Energy Research & Social Science 94 (2022) 102860

Contents lists available at ScienceDirect

Energy Research & Social Science

journal homepage: www.elsevier.com/locate/erss

Original research article

Towards a deeper understanding of up-scaling in socio-technical transitions: The case of energy communities☆

D. Petrovics [a,*], M. Giezen [b], D. Huitema [c]

[a] Institute for Environmental Studies (IVM), Department of Environmental Policy Analysis, Vrije Universiteit Amsterdam, De Boelelaan 1111, 1081, HV, Amsterdam, the Netherlands
[b] Centre for Urban Studies, Department of Human Geography, Planning and International Development, University of Amsterdam, the Netherlands
[c] Public Administration and Policy Group, Wageningen University & Research, the Netherlands

ARTICLE INFO

Keywords:
Socio-technical theory
Upscaling
Mechanismic thinking
Conditions
Strategic niche management
Energy communities

ABSTRACT

The pressing nature of the climate crisis is placing sub-national action at the forefront of climate mitigation. Energy communities have been an example of such *niche* action, as, over the past decades, they have blossomed in number and have challenged dominant narratives of the energy transition. The aggregate impact such action promises may be necessary to mitigate the global-scale problem of the climate crisis. This opens up the vexing question of what mechanisms are at play in scaling such action and how the contours of causality may be painted in the pathways towards transitions. This article aims to address this gap by building on the concept of mechanismic thinking. The innovative nature of this approach helps us identify empirical examples of conditions of scaling and brings conceptual clarity to studying processes of transitions. This article identifies conditions in relation to various pathways of transitions and the strategic management of *niches*. We identify several conditions that scaling may depend on through a systematic literature review of the energy community literature. From our review, two key results surface: Firstly, at the empirical level, the conditions identified suggest that a diversity of pathways to scaling may exist in parallel. Secondly, the conditions found in the literature can productively be mapped based on three dimensions: conditions internal to communities, conditions affecting interactions between communities, and finally, conditions related to the context of community initiatives. By feeding back our findings into leading theories in the field, our review enriches existing accounts of *niche*-internal dynamics of the strategic niche management approach. Moreover, we suggest that mechanismic thinking has much to add to the research agenda on connecting local scale innovation and higher scale impact in socio-technical thinking.

1. Introduction

If *niches*, such as low-carbon initiatives, scale, they do so through growth and replication and, in the process, affect existing institutions to their advantage [1]. This entails a quantifiable and clearly measurable spatial change and an institutional effect, which enhances the process of this spatial change.

In socio-technical thinking, the scaling of *niches* has been a subject of study for the past decade [1–7]. Specifically, the looming shadow of the climate crisis underlines the urgency and necessity to scale sub-national and local action. According to the Intergovernmental Panel on Climate Change (IPCC), the year 2030 marks the point of no return if the current rate of accelerating emissions of greenhouse gases remains [8]. This short time frame underlines the urgency to identify relevant innovation and deliver action at scale to a problem characterized by carbon lock-ins [9]. The needed action can be led by public actors, such as cities taking on climate governance [10,11] or private companies beginning to self-regulate and adhere to a variety of standards [12]. Parallel to this, citizens growingly make efforts to express their disdain – be that through alternative approaches to everyday activities [13], direct action [14], or by providing nature-based solutions to local challenges [15].

As an alternative form of citizen-led effort, clean energy communities

☆ Conflicts of interest/Competing interests: The authors report no conflict of interest.Availability of data and material (data transparency): Not applicable.Code availability (software application or custom code): Not applicable.Acknowledgements: The authors would like to thank Cornelia Fast for reviewing an earlier version of this article and the anonymous reviewers for reviewing this article.Funding: This work was supported by the European Union's Horizon 2020 programme [grant agreement #: 837752 – NEWCOMERS project].

* Corresponding author.
E-mail address: daniel.petrovics@vu.nl (D. Petrovics).

https://doi.org/10.1016/j.erss.2022.102860
Received 10 June 2022; Received in revised form 20 October 2022; Accepted 27 October 2022
Available online 8 November 2022

have gained traction over the past decades. In a European context, the institutionalization of energy communities is underlined by the EU-level directives (Renewables Directive (RED II) and the Internal Electricity Market Directive (IEMD)), which establish the regulatory baseline for energy communities through the creation of *Renewable Energy Communities* and *Citizen Energy Communities* respectively. The transposition of these directives, in effect, have created a *milieu* of experimentation and growing diversity in terms of the types of actors involved (such as municipalities, SMEs, and individuals) and the types of technologies utilized (such as production, storage, or demand response) [16]. This being said the transposition also poses a major hurdle as various member states are at different stages of transposing the directives into national law. In addition, Devine-Wright [17] suggests that we are now seeing a transformation from community to local energy. The change in nomenclature denotes a change in institutional logic from community to market [18]. Bearing these dynamics in mind, the specific scaling mechanisms of community ownership of energy assets to date has not been substantially studied.

The case of energy communities is illustrative of socio-technical transitions in that a *niche* innovation challenges the *status quo* of an established *regime* because they generally carry societal and technological consequences in the way they function and in the way they challenge dominant narratives and governance arrangements [19]. The emergence of such novelties is explained by socio-technical transition literature at large [20–22], as it discusses the interrelation of technology and society and illucidates how large-scale systemic changes come about based on local- and small-scale innovation. These innovations are called *niches*, as they carve out their own space and either grow to challenge the incumbent *regime* or fail in the process of experimentation [23]. In explaining this process, Geels & Schot [24] differentiate between four pathways: *transformation, de-alignment and re-alignment, technological substitution,* and *reconfiguration*. These pathways describe high-level processes and, to a certain extent, remain black-boxes regarding the inner workings of scaling and the conditions this depends on. This paper aims to fill this gap in the literature by exploring upon what conditions these processes may be predicated.

We adapt *mechanismic thinking* to open this black box, building on Gerring's [25] review of social science approaches focusing on causal mechanisms. Such a term is appropriate as it highlights the causality implied in social phenomena without framing these processes as mechanistic – i.e., as machine or clockwork-like. We further argue that mechanismic thinking helps concretize the abstract conceptualization of high-level processes in socio-technical theory, contributes to clarifying connections between *niche* and *regime* interactions [26] and assists in crystalizing linkages between various socio-technical systems [27]. We suggest that examining processes at the direct site of *niche* formation – instead of at the scale of global processes crystallizes operational examples of how *niches* can scale and what conditions this depends on. By doing so, our analysis aims to enrich the SNM approach with concrete empirical examples of conditions of scaling, which may be at play at the local scale. To a similar end, identifying locally actionable conditions in this context allows for the retranslation of the concrete (local-scale action) into the abstract (global *niche* development). In this sense, zooming in on specific initiatives allows for a nuanced understanding of what conditions may be at play in varied pathways of transitions contributing to translocal diffusion [28] and global *niche* formation [29,30].

Our article directly connects to Schot and Geels' [29] seminal piece on SNM, which called for a better understanding of "mechanisms that make sequences of projects gel into *niche* development" (p. 550). Later in this article, we shall demonstrate that the institutionalization of the energy community field provides a robust empirical basis for this contribution and can, in effect, help us better understand what happens within, between and in the context of initiatives leading up to their scaling. Such an approach heralds both results regarding how SNM can be enriched with pointers focusing on how local-scale initiatives organize within, what rules they develop and how they manage their resources, and what conditions are at play at various levels. To date, the only efforts the authors are aware of, which aim to explain the scaling of energy communities have been put forward by Bauwens [18] describing institutional complexity in scaling, which results from combined collective action and market logics, and by Petrovics et al. [31] focusing on the polycentric governance of energy communities.

In the following sections, several pertinent questions are answered. Firstly, the theory section outlines how the socio-technical approach accounts for transition pathways, what we mean by scaling, and how accounts of *niche* innovation can be enriched with mechanismic thinking. The methodology section outlines the details of the systematic literature review conducted, whilst the results section surveys the empirical evidence of conditions to be found in the literature. The final sections discuss how the findings can be tied into the SNM approach and socio-technical literature – with particular attention being paid to scaling pathways [24]. Finally, we propose several academic routes researchers can explore, alongside a set of practical recommendations to those active in the energy community field.

2. Theory

This section dissects what is meant by scaling, highlights the lack of explicit attention paid to the concept in to-date explored pathways of transition, introduces the concept of mechanismic thinking in light of these pathways and the strategic management of *niches*, and ultimately sketches why identifying conditions of scaling may be appropriate from this perspective.

A complete understanding of scaling requires a certain degree of clarity in the sequence of events and their causal relationships. In effect, such an exploration should constitute the identification of conditions which may lead to conjunctures and produce mechanisms with the power to unleash the movement or growth of a given societal phenomenon through multiple scales and dimensions. In his classic work *Diffusion of Innovations*, Rogers [32] discusses how innovation spreads similarly, and he outlines that "diffusion is the process in which an innovation is communicated through certain channels over time among the members of a social system" [[32], p 5.]. This account highlights that scalability's key aspect lies in planning a sequence of events dependent on certain conditions whilst considering constraints and opportunities.

Such sequences of events involving *niche-regime* interactions and the related *landscape* pressures have also been labelled as transition pathways. The typology of transition pathways sketched by Geels and Schot [24] serves as the centerpiece of our conceptualization of unpacking the conditions at play in scaling *niches*.

In line with studying the conditions needed for the scaling of *niches*, differentiating between the global-scale *niche* developments (e.g. the emergence of solar PV around the world) and local site-specific manifestations of *niche* initiatives (e.g. a community energy initiative in a city) carries power in connecting the global with the local. However, this broad conceptualization of socio-technical theory also falls in the trap of connecting the abstract processes at higher scales involving intermediaries [32] with the concrete activities of specific initiatives. The Strategic Niche Management (SNM) approach serves as a helpful framer of local-scale concrete activities.

Bearing this in mind, the following section aims to answer several questions: How can we define scaling in more detail and what is the use? What do transition pathways tell us about scaling? And how can mechanismic thinking help us better understand the strategic management of *niches*?

2.1. How can we define scaling?

In assessing how local-scale initiatives can effectively contribute to low carbon development, a number of typologies exist, which describe scaling trajectories (for example, *replicating, scaling-up, translating* [2], *upscaling, replicating, partnering, instrumentalizing* [3], *shielding, nurturing,*

empowering [4], *scaling up, scaling out, scaling deep* [5], *amplifying* [6], or *growing, replicating, accumulating, and transforming [33]*.

In this article, we operationalize scaling through two crucial outcomes: visible and measurable spatial and quantitative change of an initiative – either in terms of growth or replication, or institutional change enabling the aforementioned spatial and quantitative change. This is appropriate as studying the scalability of *niches* in socio-technical systems should entail both some type of quantification of the *niche's* development as well as a qualitative change of the institutional embedding of aforementioned *niche*.

In line with this understanding [1], van Doren et al. outlined the results of up-scaling processes in *horizontal* and *vertical* terms. *Horizontal* outcomes entail the quantitative growth of an initiative either in size (i.e. bigger) or in number (i.e. more). *Vertical* entails the institutional transformations resulting from the emergence and anchoring of a *niche* initiative. This, in effect, can open up the space for more *horizontal* up-scaling. This conceptual relationship is outlined in Fig. 1.

2.2. What does literature tell us about transition pathways?

The socio-technical approach to sustainability transitions focuses on the interrelation of society and technology and treats them as mutually indivisible and interdependent sets [36]. Earlier works focused primarily on the historical analysis of specific technologies and how they emerged – examples include digital computers or sewer systems [38]. The approach is dominated by the Multi-Level Perspective (MLP), which differentiates between *niche, regime,* and *landscape* levels in studying sustainability transitions [21,40]. The three levels describe different aspects in a transition – *niche* entails novelties or innovations, *regime* describes the incumbent socio-technical configuration, and *landscape* focuses on overarching structural conditions.

This approach can be characterized as focusing on systemic changes. It examines broad constellations of political, technological, economic, social, scientific, and cultural aspects and points to how these systems transform. It is principally concerned with long-term, structural processes. In catering to these processes, the approach works with non-linear pathways of transition, of which the major ones are *transformation, de-alignment/re-alignment, technological substitution,* and *reconfiguration* [24].

In our understanding, these pathways serve as functional conceptual building blocks for illuminating causal mechanisms in socio-technical transition theory. They help us understand in a broader sense how *niches* interact with the *regime*, what kinds of *landscape* pressures are necessary for *niches* to mature and how *regimes* may become obsolete. However, in doing so, they do not provide clarity on how scaling happens. Particularly in the field of sustainability and environmental studies, the implications of unactionable theories are immense, and for this reason, concretizing abstract pathways is a clear must for actionable science.

As mentioned, in our perspective, each of these pathways carries implicit qualities of mechanismic thinking. The sequences of events, the causal relationships of dynamics at *niche, regime,* and *landscape* levels, as well as the influences of contextual conditions in each of the pathways, point to generative causality, which "is designed to utilize mechanisms and contexts to explain outcome patterns and so provides the most complete approach to causal explanation" [41,p. 39]. Such an approach focuses on uniformities in outcome – in the case of this article scaling – which can be conceived of through understanding processes, sets of conditions and underlying mechanisms [41]. In this sense, the theorization of causality becomes one focused on mechanismic thinking.

With-in this backdrop, the various pathways imply the following mechanisms. *Transformation* is triggered by *landscape* pressures or disruptive change when the *niche* novelties are not yet completely developed. With-in this setting, *regime* actors steer the pathway towards innovative activities. *De-alignment/re-alignment* occurs when *landscape* changes are drastic enough that *regime* actors lose faith in the regime's functioning to the extent that it disrupts the *status quo* and the *regime* erodes. In this moment, multiple *niches* can compete and ultimately one will replace the *regime* constellation. *Technological substitution* occurs when one *niche* innovation is sufficiently developed when a *landscape*-level shock disrupts the regime and, in effect, steps in its place. Finally, in the *reconfiguration pathway*, innovations are integrated into the *regime* to solve particular difficulties, and by triggering further changes eventually completely alter the architecture of the *regime*.

Each of these pathways carries explanations primarily in terms of coincidences and correlations. This means that a more profound understanding requires more significant insights into the exact conditions and resulting mechanisms at play. Such insight might eventually also provide the handles to facilitate transitions better, especially if it becomes clear what conditions are necessary and how mechanisms may be leveraged. For this reason, there is a need to understand better what conditions the scaling of *niches* depends on and how the implied generative causality can be crystallized and made more explicit.

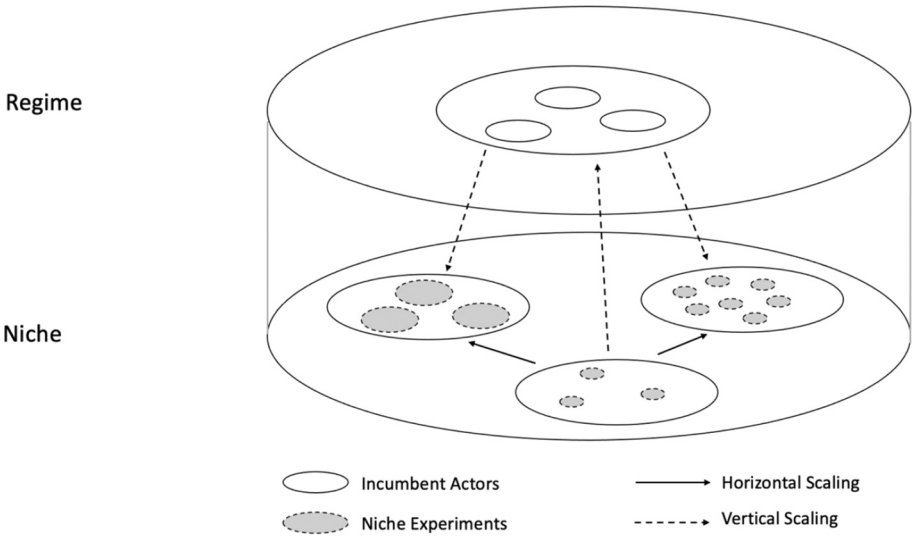

Fig. 1. Horizontal and Vertical Scaling as connectors of Niche and Regime (based on Petrovics et al. [35]).

2.3. How can mechanismic thinking help us better understand the strategic management of niches?

In appreciating the resulting complexity of governing transformations towards sustainable outcomes [19] one can conceive of generative causality as resulting in thinking of causal mechanisms [42]. Utilizing such a conceptual approach can pinpoint the key factors triggering a process and add analytical depth to studying transitions towards sustainability. To a similar end, Sengers et al. [43] discuss *embedding mechanisms* of climate governance experiments. They explore the specific mechanisms that ensure that innovation pertains beyond the experimental phase. Next to this, Ehnert et al. [3] explore *acceleration mechanisms* of urban sustainability transitions, which in broad terms construe how local-scale innovation may diffuse. To this end, we understand mechanisms as carrying several core characteristics as they: 1) can be identified based on the effect or phenomenon they produce, 2) carry a causal quality in the effect or phenomenon they produce, 3) have a structure past 'black-box' conceptualization, 4) form a hierarchy and can be broken down into lower-order mechanisms (or conditions in our understanding), and 5) can be combined and are interrelated [44].

Bearing these characteristics in mind, two key gaps are evident: firstly, what conditions are at play in such a mechanismic framing, and secondly to what extent the empirical evidence is found to guide the scaling of experiments from *niche* to *regime*. One theory taking a socio-technical approach and catering to this question is the SNM approach. This theory posits that *niches* not only emerge but can and should be protected and managed from exogenous forces, particularly when deemed societally desirable and when facing major mismatches regarding existing infrastructure, regulation, user practices, etc. [29]. To this end, the SNM approach proposes several *niche-internal processes* suitable for better understanding what happens at the innovation site. According to them, expectations and visions should be articulated; and accordingly, they should be *robust* in that they are shared by multiple actors, *specific* in that they provide sufficient guidance, and be of *high quality* in that existing initiatives continuously substantiate the content of expectations. Next to this they suggest that there is a need for building broad and deep social networks. A social network should be *broad* - including a number of stakeholders able to articulate their voices and several relative outsiders to facilitate second-order learning. Furthermore, the network should be *deep* in that members can sufficiently mobilize resources. Finally, they also underline the importance of learning, which should take place at *multiple dimensions* (e.g. technical, market, culture, infrastructure, industry networks, regulations, and societal/environmental effects) and should be *reflexive* in a manner contributing to second-order learning.

These *niche*-internal processes however fall in a similar trap as the above pathways – the level of abstraction makes measurement and actionable research difficult. The SNM approach also shifts away from the mechanismic thinking, which characterizes the four pathways of Geels and Schot [24]. This means that the core qualities of SNM propositions carry descriptive qualities, which do not necessarily gel into a sequence of events as the four pathways do.

For these reasons, as can be seen below in our discussion, we enrich these *niche*-internal processes with a number of conditions. In this sense, the focus of these processes shifts away from solely focusing on how a *niche* can be protected from exogenous forces to how a *niche* can be scaled and by this gain the critical mass in *vertical* or *horizontal* terms [1] sufficient for protecting the innovation.

A further key point put forward by Schot & Geels [29], as well as Geels & Raven [30], is that *niche* development processes take place on two dimensions simultaneously: at the local scale with specific initiatives and at the global scale carrying implications for socio-technical paradigms overall. The local scale entails any type of initiative, which is a standalone experiment whilst the global scale entails the broader macro-level developments, which may help in connecting individual, local-scale initiatives in a multiscalar manner. However, the connection between these two levels also falls in the trap of treating causality as mere coincidence and correlation rather than viewing it through a generative lens. Transitions are said to unfold in consecutive steps along multiple pathways, however the specific conditions enabling them to unfold and the mechanisms underlying the processes are to-date not clear.

Hence, in our understanding, these two levels present themselves in the form of complexity in transitions and parallel the abstract-concrete dichotomy. In this sense, the conceptual assessment of global scale *niche* formation arguably carries a certain degree of abstraction. As is elucidated in the next section, the road to clarity is paved through concrete analytical steps taken by analyzing the local level.

3. Methodology

To better substantiate generative causality and mechanismic thinking in the socio-technical approach in the following sections, we present the outcome of a systematic literature review of academic studies of the community energy literature. In our review, we heuristically searched for instances where initiatives successfully scaled, and for conditions that may be sufficient or necessary for such scaling. We conceive of successful scaling if the study illustrates a community-scale energy-linked initiative's successful expansion or replication. Similarly, we consider a condition implied if the causal linkage between a given condition and the initiative's success is illustrated through empirical examples in the given article.

Such a review entails a systematic survey of literature based on preconceived criteria [45]. In the case of this review, studies eligible for inclusion entail cases of local- and small-scale energy-related initiatives that demonstrated a certain degree of scaling with potential conditions implied. Due to the broad definition we take based on the work of Blasch et al. [16] on energy communities, the initial search involved the search string *"community energy"* OR "energy community" AND scaling AND mechanism*, which only produced eight articles in Web of Science. Due to the limited results of this first search string, we opted for a second string with the ability to provide a wider catchment: *community AND energy transition AND innovation AND sustainable development*. Both strings involve articles published up until the end of 2020. The review process, including identification, screening and inclusion, is outlined in the Fig. 2 below.

The two search strings in total resulted in 155 articles. Of this, 85 were excluded upon reviewing their abstracts if their content was irrelevant to our inquiry. The remaining 70 articles were read in full length. Of these, 36 articles were identified, which a.) studied energy-linked initiatives and b.) implied generative causality and there-in conditions. In total, conditions are found in 133 occurrences throughout these articles. The empirical examples predominantly mirror the reality found in Western Europe. This is most-likely due to two factors: firstly, the institutionalization of energy communities is predominant here, and secondly academic focus of socio-technical thinking may be geographically biased in its treatment of cases and empirical inquiry. We consider it essential to reflexively admit to this as one of the main limitations of the results of this study.

These occurrences have been analyzed through a process of open-ended and axial coding, producing 23 empirically present conditions. Taking an inductive approach, a clear pattern emerges in how these conditions link to how initiatives function, how initiatives interact with each other, and finally, what context they are embedded in. Next to utilizing this inductive approach, we also assessed the conditions from the perspective of the *niche*-internal processes put forward by Schot and Geels [29], thereby implying a deductive approach too. The results of this mixed abductive approach are detailed in the Results section.

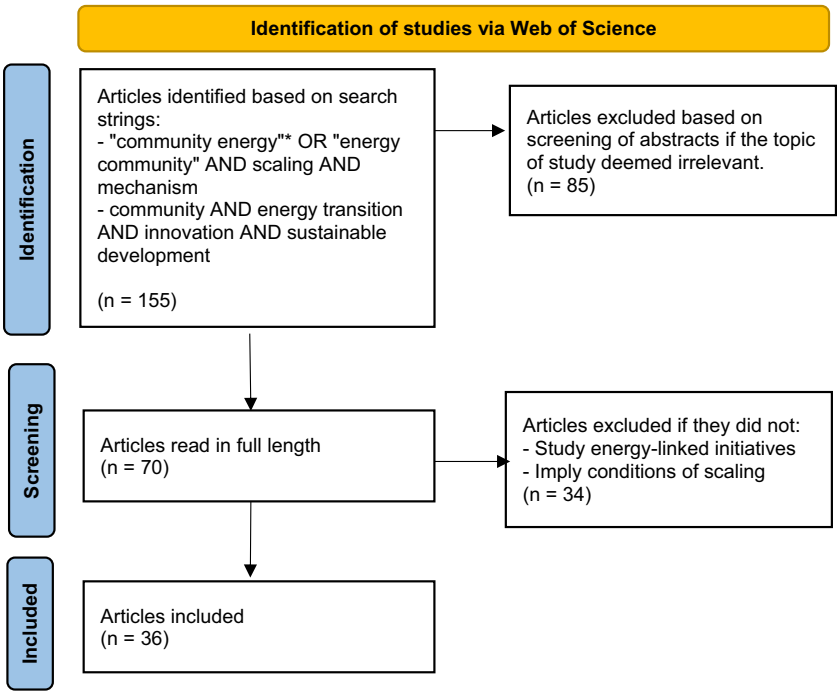

Fig. 2. Overview of Selection Process of Articles for Systematic Literature Review.

4. Results

4.1. Upon what conditions does scaling depend?

Several conditions emerge from our systematic literature review. The review results can be organized on the one hand by looking through the lens of the above *niche*-internal processes of the SNM approach and through the scale of the technological system at which the conditions can be found. The later categorization stems from the inductive approach taken to categorize the identified conditions. This categorization includes three dimensions: the functioning of communities, their networks and their broader contexts. The following section reviews conditions from the literature by illustrating them with examples and presents a matrix scheme constructed based on these two analytical entry points in Table 1.

At the level of how initiatives function, the following empirical examples support the *niche*-internal processes of the SNM approach. In terms of *articulating expectations and visions*, communication among actors has proven to be essential, particularly in the case of project coordinators running low-carbon urban initiatives in Copenhagen [1]. The *high quality* of such expectations is mirrored by the continuous substantiation of activities between these project coordinators. Setting a shared set of goals and doing so through joint visioning exercises has proven substantial in the Netherlands and the UK alike [46,47]. In establishing such a shared set of goals, leadership figures or groups have also been necessary, as seen from several examples in the UK [48,49]. These conditions primarily link to creating *robust* expectations and visions to the extent that they are all shared by multiple actors. In articulating expectations and visions, formalization processes have also taken a substantial role, once again, particularly in the Netherlands [47]. *Specificity* primarily links to the formalization processes of communities, as such framings potentially mean that the articulation of expectations and visions has to take place in a structured manner.

In terms of building broad networks within communities, Brown et al. [50] outline that engaging citizens and doing so in a simple manner has been vital in prosumer business models in the UK. In terms of *deep networks*, on the other hand, Seyfang and Haxeltine [2] highlight that the Transition Town movement in the UK relied heavily on its members'

Table 1
Summary of empirically present conditions of scaling linked to niche-internal processes of the SNM approach (with N count of occurrence of conditions in reviewed literature).

	Niche-internal processes in SNM (based on [29])		
	Articulation of expectations and visions	Building of broad and deep social networks	Learning processes at multiple dimensions
Functioning of initiatives	- Communication among actors (5) - Setting of a shared vision and set of goals (7) - Formalized organization (4) - Leadership roles within initiative (3)	- Lack of difficulty in engaging citizens (4) - Capacity for resource mobilization by community members (9)	- Space to experiment (3)
Interactions between initiatives		- External interaction of initiatives (7) - Presence of intermediaries (6) - Learning between initiatives (1) - Emergence and presence of networks of initiatives (6) - Transfer of knowledge / best-practices (3)	- Learning between initiatives (1) - Democratized distribution of knowledge (1) - Transfer of knowledge / best-practices (3)
External conditions	- Support for local innovation (18) - Frameworks for financial support (27) - Innovation focused policy (6) - Reliability of technology and policies (4)	- Local participatory process (5)	- Monitoring and evaluation frameworks with learning elements (3) - Context for entrepreneur-led experimentation (1) - Innovation focused policy (6)

capacity to mobilize resources. Finally, Pesch et al. [52] outline that experimental ownership structures have provided innovative forms of civic engagement – aspects that link to learning at *multiple dimensions* (e.g. market and regulatory aspects) as well as *reflexive learning* through highlighting alternative ownership structures.

At the scale of how initiatives interact, it becomes apparent from the review of the literature that the *articulation of expectations and visions* is not an aspect of SNM approach present at this scale. Nevertheless, aspects assessing *broad* and *deep* social networks are widely present as initiatives have engaged their wider community through external interactions in several energy communities in the UK, for example [46]. To this end, intermediary presence in the UK [51] and processes for communities to learn from each other in Friesland have also been key [53]. These activities all depend on the presence of networks at a variety of scales (local to global), which were also present among Frysian energy communities [47]. Finally, this knowledge transfer has been a critical aspect of activities in Copenhagen's energy and building sectors [1], which mirrors the social networks as vehicles for this transfer.

Regarding learning processes taking place at multiple dimensions, the type of learning (facilitated by intermediary actors) Warbroek et al. [53] outline is also valid for this condition. Next to this, a democratized distribution of knowledge has proven to be essential in Northern European grassroots energy communities [54]. The transfer of knowledge and best practices [1], similarly as in the case of broad and deep social networks, is a key aspect of learning processes, both in terms of *reflexive* learning processes and in terms of *multiple dimensions* at which learning takes place.

Turning to the external conditions of energy communities in terms of articulating expectations of visions, support for local innovation has been present in a living lab approach in the UK [55]. A living-lab approach can contribute to *the robust* and *high-quality articulation of expectations* and allow for the configuration of initiatives with multiple actors and the continuous substantiation of initiatives [56]. Parallel, supportive frameworks such as financing through grant funding in the UK [46] and innovation-focused policy through public-private cooperation in Germany [57] have also been critical in driving local-scale energy-linked initiatives, both of which arguably link to *specific* articulations of visions to the extent that they provide guidance to participating actors. Each of these elements is underlined by a perceived reliability of both technology and related policies [1] – arguably contributing to the *robust, high-quality,* and *specific* characteristics of articulated expectations and visions.

The sole example of *social networks* at this scale is the presence of local participatory processes, particularly when it comes to the distribution of benefits in North Frysian communities [58]. Such processes mirror the *breadth* of such networks rather than their *depth* to the extent that they allow for the sufficient mobilization of individuals looking to participate in an initiative.

Turning to the contextual factors, which support *learning processes at multiple dimensions*, monitoring frameworks have been a global phenomenon capable of supporting energy-related initiatives [60]. Next to this setting, a context for entrepreneur-led development has also been vital in driving initiatives linked to the urban energy transition in China [61]. Finally, innovation-focused policy [57] appears in this dimension, too, as innovation can be understood in broader terms linking to *reflexive thinking.*

Furthermore, what emerges from the review of the literature is that the various conditions have a varied spread in terms of occurrences. What immediately comes to the forefront is that supportive contextual conditions, such as those targeting local innovation (18) or the financial viability of initiatives (27), are commonly present. Next to this, in terms of what happens within initiatives, the most common conditions are linked to the capacity of members to mobilize resources (9) and a common set of goals (7). Finally, the manner in which initiatives open to the external (7) and the presence of intermediary actors (6) also signal that initiatives interact with each other throughout varying geographical scales.

5. Discussion

A number of takeaways emerge from the above results. These primarily link to the applicability of scaling pathways to a diverse set of empirical observations and potential additions to the SNM approach. Ultimately the question this section answers is: what are the added benefits of a mechanismic approach? Towards this end, the below discussion points to how the empirics of energy communities link to a broader understanding of *niche* development and addresses the four pathways of Schot and Geels [29] from the perspective of *niche* development.

5.1. What do the empirics tell us about the SNM approach?

At a first look, the above results link relatively well with the propositions of the SNM approach. Nevertheless, as mentioned, one gap remains, and a number of conditions may provide additions to the theory. First of all, the gap remaining points to the lacking empirical evidence on how and why *articulation of goals and visions* does not seemingly occur between initiatives. Considering the definition of expectations should be *robust* in that multiple actors share them, and of *high quality*, in that there is a condition for substantiating expectations based on existing initiatives [29], one would think that there would be empirical evidence of joint goal-setting between initiatives. This would also entail evidence of the institutionalization process in the *vertical* scaling terms of van Doren et al. [1]. This also carries practical considerations for those working in the community energy space, as such a harmonization – or the creation of a movement of initiatives rather than a hodgepodge of activities across initiatives – may also assist in the scaling of initiatives. Such aspects also speak to the propositions put forward by Schot & Geels [29] and Geels & Raven [30] in that *niche* development processes take place simultaneously at two dimensions – local and global. In the case of how initiatives interact and transfer knowledge, the connection between the local and global becomes clearer. Arguably community energy initiatives are present throughout the world, but the cumulative and aggregate impact is yet to emerge in empirical observation. Here future research may help in exploring common goal setting of initiatives at (supra-)national scales, the alignment of individual target setting across initiatives or the common lobbying efforts of energy communities in light of changing regulatory landscapes.

Secondly, the refinements to the SNM propositions primarily link to the potential limitations of socio-technical theory when studying energy communities, which are arguably dominated by community-led initiatives. These approaches explain large-scale structural changes but do not point directly towards what happens within initiatives. Conceptions of *niche*-internal processes still treat the *niche* as a *regime* that has not yet reached its full potential. For this reason, gaining a detailed understanding of what happens within community initiatives, and in particular, what architecture is needed and how the agency of actors can be unpacked, is to-date limited.

In line with this, the key conceptual contribution of this study is to articulate conditions as precursors of scaling processes and, in effect, elucidate the concept of scaling mechanisms as is outlined in Fig. 3.

As outlined below, a socio-technical entry point to analyzing scaling highlights further considerations, focusing on the interactions of society and technology. Accordingly, our analysis helps understand how conditions can be integrated into accounts of *niche* formation and growth in the socio-technical literature.

In line with this conceptualization of scaling mechanisms one should ask what the significance of this is for the SNM approach and socio-technical thinking at large. Mechanismic thinking may help to analytically better spell out various aspects of causality in socio-technical thinking. Considering such thinking is engaged with better understanding broad processes of *niche* formation and *regime* change it can be

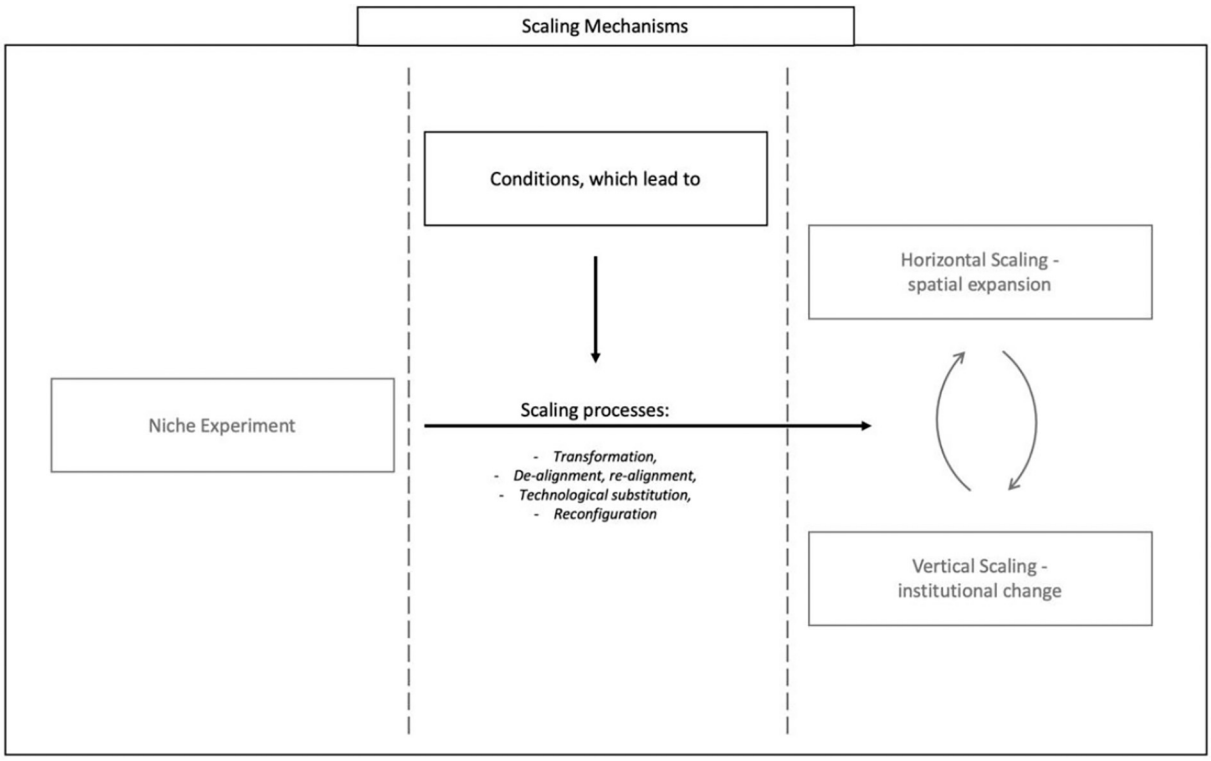

Fig. 3. Conceptualizing scaling mechanisms in SNM (source: Authors).

argued that these approaches are implicitly concerned with conditions, which may result in causal processes (such as A–>B). Fig. 3 unpacks these assumptions and conceptualizes the implied mechanisms in an explicit manner.

Accordingly, the conditions outlined in our analysis can neatly be fitted with-in these approaches. The pathways of Geels & Schot [24] can be considered as the processes resulting in scaling whilst the horizontal and vertical scaling observed by van Doren et al. [1] can be understood as the outcomes of these causal processes. Such a mechanismic conceptualization helps move past the type of 'black-box' understanding of processes found in many social science disciplines [44].

The empirics also suggest that conditions can focus on the definition of clear rules and procedures within community initiatives [62], how members should negotiate the distribution of financial benefits among themselves [58], and how all of this should link to the creation of a sense of co-ownership among participants [63]. These aspects highlight that a set of principles on how to architect a community-led *niche* may be needed for the SNM approach when it comes to discussions about the scaling of these initiatives. Theories on the management of common-pool resources and on how institutions should be architected towards this end [64,65] carry potential explanatory power here. Such literature is rich in providing empirical proof to how community members can best construct micro-scale institutions for the management of a common (pool natural) resource. This can be conjoined with discussion on polycentric governance – namely, the actual governance of a system composed of diverse initiatives in multiple domains and at multiple scales [31,66,67]. This type of thinking helps better understand what types of rules are best introduced at what scale and how various actors have the capacity to adjust to each other's actions for commonly agreed outcomes.

Thirdly, utilizing such theories and their ontological entry-points could resolve the critique put forward by Patterson et al. [19] on the socio-technical approach being predominantly applicable to *ex-post* evaluations and not *ex-ante* scenario analysis. It becomes clear that by adding several principles linked to the architecture and internal functioning of initiatives, the socio-technical approach can be enriched to also look forward in its analyses, arguably an approach needed when searching for avenues out of the climate crisis.

5.2. *What can scaling conditions tell us about scaling pathways and scaling outcomes?*

The above review of conditions suggests that the energy community space, to a certain extent, illustrates all of the four transition pathways put forward by Geels and Schot [24]. Their seminal piece on these pathways briefly hints at sequential or combined pathways. This conclusion is also in line with the conceptualization of Hedström & Yilkoski [44] on the combined and interrelated qualities of mechanisms in social sciences. The following section makes a case for exploring this type of complexity in more detail – and suggests that there is a value to do so in a reflexive manner. This means that from the local-scale perspective of the *niche* (as opposed to its global counterpart), the four pathways all take partial shape.

The variety of initiatives in the energy community space – and their growing diversity in terms of technologies used and actors involved [16] – suggests that a clear model and set of common denominators for scaling to date is missing. This is not to say that a successful *niche* should be a one-size-fits-all solution, but that *niche* development is still underway. Nevertheless, the climate crisis poses a type of *landscape* pressure, highlighting that elements of the *transformation* pathway may be present. The growth in the diversity of initiatives, as mentioned above, and the type of qualitative change outlined by Devine-Wright [17] in shifting from community energy to local energy, highlight that *regime* actors are altering their course. This shift to local energy entails a growing role for private investment, the framing of citizens as consumers and producers (prosumers), and a growing focus on financial viability and economic productivity of local-scale energy initiatives [17]. The formalization and professionalization of how energy communities are organized, as suggested by van der Schoor & Scholtens [47], and the growing space for experimentation highlight that *regime* actors are reacting to the

emergence of new types of clean energy communities.

The growing diversity of energy communities also underlines a growing transformative pressure on the *regime*. The accompanied growth in awareness of any type of *regime* actor about the looming risks attached to the climate crisis - be that a municipality concerned about extreme weather events or an electric utility worried about stranded assets – signals that the avalanche change needed for the *de-alignment / re-alignment* pathway may be in sight. The above diversion from community to local energy may also signal this shift in overall terms. For example, innovative, technologically intense communities, such as those involving virtual power plants and peer-to-peer trading schemes, arguably involve commercial actors as well as public authorities. The aforementioned diversification of energy communities, both in terms of technologies utilized and actors involved [16], points towards the readiness of *niches* to follow through with potential avalanche change.

The fact that, to date, such an avalanche change is lacking also sheds light on the political nature of architecting a climate *regime* capable of challenging vested interests and supporting small-scale action. This, in turn, questions to what extent the *technological change* pathway can be left up to only technological developments. What is visible is that grid composition in the European context is changing – it is growingly decentralized, democratized and digitalized [68]. However, the driver behind this process is not simply technological change. The conditions linking to any type of supportive framework, be that for local innovation [55], financial support [46], participatory processes [58], or support for entrepreneurial activities [61], all highlight that the need for appropriate governance of a given technology – in this case the community-based governance of renewable energy assets – may play a more significant role than the transition pathways suggest. Such a critique focused on the potential pitfalls of putting technology alone on a pedestal has been outlined in detail by Lawhon & Murphy [65] in the past. Takeaways from the energy community field related to each of the pathways are summarized in Table 2 below.

Table 2
Key take-aways from energy community literature in relation to the scaling pathways of Geels & Schot [24].

Pathways [24]	Key takeaway from examining energy community literature	Potential conditions enabling pathway
Transformation	*Regime* actors (such as public authorities) drive the institutionalization of local-scale energy transition by introducing formal legal status for initiatives and incorporating market logic into their day-to-day functioning.	- Local participatory processes - Frameworks for financial support - Formalized organization
De-alignment / Re-alignment	Authorities make institutional adjustments to enhance the uptake of renewable energy assets at the local- and community scale. This, in effect, creates diverse but relatively fixed models of local-scale energy initiatives without any type becoming a clear champion.	- Innovation focused policy - Support for local innovation
Technological change	Up-take of renewable energy assets visibly alters the composition of the grid (i.e. more decentralized, democratized, and digitized). This in itself opens up (potentially political) tensions between incumbent and *niche* actors on a technological basis.	- External interaction of initiatives - Reliability of technology and policies
Reconfiguration	The growing diversity of actors (from community-only to pluralist arrangements including public authorities and private companies) and types of technologies (move from only production to demand response, storage, and virtual trading) in the energy community field highlights gradual changes to the *regime* composition.	- Emergence and presence of networks of initiatives - Transfer of knowledge / best-practices - Learning between initiatives

Finally, elements of the *reconfiguration* pathway are clearly visible as, on the one hand, *regime* actors such as commercial parties are becoming growingly involved in the community energy space whilst public authorities are also taking a growingly proactive role as is outlined above. To illustrate, certain leading countries, such as Denmark or Germany, have in the past architected a regulatory environment (building primarily on Feed-in-Tariffs), which support citizens and cooperative groups interested in investing in production capacity [69]. Despite recent years' regulatory uncertainty [69], this shows that *regime* actors are taking steps to incorporate elements of what is still seen as a *niche* and step-by-step approach a *regime* constellation. Moreover, the diversifying trend of the types of technologies utilized – ranging from smart-metering, through demand response, to virtual power plants – also signals this gradual change and recomposition of the *regime* in technological terms [68].

In terms of scaling outcomes, *horizontal* outcomes are visible in the European setting to the extent that the number of initiatives has grown to at least 7700, servicing over 2 million citizens [70]. The overall investments made by such communities are estimated at app. 2.6 billion EUR [70]. Nevertheless, the growth in the number of initiatives does not explain whether there is a limit to how big an initiative can be in terms of the number of members or energy output in general. This is a gap to be explored by future research. In terms of *vertical* outcomes, once again, the emergence of supportive policy frameworks highlights that a specific institutionalization process is well underway. This is indicated by targets set by the EU, namely to set up at least one energy community in every municipality with more than 10,000 inhabitants by 2025 [71].

This is further mirrored by the European Union codifying what constitutes an energy community in its Clean Energy Package. The revised Renewable Energy Directive (EU) 2018/2001 sets the framework for *Renewable Energy Communities* covering renewable energy, and the revised Internal Electricity Market Directive (EU) 2019/944 introduces new roles and responsibilities for *Citizen Energy Communities* in the energy system covering all types of electricity. Based on our analysis above, we conclude that these two types of scaling will, in general, follow an iterative process, which in effect ties in with the mixed approach of the four pathways of Geels and Schot [24]. The growth or replication of an initiative is likely to open up societal and political discussions, which in effect can alter the institutional framework. This, in turn, can contribute to the emergence of further initiatives, overall strengthening *niche* formation [1,35].

6. Conclusion

The prime normative assumption this article takes is that the successful mitigation of the climate crisis requires a socio-technical system change. Building on this backdrop, it is also important to understand that systems by definition are made up of sub-systems, which can also function (and serve higher-level functions) in and among themselves [67,72]. This means that to a certain extent, broader structural changes such as those discussed in socio-technical and transitions literature require the examination and unpacking of the last building blocks within a system and the mechanisms, which may drive their emergence and scaling. To this end, the connection between the global and the local as well as the abstract and the concrete can be illuminated, primarily by looking at local- and small-scale innovations, such as energy communities. This article aimed to do this by answering a set of empirical and theoretical questions.

Firstly, the article aimed to outline theoretical accounts of *niche* development and connect these accounts to address scaling. This was done by applying mechanismic thinking to accounts of socio-technical and SNM literature. Particularly making connections with the four pathways of Geels & Schot [24] and the *horizontal* (i.e. spatial expansion and reproduction) and *vertical* (i.e. institutional embedding) scaling outcomes of van Doren et al. [1]. Such an approach has helped us better

explore the implied causality of socio-technical and SNM literature and by this make an analytical and conceptual contribution, which separates a body of literature into conditions, processes and outcomes. Overall, we hope this approach can benefit socio-technical thinking at large in concretizing the various aspects of causality and the given steps of (scaling) processes. Secondly, at the empirical level, the article applied the resulting framework to address what can be learned about the scaling of *niche* innovations, particularly by looking at the community energy literature.

Evidence throughout this literature suggests that the four pathways of Geels & Schot [24] – *transformation, de-alignment / re-alignment, technological substitution,* and *reconfiguration* – all carry assumptions of mechanismic thinking and are all present when looking at community energy literature through a global lens. Nevertheless, this only becomes explicitly apparent by viewing the pathways through the lens of generative causality [41] and in effect mechanismic thinking.

Such an approach highlights that potentially, the global-local parallels of *niche* development set out by Schot & Geels [29] and Geels & Raven [30] may take on different forms in different localities, nevertheless contributing to a global-scale system change in aggregate. However, the conceptual challenge such a framing poses lies in that the global remains abstract, whilst the local brings certain empirical clarity to studying transitions. Such a conclusion can fruitfully open opportunity for further research along a number of lines. Firstly, developing a deeper understanding of how multiscalarity in sustainability transitions [72] may manifest in the community energy field may highlight at what spatial scale what type of intervention is the most appropriate [73]. Secondly by better understanding what polycentric governance literature tells us about local-scale initiatives – and energy communities in particular – it may become possible to provide fuller accounts of governing the climate crisis at multiple scales and in multiple domains [31,66,67,74]. Next to this, critical assessments of the socio-technical literature – primarily targeting the politics of transitions [59] and questions surrounding governance should be a centerpiece of such assessments [19]. These outstanding issues remain despite this broad review of the literature.

These limitations highlight that a stronger coupling is needed between the local- and the global-scale in transition theory *in toto* and the SNM approach specifically. Conceptualizing system architecture and approaching it in a manner that sees the broadest system and its subunits through an overall holon structure can add analytical depth to this process. Here once again, polycentric governance thinking can be useful, particularly in that such a governance approach explains multi-scalar and cross-scalar dynamics between actors and within systems operating under an overarching set of rules [64,67,74,75]. Combining the SNM approach with polycentric governance thinking and particularly testing it empirically is a potential future avenue for research. Next to this, the empirical gap still remains from the above review: Why is there no evidence for the articulation of expectations and visions at the level of how communities interact and engage with each other? Furthermore, what are the practical implications of this when turning to the scaling of community energy initiatives?

These final questions carry practical and normative implications for those working in the community energy space. It is not only actors in energy communities but intermediaries as well as the European Federation – the only federation to date – of energy communities (REscoop), who could take this practical consideration under their wings. Assisting energy communities in translating their individual visions, sharing them across communities, and contributing more substantially towards defining a shared vision or charter (for example, the type REScoop has) can be a practical takeaway from this gap in the literature. Such sharing exercises are well underway between communities when it comes to exchanging best practices and learnings [67]. A further step on this path could be to expand on their vision statements to encompass concrete scaling goals and the potential pathways to reaching them.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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