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Social innovation supports inclusive and accelerated energy transitions with appropriate governance

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Accelerating energy transitions that are both sustainable and just remains an important challenge, and social innovation can have a key role in this transition. Here, we examine the diversity and potential of social innovation in energy systems transformation, synthesizing original mixed methods data from expert interviews, document analysis, social innovation experiments, a representative survey, and an expert survey. Based on a thematic analysis of these data, we advance four key findings: (1) the diversity of social innovation in energy is best understood when recognizing core social practices (thinking, doing, and organizing) and accounting for changes in social relations (cooperation, exchange, competition, and conflict); (2) governance, policy networks, and national context strongly shape social innovation dynamics; (3) processes of social innovation are implicated by multidimensional power relations that can result in transformative changes; and (4) social innovation in energy generally has strong social acceptance among citizens, benefits local communities and is legitimized in key community and city organizations. We discuss an agenda for 9 future research directions on social innovation in energy, and conclude with insights related to national context, governance, and acceleration.

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Accelerating energy transitions that are both sustainable and just remains a major challenge of our time[1]. To achieve net-zero targets in order to avoid planetary endangering climate change, research is needed to examine why and under which conditions social innovation can be a successful driver of climate mitigation efforts[2]. The scope of inquiry includes which policies, institutional adaptations, behavioral changes, governance structures, financing patterns, and legal regimes would support changes from both the top-down and bottom-up[3,4]. In simpler terms, change is needed from the "grassroots"[5] as well as the "treetops"[6]. Social innovation—broadly defined as changing social relations involving new ways of doing, thinking, and organizing—represents a new leverage point to create and sustain novel technologies, services, and practices[7–11].

Social innovation in energy (SIE) encompasses changes across elements as varied as new patterns of energy storage, the coordination of energy efficiency efforts, citizen assemblies to reduce greenhouse gas emissions or shared forms of finance and ownership such as crowdsourcing or cooperatives[12–14]. In our current times of multiple, interrelated, and existential system failures, social innovation can mobilize creativity and entrepreneurship to overcome these, thereby contributing to transforming our systems of production and consumption[15–17]. For example, Ravazzoli and colleagues explored the potential of social innovation across rural areas in Europe and found that it produced strong positive "cross-sectoral (societal, economic, environmental, and governmental) and multi-level impacts (on individuals, community, and society)" that have significantly "improved the societal well-being, and contributed to the reduction of certain forms of marginality"[18]. Lupi et al.[19] write that social innovation in the form of collective action initiatives has served to raise environmental awareness, promoted the mobilization of citizens, and fostered social inclusion. Similarly, the Joint Research Centre of the European Commission writes that social innovation in the energy sector could satisfy human and societal needs while in parallel empowering vulnerable social groups alongside "cultivating civic traditions of trust, equity, and solidarity within and beyond the spatial context on which they occur"[20,21].

In this study, we examine the diversity but also the potential of social innovation for energy, synthesizing three years of original mixed methods research conducted by the Social Innovation in Energy Transitions (SONNET) project (see Section 5 "Methods" for more on our research design). This includes six social innovation experiments at the city level ("city labs"), 18 embedded case studies of social innovation fields across six countries, including 36 cases of innovation initiatives, as well as expert surveys to assess the aims and contributions of initiatives, a mapping of 500 European initiatives, and a survey of >6000 citizens in three European countries. Drawing from thematic analysis of these data, we advance four key findings about the diversity of social innovation in energy; governance and policy networks; power relations and transformative change; and social acceptance for SIE as well as energy transitions more generally.

SONNET stands out in the broader landscape of EU-funded projects on social innovation in energy in at least two ways. First, it focused on mapping the diversity of social innovation in energy in their full breadth—in doing so, it adopted a multi-actor perspective on social innovation to move the discussion beyond the prevalent focus on social innovation driven by the community, citizens, or civil society actors. In contrast, other projects usually focus on one specific phenomenon (e.g., PROSEU on collective prosumerism, NEWCOMERS on clean energy communities) or on a specific subset of social innovations (e.g., SMARTEES focusing on five energy- and mobility-related social innovations). As a consequence, SONNET was able to distill more general lessons learned from its systematic analysis of the great diversity of social innovation in energy in Europe. Second, while most projects study social innovation at the level of initiatives (e.g., COMETS and its focus on collective social action initiatives), SONNET went beyond this micro perspective by also studying the diversity of social innovation at the level of the SIE fields in which these initiatives develop. This meso-level approach enabled us to investigate the interactions between social innovations and their structural conditions in the context of broader transformation processes, as well as the institutionalization processes of social innovations, which in turn allows observers to then derive system-level policy recommendations. It lastly has strong policy relevance, given that policies such as the EU's fit for 55 package are not yet fit for social innovation, and if changed could better harness its transformative potential[22].

Results

Our thematic analysis of the original and wide-ranging evidence base offered by SONNET enables us to advance four key findings relating to the diversity of social innovation in energy; governance and policy networks; power relations and transformative change; and social acceptance. These four themes were selected based on the strength of the findings they produce, what the research team collectively believed represented the most salient findings, as well as the strength and consistency of the data behind them. The findings also capture the phenomenon of social innovation across themes such as its diversity of context (governance/networks), and its relation to institutional change (power/acceptance/legitimacy). These factors are all pertinent considering the promise social innovation holds for furthering energy system transformations.

Even though some preliminary findings have been published selectively in the earlier phases of the SONNET project, these have been rewritten for this particular study. To date, no comparative or synthesis work has been undertaken across all of SONNET's data, nor has any single study benefitted from harnessing the full array of data generated, and the analytical findings that result.

Diversity of social innovation in energy is best understood as social practices and relations. We found a compelling diversity of social innovation involving changes in social practices and/or social relations. Social innovation in energy is far more than only "doing," and it is also far more than just "collaboration", as the well-known examples of energy communities or energy cooperatives may suggest[23,24]. There is instead a heterogeneity of social innovation involving changes in social practices and/or social relations. Such novel practices include doing (changing the physical composition of the energy system by using new energy technologies such as energy storage or solar prosuming) but also organizing (changing governance by promoting deliberative principles or forming new structures for networking and exchange) and thinking (changing knowledge via new framings, values, or perceptions of energy)[7,25].

Following our definition of social innovation in energy, changes in the practices of doing, organizing, and thinking about energy ought to be matched with changes in social relations, for which we differentiate between four very distinct types (see Table 1). *Cooperation* refers to interactions that succeed in achieving shared goals when actors work together. *Exchange* could be a voluntary interaction where all parties expect some sort of reward. *Competition* refers to when actors may struggle over scarce resources but abide by shared rules. *Conflict* is when they struggle over such resources but do not abide by shared

Table 1 Types of social innovation in energy initiatives defined by practices and examples of social relations.

		Social relations			
		Cooperation	**Exchange**	**Competition**	**Conflict**
Social innovation practices	Doing	• Local or cooperative energy production and consumption • Collaborative eco-efficient housing	• Local peer-to-peer electricity exchange	• For-profit services and technologies	• Action against specific energy pathways
	Thinking	• Advocacy for specific energy pathways	• Energy education • Non-profit consulting • Peer-to-peer learning	• For-profit consulting	• Campaigns against specific energy pathways
	Organizing	• Participatory energy dialogs, experimentation, and incubation	• Platforms for direct energy transactions • Investment and finance mechanisms	• Energy gamification and nudges	• Networks against specific energy pathways

Authors, based on the deliverable[31] of the SONNET project, with more details in Supplementary Discussion Sections S1.1–S1.3, and core supporting literature cited in the references section.

Table 2 Operationalizing social innovation practices in terms of new ways of doing, organizing, and thinking about energy.

	Definition	**Operationalization**
Doing	Practices related to energy technologies and the physical composition of the energy system	Generating electricity/heat (efficiently) Supplying electricity/heat in new ways Using electricity/heat (efficiently) Exchanging electricity peer-to-peer Storing electricity/heat Implementing technology-based energy services Installing energy technology Acting against political agendas
Organizing	Governance and organizational structures within initiatives and within the energy system (i.e., institutions in terms of forms of social organization or standard operating procedures that shape behavior and find expression through rules, practices, and narratives)	Facilitating Networking Providing services Offering/facilitating financing Constructing a dialog Incubating ideas and solutions Facilitating supply/demand exchanges Nudging and facilitating behavior change
Thinking	Forms of knowledge and normative framings including values and perceptions	Raising awareness about energy Campaigning against political agendas Pushing a framing, discourse, or narrative Providing advice Transferring knowledge & skills

Authors, modified from ref. [26]. The table is based on the SONNET project, with methods explained in Supplementary Information Sections S1.1–S1.3, and core supporting literature cited in the references section.

rules, and may instead seek to destroy, injure, or incapacitate rival actors.

To empirically ground our conceptual distinction between different social innovation practices and types of social relations, we systematically analyzed 500 social innovation initiatives and confirmed both the salience of social practices (new ways of doing, thinking, or organizing) as well as the four types of social interaction (cooperation, exchange, competition, and conflict). Table 2 operationalizes these different practices, and examples of each form of practice and type of social interaction are summarized by Table 3, with more details offered by Hielscher et al.[26].

Rather than taking the "social" as an afterthought of technological innovation, these diverse types of innovation highlight how energy system transformations are also driven by the changes in the manifold social relations, roles of actors, and the different activities they engage in[7,12,27]. The results highlight the importance of diversity in actors for driving social innovations: Social practices and relations of actors like action groups and civil society actors (e.g., in local energy production and consumption, action against specific energy pathways), municipalities, and other governmental actors (e.g., participatory energy dialogs, non-profit consulting, or investment and finance mechanisms) and private firms from start-ups to large multinationals (e.g., collaborative eco-efficient housing, peer-to-peer learning or for-profit services and technologies) all contribute to the described types of social innovations.

Moreover, identifying the diversity of social innovation in energy has the potential to open policy discussions, by showing that there are many forms of such innovation which all could benefit from public policies to thrive, or that their potential is not fully harnessed for the energy transition, for example, due to regulatory obstacles. At the same time, framing "conflict" initiatives as social innovations (what may go against popular association) exposes the use of power/momentum of conflict to speed up energy transitions, and what the risks of it are. It also explicitly takes up the notion that transitions are not emerging without tensions - be it between the existing system and practices or between a variety of possible pathways or their terms of implementation[28,29].

Table 3 Exemplars of social innovation practices and social relations drawn from the SONNET database ($N = 500$ initiatives).

	Form	Name	Country	Description
Social innovation practices	Doing	Living Lab Walldorf	Germany	The aim is to test the future of a decentralized power supply from renewable energies. To this end, ~40 households and commercial companies are intelligently networked with their own energy generation systems, optimally coordinated and connected to form a community.
	Organizing	Stadslab2050	Belgium	In Antwerp, this Living lab is facilitating experimentation to address societal challenges, organized by the Municipality, a place for thinkers and doers in and around Antwerp and the aim is to work towards a more sustainable city.
	Thinking	POAL (Plateforme opérationelle anti-linky)	France	POAL is a collaborative tool meant to fight the spread of smart meters. It is intended to create campaigns and therefore new ways of thinking about smart technology.
Social relations	Cooperation	Allianz Atomausstieg	Switzerland	The alliance against nuclear energy has several member organizations that act independently and manage their own issues relating to the risks and dangers of nuclear power. The Alliance acts as a platform for exchange, coordination, and strategy. It supports its members through communication channels such as its own website or through its broad network at national and regional levels.
	Exchange	Jouliette	Netherlands	Spectral and Alliander have launched a new blockchain-based energy-sharing token at De Ceuvel in Amsterdam. Named the Jouliette, the new token aims to empower individuals and communities to easily manage and share their locally produced renewable energy.
	Competition	Student Switch Off	United Kingdom	The Student Switch Off is a campaign that aims to encourage students to save energy when living in university halls of residence. It is an award-winning inter-halls sustainability competition incentivizing groups of students who achieve the biggest savings in energy, water, and/or have the best recycling rates.
	Conflict	Obóz dla Klimatu (The Climate Camp)	Poland	The Climate Camp is formed by an informal group of people who strive to regain agency, actively opposing unfair social relations and all forms of exploitation. During the camp, they create space for civil disobedience, mutual education, self-organization in the fight against human and natural exploitation, and establishing contacts between dispersed groups.

Authors, based on the SONNET project, with methods explained in Supplementary Information Sections S1.1–S1.3, and core supporting literature cited in the references section.

Governance, policy networks, and national context shape social innovation. Social innovation in energy involves a large variety of actors, actor networks, and institutional logics[30]. Local governance arrangements and policy networks catering to social innovation in energy vary and benefit from a multitude of enabling conditions.

To understand how policy network structures can impede or enable SIE, we combined qualitative structured interviews (at least 10 per city) with an online survey (see Supplementary Discussion, S1.6 within Supplementary Information)[31]. Our findings across the cities show that translocal networks (those cutting across more than one location) form a prominent enabling condition for SIE and more generally for pushing forward sustainable energy transitions. Those networks provide infrastructure for the development and dissemination of persuasive narratives of change through which socially innovative concepts gain legitimacy. Specifically, our investigation shows that discursive shifts change expectations about how transition processes are supposed to be perceived and managed. These involve discursive shifts from technocracy to participation, from centralization to decentralization, from silos to cross-departmental and cross-sectoral organizing, and from climate change to the climate emergency.

Furthermore, within the survey, we explored the composition of SIE-related networks across the cities, which demonstrates the strong role of civil society groups as well as market and state actors. Mannheim and Warsaw have both a strong industrial background and still a high dependence on fossil fuels, which in those cases manifests in high-energy consumption. While such aspects may also result in a higher interest of market actors in technological innovation and the transformation of the energy system, in the observed situations market actors seem not to be associated with nor engaged in social innovation. Both cities have the lowest shares of market actors referred to in their policy networks. Moreover, there are particularly many intermediaries working towards enabling technological innovation[32], whereas actual social innovation initiatives and projects as well as bottom-up processes are mostly driven by civil society actors, whose presence is outstandingly high in both cities. Basel by contrast exhibits a stronger role of the city administration and state actors, whereas Bristol and Grenoble typify the strongest role of market actors, which reflects the level of advancement of the policy networks around SIE in these cities. Additionally, in these cities, the administrations take a proactive approach by coordinating interactions between diverse actors engaged in SIE-related processes. Furthermore, Bristol, Mannheim, and Grenoble use market-based governance modes to facilitate social innovation. They explicitly encourage energy communities through financing schemes: buying shares, providing seed money, and mentoring. Cities utilize network-based governance modes to nurture grassroots creativity and knowledge exchange via the organization of knowledge hubs (Antwerp), climate hackathons (Basel), or citizen panels (Warsaw). They draw on hierarchy-based modes to impose an obligation to consult and/or involve certain actors in decision-making or to design procurement schemes privileging community-based energy companies and, more generally, energy transition initiatives (e.g., practiced in Grenoble and Bristol).

Social innovation potential in cities is best developed when complementary logics of hierarchies (command-and-control), markets (allocation of scarce resources through prices determined by supply and demand), and networks (based on flat relationships, the sharing of common resources and negotiations) are used. In addition, city administrations, similarly to other actors involved in SIE governance, learn in networks, most importantly in policy networks, that shape perceptions about the proper content and character of norms and regulations in the energy sector. Table 4 summarizes corresponding enabling conditions deemed critical from the SONNET project and especially from the survey on cooperation in the six SONNET cities to effective local governance and robust policy networks, including network structure, personal relations, the role of cities, policymaking dynamics, and venues.

Lastly, different national context conditions shape social innovation patterns. The political, economic, technological, and cultural conditions of a country can have a substantial impact on the success or failure of social innovation in energy. The selected countries have different political systems, follow different transition pathways, and face different problems such as environmental concerns, economic challenges, and social equity issues. In Poland, for example, the energy sector is heavily dominated by large state-owned utilities, making it difficult for smaller initiatives to emerge[33]. In France, the highly centralized 'nucleocracy' managed by the technical elite disempowered both consumers and local governments[34,35]. In Switzerland, on the other hand, there is a strong tradition of citizen participation and decentralization, which has facilitated the growth of energy cooperatives[36]. In the Netherlands, the government has actively supported the development of renewable initiatives through favorable policies and subsidies[37]. In Germany, their *Energiewende* policy has spurred the growth of community-owned renewable energy projects and waves of municipalization of energy assets[38], while in the UK, the government has backed a more liberalized approach where community actors experiment with alternative ways to trade energy[3].

Multidimensional power dynamics permeate innovation patterns. The SONNET project embraced, and sought to validate and test, a multidimensional framework of power and power relations within and across social innovation initiatives[26,39]. Through the empirical case studies as well as designing and implementing a 'Transformative Power Lab', the concepts were developed and operationalized in an inter- and transdisciplinary way, resulting amongst others in seven 'ingredients' presented in a 'Power guide' aimed at supporting SIE practitioners in understanding and acting on power dynamics. Central to this work were three core types of power. *Power to* refers to "getting things done" and involves the capacity to mobilize resources to achieve specific goals, such as being an owner in an energy cooperative or more self-sufficient low-carbon communities. *Power over* refers to "forcing and dominating" others to do what they would ordinarily not do; this can be visible, hidden, invisible, or even subconscious. Examples include the lobbying power of incumbents to influence rules according to their needs, and the design of grid tariffs in a way that benefits a particular class of elite actors. Power over can also include forcing others to adopt particular rules about money or financing (interest rates), or structural or systemic inequities in income or gender, driving or often constraining innovation patterns. *Power with* refers to "acting in concert" and encompasses the collective capacity to collaborate to achieve common goals, or to empower. Examples could be the involvement or inclusion of marginalized groups in government planning, or generating income for the poor through local electricity exchanges[40]. While typically all these three types of power manifest within initiatives, some types of power are illustrated more strongly in certain initiatives than others.

All three forms of power relations are exhibited within our SONNET evidence base of social innovation initiatives. For example, in the United Kingdom, Talk Fracking, an anti-shale gas group, successfully displayed *power to* in order to challenge the National Planning Policy Framework and to have the language removed that mentioned the importance of fracking and onshore

Table 4 Enabling conditions for social innovation and effective climate governance.

Enabling condition	Factor	Description
Network structure	Diversity of actors involved	There is a good mixture of different types of actors in SIE (such as state, civil society, and market actors)
	Roles of actors involved	Different types of actors are equally involved in SIE (i.e., no one actor is dominating the network)
	Role perceptions	Encourage the engagement of different types of actors in SIE by avoiding prejudices and negative role perceptions
Personal relations	Personal ties	The network builds on strong personal ties without being 'exclusive'(i.e., strong personal ties enable longer-standing implementation of SIEs beyond the scope of singular project funding)
	Engagement	Different types of actors are equally and actively engaged in SIE
	Competences	Different types of competencies and knowledge are included in the network
Role of city administration	Proactive approach	The city administration actively engages in supporting SIE
	Resources	Financial and personal resources are provided by the city administration to support SIE
	Competences	The city administration provides competencies (e.g., knowledge and practical skills) concerning SIE and related topics
Policymaking	Political support	SIE is supported by officially appointed politicians
	Access to decision making	SIE initiatives have the possibility to gain access to decision making
	Legitimacy	SIE is widely supported and legitimized within the city
Venues	Project settings	Provide possibilities to include diverse types of actors in SIE in project settings
	Formal meetings	Regularly organize meetings and provide opportunities for exchange across actor groups
	Personal meetings	Allow building strong personal ties without being exclusive through regular opportunities to meet in person in official venues

Authors, based on the deliverable[31] of the SONNET project, with data presented in deliverable D2.2. *SIE* social innovation in energy.

hydrocarbons. Talk Fracking also convinced the United Kingdom High Court that the National Planning Policy Framework was not compatible with the government's Clean Growth Strategy. This example demonstrates that with sufficient resources (e.g., money, knowledge, experts), such socially innovative initiatives are able to organize to win court cases through "power to". For financial resources to be sufficient, funds were raised through several creative crowdfunding activities, such as walks and art sales.

Another example is the living lab Stadslab2050 in Belgium which saw national policymakers exert *power over* its mechanisms for incubation and experimentation by challenging the Lab's efforts to reduce energy use among commercial neighborhoods in Antwerp. City planners did not appreciate the emphasis Stadslab2050 placed on challenging societal norms and deeply engrained behavioral routines, and turned politically against the Living Lab. In 2020, the city discontinued the experiments and integrated the Lab into the city's larger climate strategy, placing it under its direct control.

A third example, the Silesian Climate Movement in Poland, typifies *power with*. Launched in 2018, it utilizes bottom-up methods of self-organization and social organizing. It is easy to join the movement, and working groups do not have sharp boundaries, with members fluctuating between them. This illustrates a form of "power with", in which several groups can come together as a movement that tries to make processes more inclusive, so that a wide variety of people can participate in organizing and implementing activities.

While social innovation is often and typically associated with power to (capacity to achieve outcomes) and power with (coaction and empowerment), SONNET's findings show how social innovation also involves considerable *power over*. This is not only about how incumbent structures and institutions are impeding social innovations, but also about how social innovations exercise *power over,* i.e., 'make others do things they would otherwise not do' by developing new structures and institutions.

Social innovation has strong social acceptance and political legitimacy. Our final finding relates to the social acceptance of, or consumer willingness to engage with, social innovation in energy, as well as the legitimacy of social innovation among existing institutions. We find that, although variations exist, generally social innovation has strong support among both citizens and city administrators and ultimately can make a positive contribution to both local and European Union energy goals.

For instance, a demographically representative survey (see details S1.5 in Supplementary Information) of the adult population in France, Germany, and Poland ($N = 6141$) applying discrete choice experiments found that 79–90% of participants would invest in the decentralized renewables energy community projects shown in the experiments[41]. In a related survey question, between 20 and 29% of respondents indicated that they were already planning to invest in a green/sustainable crowdfunding project, in a renewable energy company, or in green/sustainable investment assets. These findings suggest popular interest in social innovation projects, and a strong future potential for their widespread adoption, but harnessing this potential requires enabling policy changes and attractive business models.

The salience of financial criteria for respondents in the SONNET survey has compelling policy implications in terms of spurring wider citizen involvement by better covering possible project losses (i.e., via risk insurance) as well as lowering barriers to entry (such as low minimum investment requirements). Furthermore, our results on socio-demographic factors suggest that persons younger than 35 years and with higher income are more likely to invest in renewable electricity generation projects, revealing a largely untapped market for younger adults – or put differently, showing that it will be comparatively difficult to engage senior citizens. According to our SONNET data, this further underlines the need to create investment types where participation with relatively small sums of money is already available to tap the potential of people with low income or wealth.

Social innovations in energy such as cooperatives, decentralized renewables, and local energy production hold appeal not only among citizens; they are also supported by other city actors and organizations (see also ref. [42]). We found in our case studies that public administrations can legitimize social innovation by directly financing projects, reducing administrative barriers, or providing "sandboxes" to test ideas and build networks. Indeed, a

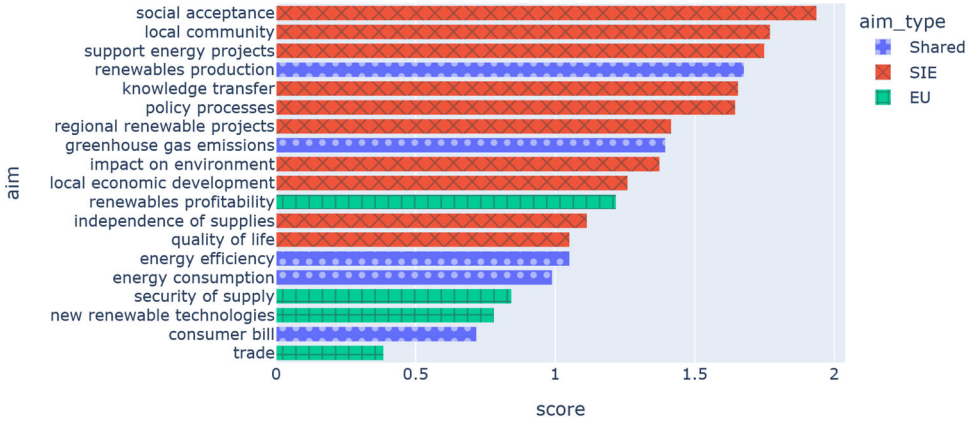

Fig. 1 Perceived contribution of social innovation in energy initiatives for different social objectives. SIE social innovation in energy, EU European Union. Score = 4-point Likert-scale rating from 0 (=No effect) to 3 (=Significant effect). See Annex 1.3 for more details.

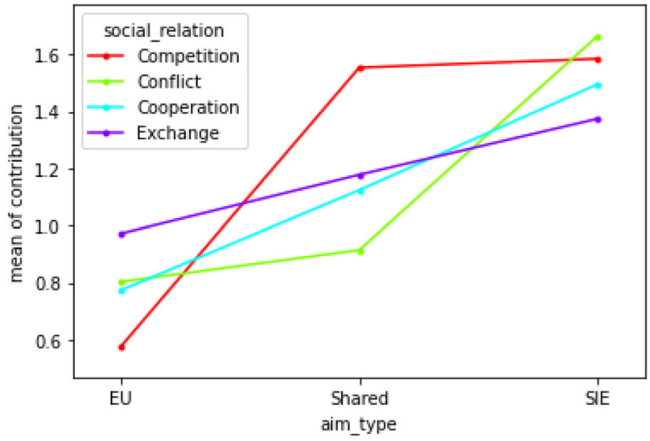

Fig. 2 Mean contribution score per social objective for social innovation in energy initiatives engaged competition, conflict, cooperation, or exchange. SIE social innovation in energy, EU European Union. Mean contribution = 4-point Likert-scale rating from 0 (=No effect) to 3 (=Significant effect). See Annex 1.3 for more details.

survey that was carried out in parallel to the case-study interviews among the participating researchers, SIE representatives, and field actors (see Supplementary Discussion S1.3) showed that SIE initiatives are perceived as effective for achieving other non-energy objectives (shown in Fig. 1) such as strengthening the local community, improving the transfer of knowledge, or reducing impacts on the environment[43]. Not surprisingly, the SIE initiatives mostly contribute to their own aims like strengthening the "local community" (seen in items with perceived contribution in Fig. 1). However, increasing "renewables production" and reducing "greenhouse gas emissions" are also highly ranked and are aims of both the SIE and the EU (so-called "shared aims" as defined by the SIE literature and EU objectives, see S1.3 in Supplementary Discussion for details).

Notably, as shown in Fig. 2, the mean contribution scores of the SIE initiatives in our survey were related to the type of SIE initiative and the aim type. For example, SIE initiatives primarily engaged in *conflict* (such as actions, campaigns, and networks against specific energy pathways) achieved a much lower mean contribution score for the shared aims of "renewables production", lower "greenhouse gas emissions", higher "energy efficiency", lower "energy consumption" and lower "consumer bills", compared with other types of initiatives. SIE initiatives engaged in *competition* (such as for-profit services, for-profit consulting, gamification, and nudges), on the other hand, achieved a higher mean contribution score towards shared aims than the other types of initiatives. Thus, initiatives engaged in competition are more likely to achieve financial benefits through reduced "consumer bills", which was revealed to be an important factor for a more widespread acceptance of, and involvement in, social innovation activities. Therefore, the contributions of the SIE initiatives may influence the potential for growth and, ultimately, the transformative power of SIE.

Discussion

Although our core four findings in Sections 3.1–3.4 are backed by numerous sources of evidence from the SONNET project, our research design does have some limitations. The interviews and case studies had data collected at one point in time, meaning dynamic perceptions or reflections are not represented, especially insofar as they relate to concerns about local energy use and security. With data having been collected before Russia's war against Ukraine, any consequently changed perceptions are not captured. In addition, due to the complexity of the investigated phenomena, we were not able to fully grasp the impact of the studied social innovation types on transition pathways. As is expected, in many cases any impacts would be multidimensional, changing over time, and are often hard to be comprehensively quantified.

Furthermore, many of our methods (interviews, surveys) rely on self-reports and stated preferences rather than revealed behaviors and preferences; while city labs provide opportunities to observe participant behavior and manifestations of their engagement, but, by design, in an experimental setting. Our results might thus be subject to hypothetical bias, although the amount of data collected, and the variety of methods used decrease potential biases in this regard.

Even though our sample for the survey carried out by an online panel is demographically representative of the population in terms of our quota requirements, the sample is not representative of the population in terms of other characteristics such as socio-professional categories or prior involvement with the energy transition. While our multivariate analysis controls for many factors, we cannot exclude that unobserved factors bias our results. Moreover, respondents who were excluded from the survey because they failed the attention checks or because they were speeders might systematically differ from other respondents, e.g., in terms of their preferences for attributes, thus influencing our results. Finally, it should be noted that our research was conducted in the middle of the COVID-19 pandemic, which particularly impacted our qualitative research methods. Face-to-face citizen involvement in the city labs and site visits of SIE

Box 1 | Future research directions for social innovation in energy or policy needs posed by the SONNET research team

1. **Collecting better data and impact evaluation**. It is difficult to find common indicators for such a diversity of social innovation practices and initiatives. Therefore, new methods and indicators may be warranted to help evaluate performance and the importance of different types of SIE in different transition stages. SIE initiatives are seen to provide lower energy bills and may reduce the lead for renewable investments, therefore indicators need to be developed allowing to estimate such contributions.
2. **Changing innovation roles for accelerating transitions**. Among the diversity of social innovations in energy, it is important to identify those that can contribute most in the phase of accelerating transition and help to overcome current barriers, such as integration of innovation with the whole system or changes in norms, values, and lifestyles. Thus, classifying SIE diversity by its role in the transition stages and assessing its scalability would be worthwhile.
3. **Enhancing the inclusiveness of social innovation**. Large groups in society are interested in participating in social innovations in energy, but few have done so. This leads to the question of what types of barriers to participation exist and how they can be removed, including for marginalized groups, so as to better harness such largely untapped potential.
4. **Finding a common language**. Initiatives (and researchers) engaging in social innovation can miss out on learning or collaboration opportunities when shared goals/visions/approaches are not apparent due to disciplinary and sectoral thinking. More engagement in shaping shared language could help bridge this communication gap.
5. **Exploring future power relations**. Considering rapidly changing energy contexts, we recommend further Power Labs which can explore future changes to power relations including more incumbent actors, and understanding how to develop policy to support SIE while accounting for changing power relations.
6. **Investigating energy sufficiency and energy efficiency**. While current research recognizes the diversity of SIE, most in-depth research focuses on initiatives that contribute to changing the energy mix. Additional research is needed that addresses how SIE can contribute to decreasing energy use (energy sufficiency) and fasten the implementation of energy efficiency measures.
7. **Exploring the role of social innovations in different phases of the energy transition**. While in the first phase, social innovation which realizes and promotes renewable energy projects is key, in later phases new ways of organizing and promoting institutional changes well as initiatives that influence behavioral changes might gain importance. How and why such initiatives emerge and interact in different phases has been underexplored.
8. **Promoting diversity and policy alignment**. Social innovation in energy would benefit from considering it in long-term policy strategies that govern sustainable energy transitions. These should concretely spell out its foreseen role in these transitions and take into account the diversity of SIE and their policy needs, which may also help to clarify the expectation of these innovations' impacts and potential.
9. **Tracing the relationality of innovation dynamics**. Future research should empirically analyze how the different types of SIE may influence each other. SONNET was very focused on studying the types/fields within a specific geographic boundary, but how exactly they collaborate and empower each other (or not) remains a promising area of inquiry.

initiatives, as well as in-person interviews and policy workshops, among others, were constrained by mobility and data gathering restrictions. While the effects of the pandemic were not systematically researched, this circumstance offered an opportunity to observe the resilience and flexibility of people involved in SIE adapting to difficult situations and remote collaborations to further pursue their goals.

Although our findings are based on an extensive collection of original data within the SONNET project, there are still a number of compelling research topics posed by the collective authoring team in Text Box 1 that we are unable to answer but believe are worth exploring. Examining the aims and objectives of social innovation initiatives is particularly daunting given initiatives have such subjective and heterogeneous aims, and that the diversity of actions makes comparison difficult. For some forms of social innovation, such as "thinking," impacts are not even physically observable, but rather mental, which is challenging to measure, but they will nonetheless be important for successful energy transitions, particularly in the early stages to lay the ground for initiating SIE initiatives also involving "doing" and "organizing" energy differently. Many social innovation initiatives also lack the resources or data to evaluate their contributions. That said, apart from enabling policy mixes, SIE may also benefit from collecting better data and improved impact evaluations of SIE which in turn may enable changes that lead to more members and attract more interest, more effective financial models, stronger impact within communities, and ultimately greater social benefits. Other recommendations center on power relations, energy efficiency, policy learning, or even supporting SIE for more than instrumental reasons[12].

Our research shows that SIE is invariably and intricately diverse in terms of how they contribute to changing social practices and social relations. Our typology is however less informative when it comes to understanding how these innovations can contribute to accelerating the energy transition. Additional research could for instance highlight which of the three pillars of the energy transition (energy sufficiency, energy efficiency, and renewable energy production)[44] is addressed by these innovations. Moreover, previous research showed that community energy, which is one form of SIE, faces difficulties scaling[45,46]. Additional research could provide a more systematic analysis of the potential scalability of other forms of SIE.

Conclusions

Social innovation in energy an accelerate and deepen future decarbonization pathways and net-zero energy transitions in ways as compelling as they are varied. The SONNET project captured a variety of social innovation practices and initiatives in energy and documented the interconnectedness of innovation processes displayed on multiple governance levels, in diverse geographical locations, and within various social relations (e.g., cooperation, exchange, competition, and conflict).

Nevertheless, social innovations in energy are heavily influenced by the national and regional context in which they emerge. The political, economic, and cultural conditions of a country impact the success or failure of these innovations. For example, countries that have a strong political commitment to renewable energy are more likely to adopt and support social innovations in this area. Similarly, countries with a strong culture of environmentalism may be more receptive to social innovations that promote sustainable energy practices. In addition, economic factors such as the availability of funding, access to technology, and market demand also play a critical role in shaping the development and diffusion of social innovations in energy. Tellingly and challengingly, the national context conditions of social innovations in energy are complex and multifaceted and require a comprehensive understanding of the local context in order to effectively foster and support these innovations.

Social innovation enforces more effective governance dynamics and can shift, subvert and even transform power relations. Their potential to do so resides in high degrees of social acceptability exhibited via consumer willingness to invest or engage in such initiatives. Our findings reveal that up to 90% of citizens surveyed would consider investing in renewable energy, and up to 80% would join an energy cooperative—if the conditions are right. These forms of social innovation thus have immense potential, but only if policy mixes contribute to creating supportive conditions for nurturing and sustaining such efforts.

Social innovation in energy can further realize its potential to accelerate sustainable energy transitions by configuring diverse social relations and forms of action, while also shaping governance and policy context. These could in turn pivot institutions towards transformative power relations and greater degrees of social acceptance. Ultimately, this may culminate in collective energy action that furthers progress toward net-zero climate policy alongside more just and equitable forms of community involvement.

Methods

For our research design, we draw from original data collected over three years within the Social Innovation in Energy Transitions (SONNET) project, funded by the European Commission's Horizon 2020 program. SONNET aimed at understanding the diversity, processes, and contributions of social innovation in energy. It did so by investigating how, to what extent, and under which enabling conditions diverse types of social innovation may result in new breakthroughs or successfully contribute to overcoming transition barriers, such as limited citizen engagement or slow adoption of new technologies.

Overall, we gathered our research data from eight European countries, namely Germany, the United Kingdom, France, Poland, Switzerland, Netherlands, Luxembourg, and Belgium. These countries were selected for covering varying contexts for SIE. The relevant dimensions of diversity are grounded in (1) findings on important contextual factors that influence SIE including carbon intensity, the degree of liberalization of the energy market, policy attention towards SIE, history and culture, and the level of technological innovation stimulating SIE; (2) researchers experience in working on SIE, and (3) the national implementation of EU energy goals.

As Fig. 3 highlights, SONNET combined a profuse yet simultaneous array of different methods to explore these questions. First, the SONNET team, consisting of researchers and city partners, conducted six transdisciplinary city labs in Manheim (Germany), Antwerp (Belgium), Bristol (United Kingdom), Grenoble (France), Warsaw (Poland), and Basel (Switzerland) to experiment with unfolding social innovation in energy and their dynamics in an urban context. Second, SONNET researchers examined 18 original SIE case studies in six different fields and across six countries, by drawing on 171 original research interviews, secondary analysis of 298 documents, and participant observation at 37 events. Third, the SONNET team mapped 500 social innovation initiatives to explore and systematize the diversity of SIE. Fourth, SONNET academics also investigated the aims and respective contributions of 36 SIE initiatives in Germany, Belgium, Netherlands, Luxembourg, the United Kingdom, France, Poland, and Switzerland using expert surveys ($N = 96$). Fifth, we lastly conducted three demographically representative surveys on four types of social innovation in energy across France, Germany, and Poland, analyzing completed responses from >6000 citizens. Supplementary Information sections S1.1–S1.6 offer more details of these methods, including selection criteria, as well as limitations of our approach.

As Fig. 3 also indicates, SONNET was based on a multi-method research design that combined a variety of qualitative and quantitative methodological approaches which inform and complement each other. In doing so, it drew on the principle that valid findings can only be brought forward by a combination of different methodological approaches that systematically cater to the shortcomings of the respective other methods. Additionally, SONNET combined different levels of analysis which allows researchers to deal flexibly with the fact that in social innovation the appropriate levels and units of analysis are not evident from the outset. The in-depth case studies provided a historical perspective on social innovation processes, the city labs were aimed at getting a better understanding of social innovation in the making and the survey examined the future potentials of SIE. Practical reasons determined where we could not carry out the survey due to financial reasons.

The author team then undertook a deep, thematic analysis of these combined data. Thematic analysis is a "type of qualitative analysis" used to "analyze classifications and present themes (patterns) that relate to the data"[47]. Thematic analysis thus refers to a form of pattern recognition that involves identifying core themes via the careful reading, and rereading, of the material[48]. Similar to other approaches within the social sciences such as ethnography, phenomenology, and content

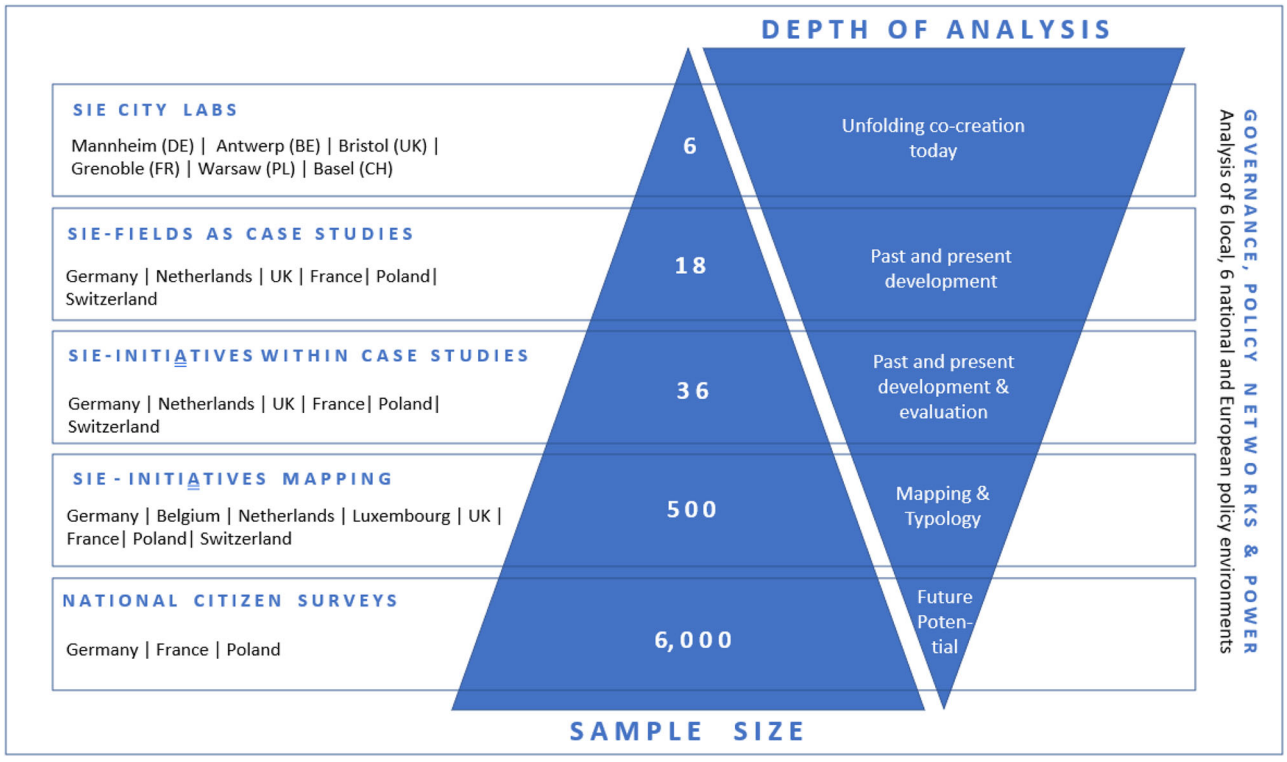

Fig. 3 An overview of the mixed methods approach utilized in the SONNET project. SIE social innovation in energy. Supplementary Discussion provides more details on these methods, with S1.1 summarizing the mapping of initiatives, S1.2 the city labs, S1.3 the case studies, S1.4 the evaluation and survey of initiatives, S1.5 the citizen surveys, and S1.6 the policy network analysis.

analysis, thematic analysis extracts meaning from data and encompasses the pinpointing, sharpening, recording, and/or evaluation of recurring themes. In our study, we followed the guidelines from ref. [49,50].

Data availability

Data sharing is not applicable to this article as the data used are confidential.

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Author contributions

B.K.S. led the paper and the synthetic analysis, writing, rewriting, and revising. K.R. served as P.I. for the project. All other authors H.B., I.B., A.D., D.W., A.L.V., R.B., F.A., T.d.G., A.D., E.D., S.H., M.I., L.M., J.M., A.R., J.S., A.S., M.S.K., C.W., and J.W. contributed equally to the analysis, writing, and revising. All authors have made substantial contributions to the conception or design of the work; or the acquisition, analysis, or interpretation of data; or the creation of new software used in the work; or have drafted the work or substantively revised it. All have approved the submitted version. All have agreed both to be personally accountable for the author's own contributions and to ensure that questions related to the accuracy or integrity of any part of the work, even ones in which the author was not personally involved, are appropriately investigated, resolved, and the resolution documented in the literature.

Competing interests

The authors declare no competing interests.

Additional information

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