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Research Article

Fit for social innovation? Policy reflections for EU energy and climate policy making

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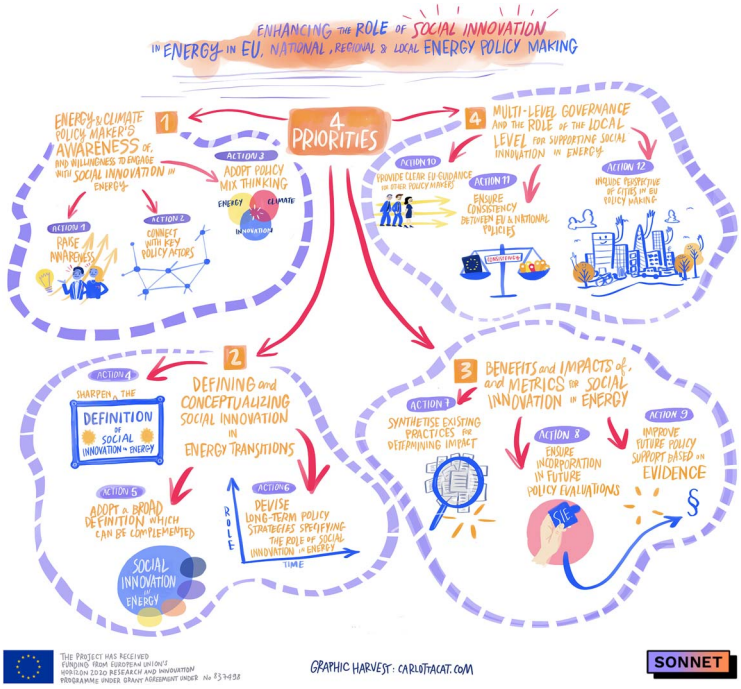
Abstract

Achieving climate-neutrality by mid-century and its intermediary reduction targets for 2030, notably the EU's greenhouse gas emissions reduction of 55% by 2030, requires an accelerated transformation of our systems of production and consumption. In essence, such transformations are socio-technical change processes that require a combination of technological and social innovation. While it is widely acknowledged that ambitious climate and energy policies are needed to accelerate such transition processes, research and practise have largely focused on their importance for spurring technological innovation. In this research perspective, we argue that energy and climate policy making should pay more attention to social innovation as much needed additional puzzle piece for successful decarbonisation. Such social innovation is diverse, ranging from renewable energy cooperatives, to participatory incubation and experimentation, and crowdfunding as well as local electricity exchange. Based on a literature review that informed an EU policy dialogue bringing together policy makers, practitioners and researchers and followed up by a workshop with city administrations, twelve practical action points were co-created on how to better consider social innovation in energy and climate policy making in the EU (and beyond). We thereby hope to stimulate a broader discourse on the dual need for social and technological innovation for reaching climate-neutrality.

Graphical Abstract



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Lay Summary: New social practices – or revived practices from the past – are known as 'social innovations'. Social innovations in energy, like energy cooperatives, participatory experimentation, local electricity exchange and other novel social practices, can help to achieve climate-neutral systems. However, to tap their full potential, energy and climate policy makers must pay greater attention to designing policies that support – rather than block – the further development of such innovations. In this research perspective, 12 practical action points are proposed based on a policy dialogue and workshop, sorted into four overarching priority areas, for how to do this. The paper thereby stimulates a broader discussion (especially among policy makers) on the need for *both* technological *and* social innovation in order to reach climate-neutrality.

Keywords: social innovation, policy mix, energy transition, energy and climate policy, Fit for 55

INTRODUCTION

Achieving climate> neutrality by mid-century requires transformational change in our systems of production and consumption, such as in the energy, mobility or agri-food system. Policies can encourage such transformational change by creating 'new opportunities for innovation', as for example intended by the EU's 'Fit for 55' policy package [1]. For such transformational change towards decarbonisation to occur, policies are needed to help overcome transition barriers arising from existing systems locked into fossil-fuel based technologies, infrastructures and practises [2–5]. In addition, given the urgency of achieving climate neutrality and energy security, such policies need to aim at accelerating such system change, despite the slowness of past transition processes [6–8]. In this research perspective, we aim to draw policy makers' attention to social innovation as a source of transformative change and the role that it could play in critically sharpening transformative ambitions and in supporting and accelerating decarbonisation [9,10]. We understand social innovation here as new ways of doing, thinking and/or organising energy that change social relations [11]. In such an understanding, social innovation is multi-directional and also has the potential to contribute to decarbonisation and energy transitions through e.g. addressing energy poverty, enhancing energy democracy, empowering citizens and ensuring just energy transitions [12–16]

In the EU, social innovation has, since the early-2000s, been recognised as an important tool for achieving smart, sustainable, and inclusive growth, as set out in the Europe 2020 Strategy [17]. By 2009, the Bureau of European Policy Advisors had already done important work that put social innovation on the European policy agenda as an instrument to address societal challenges [18]. Over time, social innovation has found its way into the EU's research and innovation programmes, including FP7 and Horizon 2020, and into policies by the European Social Fund [19]. Recent policy renewals for the funding period 2021–2027 (Horizon Europe) frame social innovation as a horizontal 'key specific issue' [20] and provide dedicated support for social innovation research. Furthermore, the European Commission recognises the relationship between energy transitions and social innovation, as demonstrated by the Joint Research Centre of the European Commission's engagement with the role of social innovation for energy transitions [21]. Through this work and via its research and innovation programmes, it is clear that Europe aims to support social innovation and recognises the link between social innovation and the energy sector.

However, social innovation does not yet feature prominently in climate and energy policy but more often than not seems to be under-recognised. For example, a keyword search in the 'Fit for 55' proposals released in July 2021 – including various policy changes aiming to help reduce the EU's net greenhouse gas emissions by at least 55% by 2030 – reveals that social innovation in general is not mentioned as such (but once in the Renovation Wave). However, a closer look at the electricity sector reveals that some policy proposals do refer to specific types of social innovation in energy. For example, the potential of renewable energy cooperatives is recognised and directly addressed as part of the foreseen revisions of the Energy Efficiency Directive and the Renewable Energy Directive. Nevertheless, some prominent types of social innovation appear to be neglected completely, such as the role of peer-to-peer learning. In the cases where specific types of social innovations are noted, their recognition tends to be limited to mentions in only a few policy proposals – most often the Energy Efficiency Directive and/or the Renewable Energy Directive, followed by the Social Climate Fund.

This implies that some types of social innovation are recognised as important for creating acceptance for decarbonisation, particularly in the context of clean energy transitions [22,23]. However, the full potential of social innovation does not seem to be harnessed yet, despite its potential contributions to EU goals, such as increased renewable energy productions, increase in social acceptance of renewables, or improved knowledge-transfer in the energy sector [24]. Such under-recognition represents a missed opportunity to support the achievement of climate and energy policy targets – because the required system changes are socio-technical, and thus call for both technological and social innovation [25–27]. Policies aiming at tapping into this potential should strengthen enabling factors of social innovation in energy and weaken impeding ones [28]. For example, there clearly is significant interest of European citizens (up to 90%) to get engaged in various types of social innovation in energy if the conditions were right, as demonstrated by representative survey evidence from France, Germany and Poland [29]. Yet, to tap into this potential, energy and climate policy changes are needed. Therefore, with this research perspective we aim to draw attention to the potentials of social innovation – both as instrument for achieving policy targets and as source of wider political and cultural transformation [10,11,30]. If social innovation were recognised more widely as key dimension of sustainable energy transitions, it would appear more often on the radar screen of those involved in energy and climate policy making – including penholders and administrators but also mainstream energy system researchers and policy consultants, ensuring policies enabling rather than impeding social innovation.

This perspective draws on original research conducted witin the SONNET project[1], specfically its policy dialogue, including EU policy makers, energy pratitioners and academic researchers and a workshop with city administrations across Europe. First, we prepared a briefing document for the policy dialogue in which we synthesised policy-relevant insights on the role of policies and policy mixes for different types of social innovation in energy (see [31]). In it, we also reported on the (limited) consideration of SIE in the Fit for 55 package. Second, in January 2022, we organised and conducted a co-creative policy dialogue that

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brought together 95 participants to discuss opportunities and challenges for an enhanced consideration of social innovation in energy in the EU's Fit for 55 package (see the Appendix for agenda and graphic harvest of the event).[2] Third, after the policy dialogue, the author team reflected upon the discussions and structured its main points into four priority areas with three action points each for how to better harness social innovation in energy and climate policy making. Fourth, the twelve action points were validated and complemented through city-level insights in a co-creation workshop with city administration representatives from Antwerp, Bristol, Grenoble, Mannheim and Warsaw (for further details, see [31]). They capture ways of how to better consider social innovation in energy in future energy and climate policy making at the EU (but also at other governance levels).

Before elaborating on these twelve co-created action points in section 3, in section 2 we first briefly introduce the concept of social innovation and its diversity in the energy sector. We close by offering some overarching conclusions in section 4.

WHAT IS SOCIAL INNOVATION IN ENERGY?

A prominent definition of social innovation was coined by the Bureau of European Policy Advisers (BEPA), who put forth an understanding of social innovation as 'new ideas that simultaneously meet social needs and create new social relationships or collaborations. (…) [T]hey are innovations that are not only good for society but also enhance society's capacity to act' [18]. The emerging work on social innovation in energy is inclined towards similar understandings [21]. For instance, Hoppe and Vries [26] built on the BEPA definition when describing social innovations in the energy transition as: *'Innovations that are social in their means and contribute to low carbon energy transition, civic empowerment and social goals pertaining to the general well-being of communities'*. In a similar fashion, [32] link social innovation in community energy in Europe to the aim of improving societal well-being (p. 7).

Yet, other research on social innovation recommends decoupling the outcomes of social innovation, so as to enable a critical assessment of the contributions of social innovation to, for instance, policy objectives [33,34]. This also allows to account for 'dark sides' of social innovations, rather than considering these as inherently good [35,36]. In addition, there have been more fundamental critiques on a perspective that reduces social innovation to an instrument serving current powers and their policy agendas – and thus optimising current societal structures, cultures and practices rather than radically transforming them (e.g. [30,37–39]). Such more critical voices consider social innovation as a source of counterhegemonic social change – challenging power relations and institutional dynamics – and have a normative focus on collective empowerment or transforming structural imbalances in society. There are different streams of research aiming to reach beyond this duality to understand how social innovation relates to structural change and transformation (e.g. [10,40,41]).

In this research perspective, we follow one of these latter streams of research [9,34,42] and its application to energy, for which a broader definition of social innovation in energy has been proposed - capturing new ways of doing, thinking and/or organising energy [43]. This can include new ways of generating, distributing or consuming energy, as well as new framings that change the way we think about energy. In other words, 'social innovation' can include both changes in social practices, as well as changes in societal discourses, such as changes in how we view using new technologies to share energy locally. In all cases, at the heart of this broader definition of social innovation in energy are changes in social relations including power relations, e.g. between citizens and governments or between energy firms and their customers [11]. That is, we follow Avelino and Wittmayer [44] who have argued for considering social innovation as a multi-actor phenomenon that is not necessarily confined to grassroots, or citizen initiatives, but can originate in any institutional context, including civil society, state, or market - thus in every sphere of society. Accordingly, when we refer to social innovation in energy (SIE) we mean '*(combinations of) ideas, objects and/ or activities that change social relations, involving new ways of doing, thinking and/or organising energy*' [43].

This broad understanding of social innovation in energy acknowledges that such innovation goes beyond the classic examples of cooperative energy production and community energy [32,45], and also includes less often discussed examples like new financing mechanisms such as crowdfunding [46], campaigns for clean or against unsustainable energy pathways such as the divestment movement [47,48], or new ways of exchanging electricity locally [49–51].[3] Furthermore, it acknowledges that social innovation also includes rediscovering old practices, and finding new ways to combine existing ideas, objects and/or actions [9,11,43,52,53]. For example, although campaings against particular energy pathways might have been around for several decades, ways of organising, thinking and doing have changed over time [47]. In addition, work has gone into identifying ways of replicating, spreading and scaling social innovation to increase their impact towards transformative changes (e.g. [34,54,55]) as well as into experimenting with alternative economies [56]. This diversity of social innovation in energy has been systematised into an empirically-grounded typology distinguishing 18 different types of social innovation in energy – amongst others, peer-to-peer electricity exchange, participatory experimentation and incubation, or investment and finance mechanisms, next to campaigns against specific energy pathways, or platform-based exchanges [43].

WHICH ACTIONS CAN BE TAKEN TO ENHANCE THE ROLE OF SOCIAL INNOVATION IN ENERGY AND CLIMATE POLICY MAKING?

These insights on the diversity of social innovation in energy and its current consideration in EU policy were fed into a policy dialogue that brought together policy makers, advocacy groups and researchers to discuss opportunities and challenges for the consideration of social innovation in energy in the Fit for 55 package (see Appendix). Based on the discussions at this policy dialogue and a subsequent workshop with city administrations, overarching reflections on how social innovation could be better harnessed within EU energy and climate policy making were co-created. Four main priority areas emerged for which we offer big picture reflections for future policy making at the EU level. For each of these priority areas, we offer three action points for EU level policy makers as a way forward for better considering social innovation in energy and climate policy making (for an overview see Table 1). However, we argue that these action points also provide valuable guidance for other governance levels, in particular the national level.

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Table 1. Action points for better considering social innovation in energy and climate policy making

Area	No	Action Point
Priority area 1: Energy and climate policy maker's awareness of, and willingness to engage with social innovation in energy		
	1	Raise awareness for social innovation across energy and climate policy makers.
	2	Connect with and provide evidence to key policy actors who are drafting energy and climate policy proposals.
	3	Adopt policy mix thinking across energy, climate and innovation policies for governing the emergence, upscaling and diffusion of social innovation in energy.
Priority area 2: Defining and conceptualising social innovation in energy transitions		
	4	Sharpen the definition of social innovation in energy used by policy makers.
	5	Adopt a broad definition of social innovation in energy in general, which can be complemented by specific definitions of key types.
	6	Devise long-term policy strategies specifying the foreseen role of social innovation in energy transitions.
Priority area 3: Benefits and impacts of, and metrics for social innovation in energy		
	7	Take stock and synthesise existing assessment and evaluation practices for determining the impact of social innovation in energy.
	8	Ensure that future policy impact assessments and policy evaluations incorporate social innovation as one of its dimensions.
	9	Improve future policy support for social innovation in energy based on evidence from impact assessments and policy evaluations.
Priority area 4: Multi-level governance and the role of the local level for supporting social innovation in energy		
	10	Provide clear EU-level guidance for policy makers on other levels regarding the beneficial role of social innovation in energy transitions.
	11	Ensure consistency between EU and national policies relevant for social innovation in energy.
	12	Include the perspective of cities in EU energy and climate policy making due to their proximity to socially innovative initiatives in energy.

Energy and climate policy maker's awareness of, and willingness to engage with social innovation in energy

The first priority area captures the observation that many energy and climate policy makers at the EU (but also at national levels) seem to lack awareness of, and knowledge about social innovation in energy. As a consequence, they may also not be aware that there is a connection between their policy field and social innovation. Instead, energy and climate policy makers seem to perceive the main responsibility for social innovation in energy to be in the research and innovation domain. This limits its consideration in energy and climate policy and thereby its upscaling and wider diffusion without which its potential to accelerate energy transitions would remain largely untapped. Three action points are offered to address these concerns.

First, policy makers across different policy fields, and thus beyond the research and innovation domain, need to be aware of the connection between their policy field and social innovation in energy (action point 1). However, currently there seems to be an awareness gap among many energy and climate policy makers when it comes to social innovation. Policy makers and researchers who specialise in social innovation can directly and indirectly contribute to awareness raising by sharing their expertise and insights with mainstream energy and climate policy colleagues. Such building of bridges between innovation and sectoral policy could be, for example, further encouraged through designing research funding calls requiring such bridging between policy makers, researchers, and social innovators.

Second, the consideration of social innovation in energy and climate policy in general, and in the Fit for 55 package in particular, would benefit from connecting the Fit for 55 and other energy and climate policy 'penholders' with social innovation experts, researchers, policy makers, and advocacy groups to share evidence on SIE with them (action point 2). Whether intended or not, energy and climate policies such as those included in the Fit for 55 package often have an impact on social innovation in energy. Explicitly considering such impact in designing these policies can help to ensure that the resulting policies have an enabling impact on social innovation in energy by design, not by chance. This could happen, for example, by organising exchange meetings between EU penholders and key experts working on social innovation in energy, ensuring that their expertise is taken into account. Such exchanges can be enhanced by capacity building support for EU-level representation of SIE intermediaries, e.g. through research and institutional funding.

Third, energy and climate policy makers seem to perceive the main responsibility for social innovation in the innovation domain, with an eye on experimentation, i.e. the emergence of social innovations. However, it is the combination of energy, climate and innovation policies that influences the development of social innovation in energy, with energy and climate policies being particularly important for their upscaling and diffusion (action point 3). In addition, seemingly disconnected policy changes in other policy fields can - whether intentionally or unintentionally - have an impact on social innovation in energy, a case in point being the EU taxonomy. This interconnectedness could be made more explicit, for example, by (innovation) policy makers and funding agencies initiating research on such policy interactions across different policy domains and their impact on social innovation in energy, as well as supporting the dissemination of findings to their colleagues in other directorates.

Defining and conceptualising social innovation in energy transitions

The second priority area focuses on the observation that it may not only be a lack of awareness but also of understanding of social innovation and its role in energy transitions, which hampers its consideration in energy and climate policy making. As a complex and fuzzy concept, social innovation may not be well enough understood yet by energy and climate policy makers. As such, efforts at a clear yet simple definition of social innovation in energy remain a key issue. While various definitions exist, what would qualify as social innovation may often not be called as such. Therefore, social innovation may end up under-recognised in energy and climate policy discourses. At the same time, when used as a concept by policy makers, their understanding is commonly linked to far-reaching expectations regarding social benefits instead of as a tool for accelerating energy transitions. Perhaps

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as a consequence, while social innovation appears to be praised in general, its upscaling and wider diffusion tends to be neglected in energy and climate policy making. We therefore suggest the following three action points.

First, while the existing plurality of definitions of social innovation in energy are fruitful in academic discourses, for energy and climate policy makers this may rather lead to confusion. Therefore, innovation policy makers could initiate the co-creation of a clear, uniform and easily applicable definition of social innovation in energy - based on existing definitions attempting but yet not succeeding in this. For such co-creation to work it is essential that sectoral policy colleagues are on board, and the invitation of SIE researchers and practitioners is recommended to facilitate such an endeavour. The resulting agreed upon definition would be a useful steppingstone in better considering social innovation in energy and climate policy making (action point 4). This could be accomplished, for example, by hosting internal workshops on the topic to co-create its meaning and publishing a manual on social innovation including the resulting definition.

Second, a broad definition of social innovation in energy could help to better connect it to political discussions and get the concept out of a niche (action point 5). In addition, its diversity might best be recognised by also providing simple definitions for specific types of social innovation in energy, as already has been done for energy communities. Providing illustrative examples could be helpful for furthering sectoral policy makers' insights of what may constitute social innovation in energy. Such an overview could start, for example, with the 18 different types of social innovation in energy identified by Wittmayer et al., [43]. Together, such a general definition and concrete examples for specific types of social innovation in energy could promote a better understanding of the concept, increase its popularity, and thereby likely strengthen its consideration in energy and climate policy making.

Third, social innovation in energy would benefit from considering it in long term policy strategies governing sustainable energy transitions (action point 6). These should concretely spell out its foreseen role in these transitions, which may also help to clarify the expectation towards social innovation in energy. Innovation policy makers could support such efforts by amending research calls on energy system modelling and scenario building to specifically include the consideration of social innovation in energy, thereby generating inputs for policy making.

Benefits and impacts of, and metrics for social innovation in energy

Insights into the benefits and impacts of social innovation in energy, and developing metrics for this, is a third priority area we identified. Practitioners shared examples of how they have been measuring impacts, such as via conducting surveys with initiatives. Policy makers pointed to the availability of data on R&D funding for social innovation, as well as to the richness of available but yet to be systematically analysed research data, for example by actors such as the Joint Research Centre, to feed these into policy making processes. As next steps, we propose three action points to move forward with the inclusion of social innovation in energy in policy assessment and evaluation practises.

First, policy makers can collaborate with or ask academic researchers – ideally with the support of SIE intermediaries – to synthesise existing assessment and evaluation practices for determining the impact of social innovation in energy, and based on this suggest suitable methodologies (action point 7). In doing so, it should be discussed to which extent these methodologies can be applied to diverse types of social innovation, and which adaptations, additions or alternatives are needed to account for different types of social innovation. While acknowledging the limitations of the most suitable assessment and evaluation methodologies, such a co-creative process and differentiated approach may encourage some standardisation of assessment practices, while safeguarding the consideration of the diversity of social innovation in energy.

Second, policy makers should ask consultants and researchers to acknowledge social innovation in their policy impact assessment and policy evaluations. For this, analysts should apply existing state-of-the-art assessment and evaluation methodologies for social innovation and further advance them [57]– something that will largely depend on requirements within tenders and research calls (action point 8). It should be explored how such inclusion of social innovation in impact assessment and policy evaluation – potentially as one aspect within the examination of innovation in general – can be made mandatory and to which extent it can be standardised. An associated question then becomes which actors, organisations and institutions should be responsible for the uptake of these novel assessment and evaluation practices.

Third, it will be essential to increase the political and administrative will of energy and climate policy makers to support social innovation in energy. That is, improving monitoring, assessment, and evaluation methodologies for social innovation in energy will not be sufficient. In addition, what is also needed is the political and administrative will to build on such novel evidence when redesigning policies and regulatory frameworks that better support social innovation in energy (action point 9). This could be supported by the facilitation of trainings, networking, and leadership, as well as by the adoption of a reflexive governance style.

Multi-level governance and the role of the local level for supporting social innovation in energy

A fourth priority area concerns the importance of multi-level governance and in particular the role of the local level in supporting social innovation in energy. While our focus here has been on EU energy and climate policies such as the Fit for 55 package, it is clear that other governance levels play a key role for social innovation in energy, too. Obviously, the national level is important, among others as its policy makers are responsible for the transposition of EU directives in Member States. However, cities and regions should be particularly highlighted as having a high potential for supporting social innovation in energy on the ground given their proximity to social innovators and often ambitious climate neutrality missions [58,59]. Initiatives like Covenant of Majors, Climate Alliance, Transition Towns or Eurocities indicate that major urban actors seem increasingly confident about their potential roles in transforming cities into smart, sustainable, and just communities. More often than ever, cities are being addressed as 'sustainability solutions' more than 'sustainability problems' [60]. This leads us to propose three more action points for a better consideration of social innovation in energy and climate policy making.

First, agreement on the EU-level on the importance of considering social innovation for accelerating energy transitions would provide clearer orientation and guidance for taking SIE on board when crafting EU directives and policies, and their enforcement at the national level (action point 10). Such EU level guidance regarding the beneficial role of social innovation in energy transitions matters for all policy fields of relevance for social innovation in energy. But in particular, it would be important to communicate

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that energy and climate policies – not only at the EU level – are key elements for supporting the upscaling and diffusion of social innovation in energy, and that promoting SIE can assist in faster achieving climate neutrality and energy security.

Second, EU policy makers are well advised to ensure that the measures promoting social innovation in energy included in EU directives are sufficiently transposed in Member State's national energy and climate policies (action point 11). Such compliance checks would aim at improving the consistency between policies on EU and national level, thereby sending clearer signals to social innovators and harnessing the full potential of social innovation in energy across all of Europe. A case in point are the provisions for renewable energy communities in the Renewable Energy Directive, which so far have been insufficiently transposed into the national law of several Member States, thereby undermining the achievement of EU policy goals. Therefore, it is important to better ensure the transposition of EU directives' provisions regarding social innovation in energy in national law of Member States. This, however, does not mean that the national implementation of EU provisions cannot differ across EU member states to consider the specific country context, as long as transposing policies enable SIE.

Third, EU policies could acknowledge and clarify the role of cities and regions in promoting social innovation in energy due to their proximity to socially innovative initiatives in energy. Better including their insights and perspectives may possibly lead to an expansion of their mandate to shape more sustainable energy systems at the local and/or regional level (action point 12). The EU mission that has selected 100 cities wanting to become climate neutral and smart seems well suited for this, and could pay particular attention to socially innovative approaches by the mission cities, learnings from which should be fed back to energy and climate policy makers. Finally, such policy actions at the city level will benefit from coordination with policies at other governance levels, such as national bodies.

CONCLUSIONS

With this research perspective we aim at providing a fruitful basis for intensifying the policy discourse on the potential role of social innovation amidst the broader political and cultural changes necessary for addressing the multiple social and environmental challenges that societies are facing today. Specifically, we focus on how energy and climate policy making, in particular at the EU level, can become aware of and provide space for social innovations to both flourish and to be harnessed for policy objectives.

A case in point is the Fit for 55 policy proposals. We argue that debates and negotiations should explicitly consider the impact of these proposals on social innovations and their potential for transformative change. For example, two immediate and powerful policy initiatives could be the provision of a definition of social innovation (in energy), and the earmarking of a share of the revenues from emissions trading for experimentation with social innovations. These policy changes could be included into the proposed Social Climate Fund, but could also be integrated into the existing Innovation Fund.

Importantly, such a social innovation push effort should be complemented with pull instruments to harness the full potential of social innovation via its upscaling and wider diffusion. These pull efforts for social innovations can build on the promotion of renewable and citizen energy communities within the Renewable Energy Directive (RED II), with its revision presenting a promising opportunity to tap into the potential social innovation has to offer to accelerate sustainable and just energy transitions. Ultimately, and similarly to technological innovation, we argue that policy makers can best promote social innovation by catering to push and pull effects.

In this regard, the proposed twelve action points that were co-created within a policy dialogue session and workshop with city administrators offer practical ways to better harness social innovation in energy for accelerating sustainable energy transitions in Europe. Beyond these practical recommendations, we hope to have awakened the awareness that social innovation – involving multiple actors, striving for diverse goals – needs more reflexive ways of governance and policy making so as to allow its full potential for societal transformation to unfold. Ultimately, it is our intent that this research perspective helps catalyse further discussions on better integrating social innovation throughout energy and climate policy across EU and other governance levels.

SUPPLEMENTARY DATA

Supplementary data are available at *Oxford Open Energy* online.

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CONFLICT OF INTEREST

We declare that there are no conflicts of interest.

AUTHOR CONTRIBUTIONS

Rogge, Karoline: conceptualisation, methodology, formal analysis, investigation, writing (original draft, review & editing), supervision (incl. of visualisation), project administration, funding acquisition.

Stadler, Maria: conceptualisation, methodology, formal analysis, investigation, writing (original draft, review & editing), project administration.

de Geus, Tessa: conceptualisation, methodology, formal analysis, investigation, writing (review & editing), supervision, project administration.

Hielscher, Sabine: validation, investigation, writing (review & editing), funding acquisition.

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Kotler, Adrienne: software, validation, investigation, writing (review & editing), project administration.

Mischkowski, Niklas: conceptualisation, validation, investigation, writing (review & editing).

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Ranville, Adélie: investigation, writing (review & editing).
Vernay, Anne-Lorène: investigation, writing (review & editing).

DATA AVAILABILITY

The data underlying this article are available in the article and in its online supplementary material. Further background material connected with the SONNET project deliverable D2.4 can be found on Zenodo under DOI 10.5281/zenodo.657714.

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