind power by residents; Reduced electricity import costs	Power generation from a single 900KW wind turbine sold via a licensed supplier over the public distribution network to local households; facilitated by Dutch 'postcode rose' legislation; developed by local landowners in partnership with the licensed supplier	Turbine financed via commercial loans and bonds to private individuals, repaid via member electricity bills.	Cooperative enterprise with residents as members
Buurtmolen Tzum, The Netherlands	Collective generation and consumption of local wind power by residents; Reduced electricity import costs	Proposed 1MW wind turbine on the site of a former turbine, with power to be sold via a licensed supplier to local residents, facilitated by the Dutch 'postcode rose' legislation; developed by a local sustainability initiative and owner of the previous turbine	Crowdfunding of capital costs to be repaid via sale of power to members (proposed)	Cooperative enterprise with residents as members
Dalby Solby, Sweden	Creating sustainable lives through collective solutions	A cooperative housing association established in 1979, with rooftop solar PV and solar thermal providing power and hot water to communal areas	Financed via member investments	Collective decision making by all residents on the housing association board.
Economia Rinnovabile e Circolare (ERiC), italy	Expert advice and support to install residential solar PV systems	Advice and training to households seeking to install domestic solar PV, ERIC creates purchasing groups and guides residents through installation	One-off membership fees paid by households, share of revenue from engineering consultancy, who helps householders	Non-profit social enterprise; all financial decisions rest with householders
Energy Local clubs, The United Kingdom	Fairer prices for generators and consumers through a dynamic regional tariff, operated as a set of clubs	Supply of locally generated power to local households on a 'match tariff', under a regulatory exception, with power allocated using a smart algorithm.	Designed with minimal overheads, each party benefits financially, and a member fee covers costs of running the cooperative.	Cooperative enterprise at centre, with generators and consumers as members, alongside social enterprise and licensed supplier working collectively to deliver each club
GEN-I Jesenice, Slovenia	Collective generation and consumption of renewable energy by residents of an apartment block	Design and installation of two solar PV systems: (1) 16 KWp system providing power to individual apartments, (2) a 15 kWp system supplying power to communal areas and a heat pump for communal hot water; developed by a local resident in partnership with a national supplier	Financed via loans and capital grants, repaid via resident bills, allocated using pre-define cost distribution keys.	Informal, consensus-based decision-making by residents
Project Z, Germany* **Due to commercial sensitivity, the anonymity of this case has been preserved.*	'Regional, sustainable energy autarky' via neighbourhood peer-to-peer trading	Trading of regional solar PV generation between prosumers and consumers using modified import/export contracts with a licensed supplier, developed by the innovation arm of the licensed supplier	Developed via R&D funding from parent company, to be finance in the long-term via member bills	Corporate, closed
Solidarity & Energy Social Housing (SO_EN), italy	Affordable and fair power for marginalised communities	Design and build of a set of 12 low energy apartments, utilising rooftop solar PV and batteries over a microgrid, operated as an energy service company by a community foundation and newly created social enterprise for residents.	financed via commercial loans and research grants.	Cooperate and networked
sonnenCommunity, Germany	'Clean, reliable and affordable energy for everyone'	A virtual power plant, in which all sonnen GmbH product or service customers, 'share' power generated by member PV and battery systems, over national energy systems controlled remotely via sonnen cloud-based software.	Member PV and Battery systems are self-financed. Participation in the virtual power plant involves flat rate utility bill and covers all power required	Corporate, closed
Zuiderlicht, The Netherlands	Energy generation for everyone', primarily via rooftop Solar Photovoltaics	Installing, managing, and operating rooftop solar PV projects, utilising long term roof leases, and power purchase agreements with building owners and a licence supplier as offtakers	Collective financing of projects via share offers	Wholly managed by members as a cooperative enterprise, with one-member, one-vote

Data was collected through 31 semi-structured interviews. Interviewees were purposively selected, with the help of community representatives to represent a variety of stakeholders involved in the ECs. Interviewees included utility/distributor managers, EC founders, organisers, board members and community leaders (Figure 1).

EC/country	sonnenCommunity; project Z Germany	ERiC; SO-EN Italy	Buurtmolen H + T; Zuiderlicht The Netherlands	Gen I-Jesenice Slovenia	Dalby Solby Sweden	Energy local UK
No. of interviews	2	12	5	3	6	3
Role of informants	Member of EC stakeholder advisory board EC manager	Experts Managers Member of cooperative Planner of EC Scientific and tech partner Technology researcher Promotors of EC Partner of EC	Energy supplier - a manager EC member (2) Intermediary Founder of EC Organizer of EC (2)	EC member – leader Energy distributor – manager Energy distributor – legal expert	EC member (2) EC participant Member of the EC Board (2) Previous member of the EC Board	EC founder and manager EC advisors (2)

Figure 1. Interviewees and their roles within the ECs

Participants were not offered any incentives for taking part in the study. Interviewers followed an interview guide that covered the following topics: (1) interactions and engagement to capture communication and information flow within the community and between the community and other stakeholders, as well as to uncover educational initiatives in ECs, (2) knowledge and skills essential to ECs; knowledge and skills learned in the process and the learning process itself, (3) and future prospects for the EC, including potential knowledge-sharing activities in ECs. The interviews were conducted online between May and June 2020. They lasted more than an hour on average. All interviews were recorded and transcribed verbatim. Participants' personal characteristics were anonymised to ensure confidentiality. The data collected were translated into English and analysed using thematic analysis to capture the skills and knowledge considered necessary to create and operate ECs.

4. Results

4.1 Knowledge and skills required to create and operate ECs

Based on the descriptions of processes in creating and operating ECs provided by the interviewees, thematic analysis identified different types of knowledge that study participants considered necessary for ECs. According to the study's findings, these different types represent a specific knowledge base that is essential for EC-related activities and the implementation of skills. The analysis also revealed that most knowledge related to EC is articulated knowledge (i.e. knowledge expressed through perspectives and described practices of respondents) or embodied knowledge (i.e. knowledge expressed through skills, know-how and expertise), while codified knowledge, captured in documents, reports or protocols, is less evident. Identified knowledge was grouped into four categories - technical, legal, business and behavioural knowledge - before being categorised as pre-existing (P), partially pre-existing or partially learned (P/L) and largely learned (L) knowledge. The results, presented in Figure 2, shed light on pre-existing knowledge that could be useful for creating and operating ECs and what must be learned in the process.

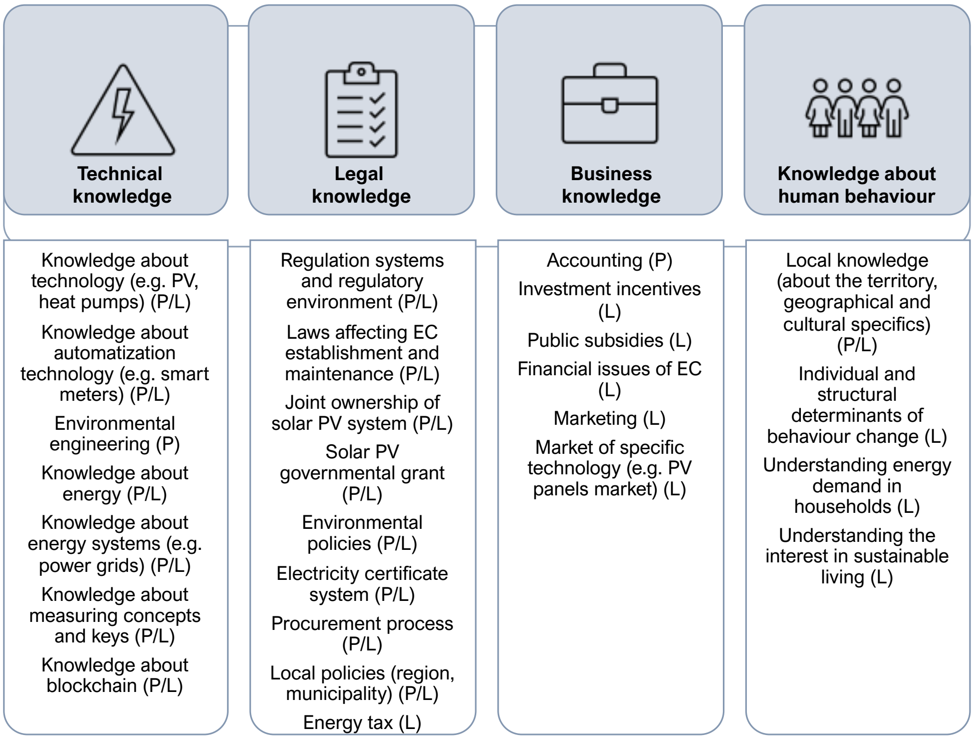

Figure 2. Types of knowledge necessary for creating and operating ECs

Three of the four identified knowledge types, namely technical, legal and business knowledge, are consistent with the types of knowledge mentioned in previous studies on ECs (Hoicka *et al.*, 2021). The fourth - knowledge about human behaviour - emerged from the data and is largely absent from existing EC-related literature. Study participants considered knowledge about human behaviour, especially understanding of behaviour change and interest in sustainable living, to be very important for the creation and operation of new ECs.

In the next step, the analysis focused on how the types of knowledge identified above are expressed in the professional competences and experiences of the participants. Again, the focus was on whether the knowledge and skills activated were something the participants already possessed in some way, or whether they had to be learned.

4.1.1 Pre-existing skills and knowledge

The analysis has shown that both technical and social skills are considered necessary to create and operate ECs. They are especially necessary for those who are seen by the study participants as the backbone of the community project (individuals or a group of people acting as initiators). However, to some extent, pre-existing skills were also mentioned as useful for other members of the community.

In most cases, the project initiators were well acquainted with energy issues; they had a professional background in engineering or other technical knowledge. For the initiators or founders of ECs, prior technical, financial and legal knowledge base and hard skills are seen as almost indispensable prerequisites for establishing an EC: '*It's quite advanced ... you have to have a good understanding of how a wind project works*' (participant from Buurtmolen Herbaijum). A participant from Buurtmolen Tzum elaborated on this:

> So in Tzum it is a person who is an energy advisor. That is his job, so to speak. So, he advises other cooperatives and other projects. He is very involved; he comes from that reality. ... And he also has a lot of understanding of setting up these kinds of wind turbines, so he is a very big driving force ...

Although technological factors vary from community to community, the need for technical knowledge is more or less evident in all case studies. However, the data suggest that this type of knowledge is not sufficient for the successful creation and operation of ECs. It needs to be combined with non-technical, mostly soft skills, such as organisational skills. A participant from

Buurtmolen Herbaijum confirmed this in his own words: '*... organising the interconnection and all the administrative matters involved, as well as getting permits ... it's not for amateurs. Basically, it requires a certain level of knowledge or at least professional support to organise that*'.

For example, skills are needed to organise and manage people from different educational and professional backgrounds, as well as to communicate with external stakeholders, including local authority decision-makers, grid operators, technology providers and others. In general, participants felt that the ability to encourage and organise people was absolutely essential. One participant from Dalby Solby said:

> ... If you look at the size of Solby, 50 households … you have ways of organising these people that give you much more power; one person would never have been able to do anything, so knowing how to organise people is a crucial factor for success.

Those members who have technical knowledge and skills should also be able to participate in people-oriented activities and 'translate' the technical knowledge to other members of the community. This was mentioned in the ERiC case study: ' *...we must be good at this ...We technicians need to put these complex words, these complex numbers that result from algorithms and calculations, into a simple, understandable form*'.

4.1.2 Learned skills and knowledge

In terms of learning new skills and knowledge in the EC, mainly specific, non-technical skills - soft skills and some hard skills - were mentioned as being learned (or needed to be learned). These included skills such as collaboration, persuasion, marketing-related skills, etc. One of the ERiC participants described a way to communicate with potential members: '*I had to acquire some techniques, in the sense when I said, 'Good morning, I'm XX from the ERiC project', I followed the model of the telephone operator, the switchboard operator*'.

In most communities it was emphasised that people must learn to work together. In Buurtmolen Herbaijum, one participant stated: '*the social aspect of coming together and creating something ... requires a different dynamic than when you only talk about numbers, investments and investment returns, etc*.' A participant from the same community also mentioned the importance of pooling and using all the knowledge and skills of different people. In Dalby Solby, which prides itself on being a true democratic community, great efforts have been made to organise the so-called 'social part': '*... how we handle the monthly meetings is a good example. We also have other systems ... different working groups and house groups represent effective self-management in this area*'.

At least some basic technical and maintenance knowledge and skills also had to be learned by the members of the communities. In the case of Gen-i Jesenice, a participant acknowledged that community members usually want to understand things and learn the basics in case that something goes wrong: *'That it's a heating system and what we connect it to. Basic things like the payback, the maintenance costs, the lifespan and the savings. Nobody really needs to understand how it works, but the basic things*'. In the ERiC case study, one participant freely admitted that he/she acquired most of his/her knowledge only after participating in the project: '*I consider myself the result of an experiment, because apart from the basic concepts of photovoltaics, I did not know the differences between the different types of photovoltaic panels before I joined the association*'.

Despite the impression that many soft skills need to be learned, the interviews also showed that previous experience from everyday life or other work contexts was very helpful to engage in project development. In some cases, however, these skills and knowledge remained an untapped potential. One participant from Buurtmolen Herbaijum tried to explain this:

> We have some people who know everything about the local society, like the baker. For example, everybody knows him. Yeah, everybody buys bread. Is the knowledge, when I look at our community many people work outside ... that kind of knowledge is not used at all. ... We have found that all knowledge is available within a kilometre.

The data shows that knowledge in ECs is often highly contextual, applied and based on experience and action rather than written documents, protocols or manuals. This means that tacit knowledge is far more common in CEs than explicit knowledge. It is also clear from the responses of some interviewees that participation in the EC itself and engagement in a community project has led to acquiring new knowledge and skills without explicit instructions or formal learning.

4.1.3 A typology of skills for EC

The above analysis identified various skills that underlie study participants' views on what is important for activities related to the creation and operation of ECs. It was found that people involved in ECs need to have both technical skills, such as engineering skills and some energy-specific knowledge, and non-technical skills and other forms of knowledge. This spectrum from technical to non-technical skills provides one axis in a matrix of EC-related skills. The second axis concerns when the skills were acquired, with previously acquired skills at one end, to learning within the EC at the other.

Using these axes, a typology of EC-related skills can be formed (Figure 3), on to which skills identified within the cases have been placed. Viewed in this way shows how technical skills are more likely to be pre-existing, whilst non-technical skills are more likely to be established or fostered in the creation and maintenance of ECs. The analysis of the study data revealed the importance of knowledge about human behaviour or people-related skills. They are seen in the literature as a necessary complement to hard and technical skills in engineering and management (Munir, 2022), and the study data also suggests that they are as important as technical skills in the context of ECs.

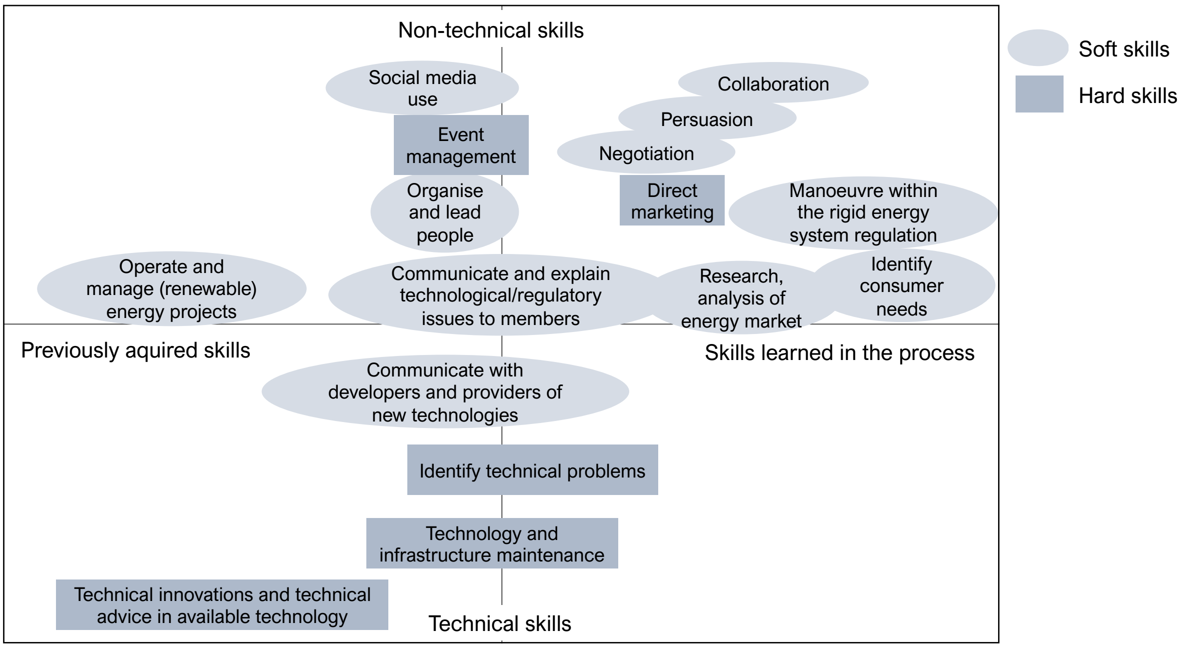

Figure 3. A matrix of skills for ECs

4.2 Knowledge sharing within and outside of the communities

The last part of the study focused on the dynamics of the knowledge use and creation. ECs are a relatively new phenomenon, often initiated, built and led by enthusiasts and innovators. Consequently, the most frequently mentioned learning process in all ECs studied can be classified as 'learning by doing'. This result reflects the importance of sharing tacit knowledge (i.e. knowledge embodied in skills and know-how) among community members as an important form of learning in ECs. It also highlights the social dimension of learning associated with the active participant perspective - both of which tend to be neglected in traditional models of knowledge transmission (Bradbury and Middlemiss, 2015). One interviewee from SO _EN stated that learning by doing should be part of the design of knowledge transfer in ECs:

> We need to activate this cognitive ability. This aspect must be considered in the design phase. If I put people in a classroom and show them a presentation and have one of our technicians give them a lecture, they will not understand anything. But if I tell people, ‘Come with me and we will clean the water filter and the system and so on and so forth,’ and I work with them for a couple of hours in the sun and at the same time explain to them how it works, what the advantage is and so on, they put their hands there and the

sweat becomes emotional, and then that information is absorbed a little more effectively.

The findings show that knowledge creation related to ECs mainly takes place in informal networks of heterogeneous actors involved in the creation and operation of ECs, encountering problems and challenges. Processes of learning by doing are characterised by a variety of perspectives brought together by heterogeneous actors, such as a network of environmental associations, local legal experts, associations of energy providers sharing their technological knowledge, knowledge of legal issues, business issues and human behaviour. Some communities have invented mechanisms such as the biannual rotation of EC board members to promote wide-ranging and inclusive learning processes in the EC and to encourage a greater number of EC members to become more knowledgeable about various topics, including financial issues. Respondent from Dalby Solby provided some of their methods for organising community activities to enable knowledge sharing among community members in completing various tasks: '*We have a system for encouraging people to learn about the different systems we have by participating in different activities ... and by taking part in an activity, they become familiar with the systems*'.

The analysis revealed that different ECs take different approaches to encouraging their members to transfer relevant knowledge. These range from approaches that encourage communication and dialogue between members, such as regular formal and informal face-to-face community meetings, communication platforms, weekly breakfast meetings, decision-making forums, to approaches that encourage members to keep up to date with current issues, innovations and problems through newsletters, online portals and social media profiles.

Above all, the results indicate that shared knowledge is often directly related to practice (rather than something that must first be acquired and then applied). Interestingly, an important knowledge gap that emerges from the data (although not present in all case studies) is also the lack of formalised, in-depth knowledge about ECs and the lack of models and action guides for setting up and operating different models. Nevertheless, there are communities that actively promote EC models by organising face-to-face meetings in local clubs or schools to reach potential new community members. Some of the cases studied were pioneering and are considered models for the calculation of shares among members of EC, the legal forms for applying for the project, the forms for obtaining citizens' consent and the sequence of important steps to be taken in the process. In some cases, these steps are recognised, written down and used to promote the energy transition, e.g. from multi-family housing to business models for ECs. One interviewee from Gen-i Jesenice explained: '*Even competitors are trying to do something, but they are also waiting for us to implement one or two more cases, some kind of pipeline, so they can copy it, because then we would have a model*'. One participant from Sonnen also mentioned that solved problems can serve as learning models for overcoming barriers to starting and operating clean ECs.

The findings also point to the need to better publicise the good outcomes (such as cost reduction, energy savings, community building, sustainable living, return on investment, energy tax savings) of ECs to the wider public in order to generate interest and encourage more people to participate in a clean energy transition. In addition, some of the interviewees stressed the importance of building informal networks with policy makers and formal communication channels with political institutions at different levels (local, regional and national government), as many politicians and decision makers lack knowledge about energy and are not sufficiently informed about issues related to ECs. As long as knowledge about ECs as part of a clean energy transition is not formalised to a certain extent (e.g. with state-supported business models), the clean energy transition in which ECs play a strong role will have a questionable future and its speed will depend heavily on enthusiasts and their willingness to invest their private time in energy projects.

Finally, it is significant that respondents in all case studies found that knowledge and skills related to energy production and consumption (and sustainable living) increased among EC members in general, and in some cases even among members who had shown no interest in sustainable living before joining the EC. The data thus suggests that the learning processes in the ECs studied are far from being merely instrumental (acquisition of new knowledge and skills). They are primarily communicative (learning how to work together to build new knowledge and solve problems), but also transformative (developing new attitudes, values and behavioural changes towards more sustainable living).

5. Conclusions

To some, such as the European Commission, ECs are expected to play an important role in the creation of decarbonised energy systems. Since ECs are defined in large part by the involvement of citizens, questions of how citizens develop the knowledge and skills required to create and operate ECs is a pressing research concern. To address this lacuna, this paper has examined 10 case studies and analysed 31 interviews with EC participants to understand the types of knowledge and skills required to set up and operate ECs; how knowledge and skills are obtained; and how they are transmitted or shared beyond focal communities.

Despite the studied ECs being diverse - in terms of generation technologies used, business models developed as well as actors involved (Table 1) - the analysis performed here suggests multiple commonalities between cases in terms of knowledge, skills and learning. All cases required a range of technical, legal and business knowledge as well as knowledge about human behaviour. The latter form of knowledge arising from the data without precedent in previous studies. A lack of understanding and interest in sustainable living, for example, was seen as an important barrier to people engaging in ECs. This result, although not previously recognised, supports the conclusion of Hoicka *et al*. (2021) that the diffusion of ECs depends on cooperation between established actors, who are likely to be technologically savvy and highly motivated, and new participants who may lack such knowledge and consequently motivation but who are more attune to social rhythms and practices of citizens.

The data shows that skills can be divided into two categories - technical and non-technical - and that pre-existing technical skills are necessary but not sufficient to establish and run ECs. Interestingly, the participants in the study felt that many of the non-technical skills were acquired through learning by doing, whilst building on previous experiences.

In terms of knowledge sharing, this analysis mirrors the findings of previous studies on learning in sustainable communities. The data shows that tacit knowledge is more prominent than explicit formal knowledge. Informants emphasised that learning by doing is the most commonly used strategy for acquiring skills and knowledge. This means that as participants (especially professionals) continuously solve problems, they get a sense of what kind of knowledge and skills are useful. In this way, they help drive the operation of the ECs (Paavola *et al.*, 2004) and move up the learning curve, becoming more knowledgeable participants and in turn teaching others by sharing their skills and knowledge.

The study suggests there exists little explicit knowledge about how to set up and run ECs. Limited formalised knowledge on the formation of ECs subsequently represents a barrier to the growth of ECs across Europe, with most practitioners having to rely on previously acquired technical knowledge combined with learning-by-doing.

Finally, the study shows that ECs can also play a role in raising awareness and increasing energy literacy among the population, although their actual impact has yet to be determined. Nevertheless, respondents mentioned, for example, study visits to their EC, meetings in local clubs and schools, and media attention as evidence that people outside the EC are interested in their models. The findings provide a solid basis for finding ways to advance the process of creating conceptual knowledge and models that can be used to scale up and disseminate ECs in the EU. In this sense, one sees at least two possible implications arising from the findings. First, ECs can be encouraged to create and produce practices and accessible documents, reports and databases that help to expand (and eventually formalise) knowledge. This secures intellectual resources that can be further developed, valorised and used in subsequent activities. Secondly, the categorisation of knowledge and skills could serve as a basis to rethink education and training policies in member states and promote the development of interdisciplinary study programmes (e.g. new higher education programmes, lifelong learning programmes, learning platforms, workshops...) that would help build and disseminate relevant technical and non-technical skills and knowledge that citizens need to master in order to actively participate in the energy transition. It can also contribute to debates on how to enrich existing engineering curriculums in universities. Not only by including more content related to the technical EC aspects, but also by changing the ethos of engineering (Munir, 2022) to include more knowledge about human behaviour and people-related skills.

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