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Virtual user communities contributing to upscaling innovations in transitions: The case of electric vehicles

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ABSTRACT

Users are increasingly acknowledged as important actors fostering those fundamental socio-technical innovations needed to achieve a sustainable society. In the literature, users have so far been portrayed mostly to play a role in early phases of technology formation. However, more recently users have become important players in the upscaling of various innovations. With the advent of new social media, users may interact effortlessly across large distances, exchange knowledge and so increase their contribution to upscaling. We investigate the new potential of virtual user communities. Conceptually, we build on recent insights from socio-technical transition studies to identify different upscaling dimensions. We conduct an internet ethnography of a large virtual community that formed around the Electric Vehicle (EV). Based on these data, we present virtual community characteristics and core mechanisms of participation in upscaling. We find that the community plays an important and distinctive role in fostering electric vehicle use.

1. Introduction

Widespread adoption of sustainable innovations helps to address persistent problems such as global climate change, local air and water pollution, and fossil fuel dependence. In the past few years, a number of these innovations have begun to move out of their early market niches and scale up into larger markets. However, this diffusion seems still focused on particular user segments. A main reason for the limited uptake is that, in contrast to conventional products, sustainable innovations represent systemic innovations, which require the building up of an entire support system of actors, networks, infrastructure and institutions, across geographical scales and contexts (Hekkert et al., 2007; Bergeke et al., 2008; Geels et al., 2017).

This systemic nature also implies that consumers or end-users often play a different role in sustainability-oriented products. In conventional products, users can be portrayed as passive evaluators (the market), judging the suitability of new offerings, in terms of serving established preferences and routinized use patterns. In the context of sustainability-oriented innovation processes, users have often been described as much more proactive contributors to the shape and meaning of new technologies (Truffer, 2003; Ornetzeder and Rohracher, 2006, 2013). Especially in the early development phases, their contributions could span the creation of new supply structures, the shaping of specific technology characteristics, the development of new use patterns and preferences of prospective users, and the shaping of the social image of specific use forms. Beyond these early formation phases, user communities typically encounter a number of inherent limitations (Truffer, 2003; Hossain, 2016). Strong ties to a specific local milieu often limit scaling

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into other user segments. A major challenge is also the lack of appropriate capabilities to scale up the business model from arm's length interactions in early community-based operations to managing rapidly scaling companies. However, some recent studies have stressed that user communities can play an important role in maturing innovation systems (Dewald and Truffer, 2011, 2012; Kanger and Schot, 2016; Randelli and Rocchi, 2017), as they mobilize support for the innovation, align different actors, and embed the innovation in their daily practices.

In addition, the advent of the internet and new social media facilitates interaction between like-minded pioneer users all over the world with no time delay. This holds promise to overcome some of the essential limitations that traditional user communities encounter and enables the leveraging of user-generated resources in the innovation process much more quickly and at a larger scale. The emergence of virtual user communities therefore is interesting as it potentially enhances the role of users in the innovation process (Grabher et al., 2008; Grabher and Ibert, 2013; Hyysalo et al., 2013a; Hyysalo et al., 2018).

To assess the role that virtual user communities can potentially play in the upscaling of innovations requires a broad understanding of how new socio-technical systems emerge and mature. This has been the main occupation of the field of sustainability transitions studies (Markard et al., 2012; Bergek et al., 2015; Geels et al., 2017). The present paper aims to identify potential roles that virtual user communities can play in the upscaling of systemic innovation. Drawing on an extensive case study, we identify the agency and core mechanisms of change enacted by a virtual community, in the context of an overall system perspective on socio-technical innovations. We describe virtual community characteristics and specify detailed mechanisms of user contributions to three core development dimensions of socio-technical transitions: system build-up, geographical circulation, and reconfiguration of incumbent socio-technical regimes.

The case study focuses on a virtual user community that formed for Electric Vehicles (EV) and we conduct an “internet ethnography” (Garcia et al., 2009; Kozinets, 2015). Threads from the Tesla Motors Club online forum are analyzed. Discussions on this forum are not limited to Tesla cars but include a broad range of general EV-related topics. The focus of this study is on EV users from The Netherlands. This is a suitable case as the Netherlands have seen an increasing adoption of EV beyond initial niche experiments (NEA, 2018). Importantly, the studied interactions on the Tesla Motors Club forum are not exclusively between these Dutch users, but also between Dutch users and users of other countries.

The paper is structured as follows. In Section 2, we discuss relevant literature on sustainability transitions and (virtual) user communities. Section 3 describes the methodology. Section 4 presents the results. Section 5 discusses the findings critically, lines out avenues for further research and concludes.

2. Conceptual starting points for assessing the role of virtual communities

In order to identify potential contributions that virtual communities may make to the upscaling of innovation in transitions, we have to first specify the vantage point from where such an assessment can be undertaken. Drawing on a blend of Science and Technology Studies (STS) and evolutionary and institutional thinking, the sustainability transitions field has extensively studied the development of systemic innovations (Markard et al., 2012). We draw on recent insights of the sustainability transitions field in order to derive basic upscaling dimensions that should be considered. Studies in the sustainability transition field also pay increasing attention to users (Truffer, 2003; Schot et al., 2016). Accordingly, we review the literature on users in transitions following the identified upscaling dimensions. We then draw on studies into virtual user communities, to explore how the virtual aspect of the community could potentially change user contributions. This provides us with a starting approach for analyzing user contributions from our case study.

2.1. A socio-technical systems perspective on user communities in upscaling

The sustainability transitions literature has provided a large number of detailed explanations about the success conditions of early formation processes of sustainable technologies. The analysis of rapidly scaling innovations has started more recently, on par with the rapid growth of a number of renewable energy technologies such as wind and solar PV. Unlike conventional diffusion processes observed for discrete products, exhaustively captured by the classical diffusion literature (Rogers, 2010), the upscaling of systemic innovations needs to take account of an entire socio-technical system of actors, supporting infrastructures and institutions across geographical contexts. Institutions are defined here as “sets of common habits, routines, established practices, rules, or laws that regulate the relations and interactions between individuals and groups” (Edquist and Johnson, 1997, p. 46). Regarding the analysis and assessment of growing and maturing socio-technical systems, the TIS literature (Technological Innovation System) has been most explicit within the transitions tradition (Hekkert et al., 2007; Bergek et al., 2008; Suurs and Hekkert, 2009). The TIS approach posits that successful innovation processes are characterized by balanced *system-building*, that can be captured in a number of core processes or functions: the generation of new knowledge, entrepreneurial experimentation, guidance of search, the mobilization of different kinds of resources, the formation of appropriate markets and the creation of legitimacy for the technology. The MLP (Multi-Level Perspective) on transitions also describes endogenous processes fostering system-building, including learning economies, the development of complementary infrastructures and the development of positive cultural discourses (Geels et al., 2017). When developments in the different processes are well-aligned, they result in patterns of cumulative causation or “momentum” driving upscaling (Hillman et al., 2008; Suurs and Hekkert, 2009; Geels et al., 2017).

User contributions to *system-building* in upscaling have been described in most detail for the specific process of market formation. Dewald and Truffer (2011, 2012), for instance, have studied how civic cooperatives were instrumental in the build-up of the German PV sector in the 1990s and 2000s. They challenge a linear conception of market development with an account of interacting

complementary processes (knowledge generation, legitimacy creation, resource mobilization) in various market segments. Randelli and Rocchi (2017) find, for the case of organic food in Italy, that users can provide contributions to all system-building processes identified in the TIS literature. Zooming further out, Schot et al. (2016) provide a framework of the changing roles of users during the entire “life cycle” of a technology. In the upscaling phase, users contribute to system-building by acting as user-intermediaries, which help aligning the various elements of socio-technical systems. They also act as user-consumers, embedding the technology in daily practices.

The limitations of system-building by users have received more attention in the literature on innovation by grassroots communities – idealistic user communities working on all sorts of sustainable alternatives (Smith et al., 2014; Seyfang et al., 2014; Hossain, 2016). Hossain (2016) presents a long list of challenges that grassroots communities can face, ranging from network building, to capabilities and the ability to attract financial resources. These are also reflected in the work of Truffer (2003) on user-initiated car sharing initiatives in Switzerland. Here, the user-based organizational set-ups were increasingly challenged in the upscaling phase. Some members voiced strong preference for continuing as small cooperatives instead of accepting a more market oriented organizational form and growth strategy. Hence, there also seem to exist some inherent restraints to the contributions users can make to system-building.

In a sustainability transitions perspective, upscaling of new socio-technical systems does not occur in a void, but in interaction with various context structures (Bergek et al., 2015; Geels et al., 2017). We consider the geographical context in which the innovation develops and the prevailing socio-technical regime in a sector as particularly important in relation to user contributions. Regarding geographical context, scholars have noted how innovations are often deeply rooted in specific local environments (Coenen et al., 2012; Hansen and Coenen, 2015; Temenos et al., 2017). A common geographical upscaling pattern described in the sustainability transitions literature consists of the development of aggregated forms of knowledge that are then circulated and recontextualized to fit different circumstances (Geels and Deuten, 2006; Geels and Johnson, 2018). Sengers and Raven (2015) describe how in the diffusion of Bus Rapid Transit global and local processes are intrinsically connected. Place-specific factors influence the local implementation of the innovation, as well as the overall global upscaling journey. In the case of electric vehicles, Bakker et al. (2015) show the importance of connections between localized niches to come to charging standards. These studies point to processes of *geographical circulation* as part of upscaling in systemic innovation. These are not linear processes of abstraction, but iterative processes in which the innovation is continuously decontextualized and recontextualized in different localities.¹

The role of users in geographical circulation in upscaling is often described as limited. User collectives have developed remarkable and successful sustainable alternatives in a variety of domains such as renewable energy and sustainable buildings (Ornetzeder and Rohracher, 2006; Hargreaves et al., 2013). Yet the socio-technical configurations they develop are often tailored to a specific geographical context and rooted in local communities (Smith et al., 2014; Hossain, 2016; de Vries et al., 2016). Some organizations have emerged that aim at connecting local user initiatives, such as the Transitions Town Network (Feola and Butt, 2017). However, such organizations are often lacking and, those that exist typically face difficulties in aggregating highly contextualized forms of user knowledge (Ruggiero et al., 2018).

The second form of context to which the innovation emerges is the socio-technical regime, the current set of rules guiding actor behaviour in a sector. Apart from endogenous system growth, upscaling also entails a certain degree of reconfiguration of existing socio-technical regimes (Geels et al., 2017; Geels and Johnson, 2018; Naber et al., 2017). In the phase of upscaling, the innovation may get confronted with barriers to growth that relate to the current dominant system. These regime barriers include vested interests or institutions that are not compatible with the innovation. For example, the status users attach to personal car ownership can hamper the transition to car-sharing (Truffer, 2003). Accordingly, for the innovation to upscale, changes in institutions are required (Fuenfschilling and Truffer, 2016). Smith and Raven (2012) identify two mechanisms of interactions between innovations in niches and regimes: “fit-and-conform” in which the niche innovation aims to become competitive within the existing environment and “stretch-and-transform”, in which it fundamentally alters the regime. Geels and Johnson (2018) find a temporal sequence in these patterns. They describe a change from “regime-to-niche” towards “niche-to-regime” influences over time in their case of biomass diffusion in Austria. In later stages of upscaling, a powerful lobby was initiated, and actors related to the innovation were increasingly able to reconfigure the existing socio-technical regime.

Some instances of users contributing to reconfiguration of existing socio-technical regimes have been described, but there also seem considerable challenges for users to contribute to lasting regime change. Dewald and Truffer (2011, 2012) show for the case of photovoltaics in Germany how citizen groups provided initial legitimation and continuing political support for the German feed-in tariff, the installation of which further accelerated PV diffusion. Kanger and Schot (2016) describe for the case of the fossil fuel car how users set up powerful user organizations lobbying for the interests of automobile drivers in an initially hostile environment. In the literature on grassroots communities, barriers to users’ contribution to regime change are emphasized. These user communities often develop in relative isolation from existing socio-technical regimes, hence lacking the connections and resources to meaningfully change them (Seyfang and Smith, 2007; Hossain, 2016). If user communities aim at diffusing their projects into the mainstream, they face challenges related to watering down sustainability ideals and losing control (Seyfang and Longhurst, 2016).

All told, we identified three major domains in which users could contribute to the growth and maturation of socio-technical

¹ The pattern of circulation/decontextualization/recontextualization as employed in the transition literature is one among different possible patterns of geographical scaling. It assumes the existence of a global or “cosmopolitan” level at which knowledge is aggregated (Geels and Johnson, 2018). Particularly in the Actor Network Theory literature, employing a flat ontology, other patterns are described. For example, Latour (1993) describes in his work on Pasteur how knowledge traveled by recreating the conditions of Pasteur’s lab in many other sites.

systems: providing support and resources for system build-up, enabling the geographical circulation of the innovation, and re-configuring the existing socio-technical regime to reduce barriers to development. In the following we want to elaborate the way in which virtual communities particularly can contribute in these areas.

2.2. The new potential of virtual user communities

The rise of virtual communities seems to increase, or at least alter, the role of users in upscaling (Grabher and Ibert, 2013; Hyysalo et al., 2018). Virtual user communities are communities of geographically dispersed users that share an interest in a certain technology and use the internet as primary mode of interaction (Hyysalo et al., 2017). Here we review studies that have taken an in-depth look at innovation in virtual user communities, following the main domains of upscaling as described above: *system-building*, *geographical circulation* and *reconfiguration of the current socio-technical regime*.

The virtual community seems to allow for some new roles in *system-building* during upscaling. One of the few cases described of virtual communities in sustainability transitions is that of heat pump forums in Finland (Hyysalo et al., 2013a; Hyysalo et al., 2018). Hyysalo et al. (2018) show that during upscaling virtual community users provide information about the workings of the technology, not available from other market actors, and that they help articulating market demand. The provision of information reduces uncertainty, which is important in market expansion beyond environmental enthusiasts. In contrast to accounts of strongly embedded and homogenous local user groups working on innovation, more heterogeneity is reported for virtual communities (Füller et al., 2007; Hyysalo et al., 2013a; Rullani and Haefliger, 2013). Virtual user communities have a core of highly-skilled expert users that engage most heavily. Yet, there is also an influential peripheral group, able to steer the direction of innovation. Then there is a large group of “lurkers” who do not actively contribute but are still aware of developments and also share these in their own networks (Takahashi et al., 2003; Sun et al., 2014). Füller et al. (2007) discuss how the variety of users builds upon each other’s contribution in a constant improvising process of trial and error. This resembles the process of “bricolage”, defined by Baker and Nelson, (2005, p. 333) as “making do by applying combinations of the resources at hand to new problems and opportunities”. In sum, user communities seem to contribute to system-building by developing knowledge among a variety of participants.

The virtual nature of the community is expected to change the role of users in the *geographical circulation* of the innovation during upscaling (Grabher and Ibert, 2013). As described above, traditionally many user collectives have been locally organized, with their embeddedness becoming a barrier in the upscaling process. The virtual community can here form a bridge between localities, for example by connecting geographically dispersed users and serving as a centralized knowledge archive (Grabher and Ibert, 2013). The other way around, the virtual community is also helpful for recontextualizing innovations in local environments. Users here build on the generalized solutions of others, and tailor them to their specific contexts of use (Hyysalo et al., 2017).

Patterns of geographical circulation and the role of virtual communities herein likely differ across innovation types. Hyysalo et al. (2018) describe an innovation, heat pumps, that is stationary and for which local contexts and national institutions such as energy regulations are highly important. As a reflection of this, in the virtual communities they study there is a strong focus on local and national issues, such as changes that can be made to heat pumps to make them work in the cold Finnish climate. In contrast, the electric vehicles central to this study are also used across countries. Consequently, it can be expected that more international issues are addressed on the forums. There might also be a higher prevalence of interactions between online users from different countries.

It is unclear as to what extent the virtual nature of the community might influence the ability of users to engage in *reconfiguration of the current socio-technical regime*. Hyysalo et al. (2018) observe that forum users discuss heat pumps in “neutral” economic and technological terms, stressing their conformation to the existing regime. An important point to note, though, is that virtual communities are often “hybrid” communities encompassing both lay users and professional actors (Grabher and Ibert, 2013). The occupational background of forum participants is not directly shown, which reduces formal status and power differences that normally influence conversations. Grabher and Ibert (2013) give the example of doctors and patients interacting on more equal terms on a drug development internet forum than they would do in a traditional conference setting. These more equal interactions between different actor types may also facilitate discussion between users and actors associated with the socio-technical regime, such as companies or governments.

To sum up, although many conventional grassroots user communities seem to struggle in upscaling, there are clear indications that users can play important roles in the upscaling phase of transitions. Specifically, the rise of virtual communities seems to increase the potential role that users can play in the upscaling phase. We therefore aim at describing the composition of types of actors that participate in these virtual communities. Based on this, we will empirically investigate how virtual user groups contribute to the core domains of system maturation that we derived from the transition studies review, namely their contribution to internal *system-building*, the facilitation of *geographical circulation*, and their impact on *reconfiguring existing socio-technical regimes*.

3. Methodology

In line with our research aims, we considered the systemic innovation of the electric vehicle. The electric vehicle (EV) contributes to environmental sustainability by reducing greenhouse gas emissions as well as local pollution. Its widespread adoption involves a transition of infrastructures, markets and institutions (Van Bree et al., 2010; Aguirre et al., 2012). The focus of this study is on EV users from The Netherlands. The studied interactions are not only between Dutch users, but sometimes also between Dutch users and users of other countries. The Netherlands is a frontrunner country in EVs. Both qualitative and quantitative indicators demonstrate that the EV in The Netherlands has grown beyond the “start-up phase” characterized by precarious and dispersed niche experiments. Qualitatively, multiple mass production models are available and European standardization processes are ongoing (Bakker et al.,

2015). Quantitatively, there is a large growth in Plug-in Hybrid Electric Vehicles (PHEVs, which can also run partly on gasoline) and also the number of regular EVs has increased considerably. The total number of EVs in The Netherlands grew from 7410 (of which 4348 PHEVs) in December 2012, to 119,332 (of which 98,217 PHEVs) in December 2017 (NEA, 2014, 2018). The average market share was 5.6% over the 2013–2017 period (IEA et al., 2018).

The main data source of this study are internet forum threads. The forum analyzed is the Tesla Motors Club forum (www.teslamotorsclub.com). Virtual communities are very fuzzy social phenomena, with fluid boundaries (Grabher and Ibert, 2013). They often span multiple internet forums, as well as other mediums such as Facebook and Twitter. We thus had to make a very careful decision for the medium to analyze (see Kozinets, 2015, p.168). Eventually, the Tesla Motors Club forum was chosen for three reasons. First, it is a large forum with ample daily activity as well as international reach. At the start of the analysis in June 2016, it counted approximately 60,000 threads, 1.5 million messages and 40,000 members (TMC, 2016). Its international reach is exemplified by subsections dedicated to EV developments in specific (groups) of countries, in various languages. Second, it is a well-established forum, enabling longitudinal analysis. It has been around since 2006 and has attracted substantial numbers of members for years. This makes it preferable over the alternative to forum threads of e.g. EV Facebook groups, which have mostly been initiated much more recently. Finally, in terms of content, it is not strictly limited to a discussion of Tesla cars. Topics cover all kinds of EV developments, charging infrastructure and wider discussions about sustainability. There is no comprehensive overview of forum user demographics. From names, introduction discussions and pictures it is clear that the users are overwhelmingly male. Importantly for our analysis, the geographic location of almost all users is known at the city level.

To get some indication of the participation of EV users in internet forums, we included two questions on forum use in a general EV survey that was sent out to members of an organization concerned with placing public charging points for EV owners in April and May 2015 (see Peters et al., 2018, for details on the survey). Out of the 251 respondents, 67% had been active as a reader, 28% had been active as a writer on an internet forum about electric vehicles. Particularly the reading of internet forums can hence be regarded as an activity that is common among electric vehicle owners in The Netherlands.

The second data source for this study were 13 interviews with forum participants that were conducted at the end of 2017 and beginning of 2018. The interviewees were selected partly based on the forum analysis. They were sampled in order to obtain diversity in participation levels as well as role fulfilled on the forum (e.g. a user that devotes much time at helping beginner EV drivers, a user that also sells charging points). As a third data source we drew on sector reports and scientific articles about EV in The Netherlands (e.g. the monthly reports released by the Netherlands Enterprise Agency). For the in-depth analysis of the internet forums we conducted a virtual ethnography, tracing back the role of the online community in upscaling (Garcia et al., 2009). Compared to traditional ethnography, the internet forum as research site has the advantage that it is both archival and showing live communication (Kozinets, 2015). It is also well-annotated, as the exact date and time of each post, as well as the location of the poster, are noted. This was particularly helpful for our reconstruction of user activity in time and space (Yin, 2013). It should be noted that the majority of forum visitors are not actively posting on the forum, but merely “lurking” (Sun et al., 2014). However, these visitors do follow the activity on the forum.

Considering the vast size of the forum, a pre-analysis was completed to identify those threads that were most related to the development and use of EVs and had a substantial number of replies and views, and involved Dutch EV users. In certain cases, threads are short with only a few replies to the thread starter, but they can also consist of hundreds of pages and remain active for multiple years. To identify relevant threads, we went through the headers and first posts of all threads active in the subsection “Belgium and The Netherlands (Dutch)” between January and May 2016 (N = 360) and the most replied threads in this section since its conception in 2012 (N = 50). This forum section contains posts from Dutch users, as well as from users in the Dutch-speaking part of Belgium. Before 2012, there was no Dutch subsection and Dutch EV users replied in international threads. To find these we selected some “dinosaur” Dutch contributors (active since the first Tesla model Roadster came out around 2009), and went through the headers and first posts of the threads they contributed to. Based on this pre-analysis N = 26 threads were selected for in-depth analysis. We categorized these into 10 broad themes related to upscaling, such as *charging points* and *technical issues*. We then went back to the titles and first post of the 410 first selected threads to see if they fitted into one of these themes. They did, which assured us that the 26 selected threads for in-depth analysis provided an apt overview of the breadth of upscaling topics discussed on the forum.

We then proceeded with the in-depth analysis using NVivo 11. The analysis followed a constant iterative process between data and theory. We first used an open coding strategy to be able to get an overview of the topics discussed in the forum threads. Per group of related threads we also made summaries and notes about the topics discussed, to get a better grasp of the user’s activity in the often long threads. Here we also made our initial links with theory, using the meso-level upscaling processes of *system-building*, *geographical circulation* and *adaptation of the existing socio-technical system* as sensitizing concepts. With these concepts in hand we went back to the data, to see to what extent users were active in these processes. We interpreted the data in terms of the content of the contribution of users and the specific strategies they employed. In this way we could identify specific mechanisms such as *institution building in practice* and *quasi-effortless knowledge production and sharing*, linked to the meso-level processes of upscaling. Eventually, we identified seven core mechanisms through which the user community contributes to the upscaling processes. Apart from these core mechanisms, we also observed specific (changing) characteristics of the virtual community actor. Because of their importance for understanding the role of the virtual community, we decided to include them prior to the mechanisms in the results section.

The interviews were used as a source of data triangulation. The round of interviewing occurred after the main analysis of the forums. The interviews were coded using the same codes as in the forum analyses, with some additions. In general, the findings from the forum analysis were confirmed, but small adaptations were made. The interviews also allowed for the inclusion of additional examples related to the emerging concepts. They allowed for greater exploration of the community aspect of the forum and the relationships between online and offline activities, which are harder to understand from the forum analysis alone. We also used

“member checking” (Lincoln and Guba, 1985) and asked two forum participants to reflect on our findings and concepts, in order to increase the reliability of this research. Finally, the sector reports and scientific articles were used throughout the research to assist in understanding the context of the forum discussions, as well as to track the general developments in the scaling of EV in The Netherlands.

4. Results

4.1. Virtual community characteristics

Before elaborating on the core mechanisms by which the virtual community participates in upscaling, we will first describe some key characteristics of the virtual community we studied. In the community, we observed a relatively large *participant diversity*, albeit on some specific dimensions. We also observed a strong *sense of community*.

In terms of socio-demographic background of the user participants, there is little diversity. The *introduce yourself* thread gives an impression of the demographics of the virtual community. The participants are predominantly white males. The average age is around 40 years old. Virtual community members are often entrepreneurs or small business owners. Of the users who share their profession, about half work in the IT sector. Diversity was particularly marked in terms of the “professionalism” of participants. On one end of the spectrum “pure” users can be placed, on the other end professional actors. Of the latter actors, let us first consider Tesla. In our analyzed threads, it was very rare that a Tesla employee would publicly intervene in the discussion. However, there is ample evidence that employees of Tesla both read the forum and act upon the observed discussion. For example, a user posts on the forum for help with some problem with his car and is then phoned by the Tesla Service Center to make an appointment to have his car checked. Charging point companies are active in similar ways. The virtual user community is particularly useful for Tesla and other system actors, because it discusses not only systematic barriers but also possible solutions.

Policy-makers are surprisingly absent from the forums, as we did not find any instance of a policy-maker intervening in the discussions. During the interviews we spoke to a policy consultant who reads the forums to inform himself about charging locations as well as barriers related to charging. Officially, commercial activity on the forum is not allowed. However, there are various users who take up a “hybrid” role. Apart from being a Tesla user, they also have a side business that sells, for example, charging points or car accessories. Oftentimes, these hybrid roles emerge from the forum: users discuss upscaling barriers, which are then perceived by some as entrepreneurial opportunities. For example, a user who already has online shops becomes aware of difficulties with the delivery of charging cables. He then organizes an initial group purchase via the forum, and later opens a charging point shop. He does not advertise on the forum, but community members know how to find him. Here, the forum stimulates users to become system-builders in the upscaling process.

A second dimension of diversity concerns the knowledge levels regarding the EV. Especially the earlier threads, such as the one about the international standardization of charging plugs, contain long, high-level technical discussions. Here many users with expert technical knowledge participate. Users also become more knowledgeable about EV technology while reading the forum. During the process of upscaling, however, the forum is joined by more users with lower levels of technological and topical knowledge of EVs. They also have more mainstream expectations of an EV. Experienced community members however continue to be active and provide knowledge to newcomers.

Among the online users, we find a strong sense of community, which at times leads to the organization of “real world” events. Yet, the community aspect is limited to a specific group of forum members. Online users can easily opt out of community activities and use the forum as a functional source of knowledge only. This even holds for members with a high number of posts. The sense of community on the forum centers around shared feelings about pioneering and experienced barriers. Users feel part of a group of pioneers who take part in a development that will have major influence on society. Users perform joint activities such as road trips and enthusiastically report about them on the forum and blogs. They make fun of fossil fuel cars and occasionally call them “dino-juice-burners”. Not everything is rosy, however. A large share of the threads in the virtual community starts with some barrier experienced by a user. In these cases, the community is like a support group for EV drivers. Users try to help each other in finding solutions for experienced problems, online and offline. For example, a relative of a forum member drops someone off at an airport in the South of the Netherlands. The charging poles there are out of service and he risks running out of range. A message is sent to forum members. A member who lives nearby replies and the person can charge at his house and gets a coffee. Such actions are illustrative of the community spirit found amongst core forum members.

4.2. Building the system

Influenced by its distinctive actor characteristics the virtual user community takes some form of action. Seven core mechanisms through which the virtual user community participates in the upscaling process have been identified in the empirical analysis. Three of these are linked to system-building: quasi-effortless knowledge production & sharing, infrastructural bricolage and institution building in practice.

4.2.1. Quasi-effortless knowledge production & sharing

An important part of the contribution of the virtual community to upscaling concerns knowledge. In the knowledge development by the virtual community during upscaling we observe two developments. First, digital technology has made it very easy to make minor changes to products or to monitor their performance under various circumstances. Examples of such small user actions are

Table 1

User activity in knowledge development presented on the forum, ranked in terms of dedicated effort spent.

User effort level	Example
1. Day-to-day driving	<i>"I have been to Amsterdam today and noticed quite a strong wind at 5.00 AM. I saw an energy use of 255Wh/km at 120 km/h at that time. As soon as I left Zeeland energy use lowered to 230wh/km. From Dordrecht on I changed my driving speed to 110 km/h and energy use dropped to 206Wh/km"</i>
2. Trial-and-error	<i>"As I was interested, I drove with 80 km/h behind a lorry on the A12 The Hague-Gouda yesterday. I reached an average of 140Wh/km"</i>
3. Systematic analysis	<i>"Yesterday I made an 'energy use drive' Amersfoort-Harderwijk-Amersfoort; this is what I found for 100 and 120 km/h." The user then presents a detailed table with energy use against speed and possibly range influencing factors such as: temperature, air-conditioning on/off, tire pressure, driving mode, preheating temperature</i>
4. Joint testing events	<i>Seven users come together to compare the energy use of their Tesla and identify various range influencing factors such as tires and heating. Results are presented in graphs and tables on the forum</i>
5. Tool and model building	<i>Application developed by users to extract data from the Tesla to other devices and construct for example graphs and models of energy use and speed</i>

changing the settings of the vehicle and see what happens to its electricity use. Second, the internet forum facilitates sharing these small changes and their effects with the wider user community. All in all, the effort of performing and sharing an activity that makes a meaningful contribution to the process of upscaling is drastically lowered. This can be illustrated with the example of energy use. Given the limited range of the electric vehicle, a main issue among users is finding out factors that influence their energy use, as well as ways to improve their vehicle's range. Table 1 lists a number of activities the users of the virtual community have conducted in this regard, ordered in terms of the dedicated effort they put in: Developing knowledge during day-to-day driving, by trial and error during driving, by performing a systemic analysis during driving, by participating in joint testing events, and by building tools and models. This list illustrates the relative ease with which knowledge production and sharing in the online community can occur. Action 4 and 5, respectively a joint testing session and the building of a model, still require dedicated time and effort. However, the first two actions, in which people drive around for trips they would make anyway and make some notes about the performance of their EV, can hardly be classified as dedicated innovative user actions. These are simple actions that users conduct during their normal routines without much additional effort. Because the results of these actions are now so easily shared and discussed within the community at large, they still affect the emerging driving practices of other users, and consequently the upscaling process.

The forum users refer to the knowledge they develop as "true" or "real" knowledge, because it is based on experience. They see it as a middle way between the, according to them, optimistic knowledge provided by EV and charging point companies, and the arguably negative stories about EVs that appear in the press. This holds particularly for more controversial issues, such as the range of the EV in different circumstances, and technical problems of the Tesla.

Three dominant types of knowledge sharing in the virtual community can be distinguished. Firstly, there is request-based knowledge sharing. This is by far the most common form of knowledge sharing on the forum. A user has a specific problem with their electric vehicle and asks the community for help. For example:

*"Someone experience with charging in Spain? Can it be compared to France? I see you can get there easily with super-chargers, but charging locally would also be nice"*²

Users from the community then answer based on their own experience. Second, there is spontaneous sharing of knowledge that a user has developed with regard to EVs. Third, there is synthesizing knowledge sharing. Users then try to create a systematic overview of the knowledge produced by other users on the forum.

The dominance of request-based knowledge sharing exemplifies some of the limitations of virtual communities. At least two obstacles complicate the process of knowledge sharing and learning. First, the forum threads are often very long, due to all the requests by individual users. Less active users complain on multiple occasions that they have had to read many pages before finding appropriate answers. Even creating a synthesis of knowledge on a certain topic is not always helpful, because users have to find it first. For overviews of knowledge, users therefore resort to using separate blogs or websites, for example with a user's guide for new Tesla owners. Second, the nature of the knowledge users share is often very context-specific as well as subjective. On the one hand, this is an asset because it is often practical and experiential knowledge (for instance about the performance of a charger in a specific place with a certain charging card), that non-users cannot easily develop. On the other hand, the practical and experiential nature of the knowledge also makes it hard to decontextualize and aggregate the knowledge developed on the forum.

4.2.2. Infrastructural bricolage

The virtual user community does not engage in large-scale, coordinated efforts to build charging infrastructure. Yet, in their day-to-day lives and with whatever resource they have available, the members of the virtual community try to improve the material elements of the EV system. First, users engage in day-to-day charge point lobbying. If they go to a certain place, they approach hotels or other organizations beforehand with requests about charging facilities. On the internet forum they discuss strategies for convincing companies to place chargers. At a certain point, they have a list of organizations approached for charging facilities. However, these

² The forum is accessible for everyone with an internet connection and forms a public space. We did not mention any online names used when quoting. Quotes are translated (by the authors). Additionally, small modifications are made to forum quotes of users that we did not also interview.

actions are largely ad-hoc and targeted at companies that users encounter at some point in their daily life, and not a structured infrastructure-building effort.

Second, the virtual community has a dedicated “plug club” thread in which they share plugs that are needed when going abroad. Virtual community members in this way do not solve the problem of different charging standards in Europe, but work around this problem by carrying an array of plugs on holidays and sharing them with each other. Third, users help each other with the installation of home chargers. These are still not off-the-shelf products. In particular, they require a specific installation and configuration in the house, often together with other devices such as a smart meter. On the internet forum, the virtual community members discuss possible configurations. Users with greater expertise in electricity comment on the safety and feasibility of proposed solutions. As a sign of the community spirit on the forum, the users offer each other to try out their charging point (configurations) before they get their car delivered, enabling them to start driving without hick-ups straightaway.

4.2.3. Institution-building in practice

As part of the upscaling process, institutions are created to enable coordination between the actors engaged with the systemic innovation. The virtual user community contributes by institution-building in practice. As an important institution, users work out the “optimal” way of driving their electric vehicle. When the EV users go on business trips and holidays in Europe, the limitations of their car in terms of range and charging time become most apparent. In the “holidays” thread users post detailed accounts of their trips with the chargers used, charging times and conditions such as driving speed, weather and number of passengers. Some users start taking stock and “rules” for driving an EV emerge (e.g. 110 km/h is the optimal speed), which are endorsed by other forum members. The user-developed knowledge thus forms the basis for the development of practice rules. However, as an indication of the instability of the practice-in-development, the emerging rules are also continuously challenged by forum members. The driving context (i.e. other factors in the socio-technical system) is also changing with, for instance, more charging points becoming available. In the development of rules forum members also use simple modeling tools, with input parameters based on their experience. For instance, one user has developed and shared an Excel sheet for calculating the optimal speed for driving on long distances, taking into account various parameters (Fig. 1). The sheet yields the general “rule” for charging during long-distance journeys (> 250 km) in Europe, which is then (at least for a while) accepted in the community:

“With a distance of 200 km between super chargers the optimum is charging till 70% and driving at 120 km/h”

Dedicated parking places for EVs, which are equipped with chargers, are not yet a strong institution. Within the community of electric vehicle drivers, the main discussion is whether someone should free up their charging point when they have completed charging, to make it available to others. In the virtual community, new users are informed about the accepted practice, a process that contributes to strengthening the institution.

“.. but then the question remains whether I should wake up to move my car in the middle of the night, when it is fully charged. Is that the common practice?”

“I do that. If you would have a gasoline car you wouldn't park at the gasoline station for a night either. It also depends on circumstances. At fast chargers one should not park after charging. In a public parking area you can use the card [with phone number, ed.] and people can always call you if needed. If you can move your car after charging, I would always do that.”

4.3. Geographical circulation

The virtual user community is active in processes of geographical circulation during upscaling, by means of the core mechanisms of trans-local interactions & facilitating use across geographical contexts.

	A	B	C	D	E	F	G	H	I	J	K	L
1	Variables											
2	- Minimum state of charge battery	5	% (max 40%)									
3	- Distance between super-chargers	200	km									
4	- Distance	10000000	km									
5	- Overhead-time	0.25	hour	0:15	minutes							
6	- Battery	70	kWh effective use									
7	Speed (km/h)	80	90	100	110	120	130	140	150	160	170	
8	Energy use (Wh/km)	150	160	175	195	215	240	270	305	340	380	
9	range (km/h)	467	438	400	359	326	292	259	230	206	184	
10												
11	Average speed (distance / totale time)											
12	(km/u)	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%	
13	80 km/h n/a	n/a	n/a	n/a	n/a	65.5	66.0	65.6	64.9	64.2	61.1	
14	90 km/h n/a	n/a	n/a	n/a	n/a		71.7	71.2	70.4	69.5	65.6	
15	100 km/h n/a	n/a	n/a	n/a	n/a		76.3	75.7	74.7	73.6	68.9	
16	110 km/h n/a	n/a	n/a	n/a	n/a	n/a		79.0	77.7	76.5	70.8	
17	120 km/h n/a	n/a	n/a	n/a	n/a	n/a		81.5	80.0	78.6	72.0	
18	130 km/h n/a	n/a	n/a	n/a	n/a	n/a	n/a		81.0	79.4	72.0	
19	140 km/h n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a		79.0	70.9	
20	150 km/h n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a		68.8	
21	160 km/h n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a		
22	170 km/h n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	

Fig. 1. User-developed excel sheet for calculating the optimum speed and charging pattern in order to drive long distances as fast as possible.

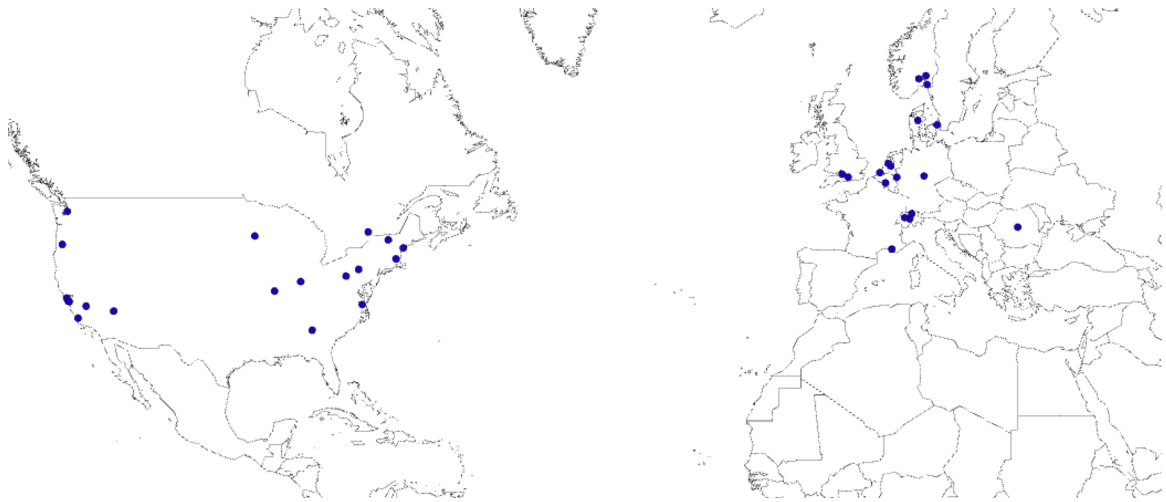


Fig. 2. Trans-local niche network: locations of electric vehicle users active in the discussion on making the Tesla Model S compatible with European charging standards, created using Gephi.

4.3.1. Trans-local interactions

In the upscaling of electric vehicles different charging standards form an important barrier. When rumors emerged in 2011 that the Tesla Model S would not support the European form of 3-phase charging, virtual community users took action. Fig. 2 shows the geographical location of the users involved in the forum thread on the potential compatibility of the Tesla with the European 3-phase standard. The thread was started by a Dutch Tesla user. American users on both coasts joined in and the virtual community became a platform of exchange between users from different geographical niches. Long discussions followed about the different electricity and charging systems in various countries, as well as on how the Tesla should be able to deal with them. Eventually a collective letter was sent to Tesla, with supporters from multiple geographical regions, in order to ensure that the Tesla Model S would become compatible with European charging systems. In the same internet forum thread, a vice-president of Tesla then confirmed it would.

The interaction patterns between users from different geographical contexts changes during the upscaling process. Initially, users from various localities around the globe reply in the same threads. As local user bases grow, gradually national subforums are created. Most users in this study are only active in the Dutch subforum. However, certain users are active in the international forum and national subforum(s). They perform a gatekeeper function by sharing topics between subforums as well as other mediums such as WhatsApp and YouTube.

4.3.2. Facilitating use across geographical contexts

The difference in charging standards between countries as well as a large variety in charging passes that are to be used across countries and regions in Europe, pose barriers to Dutch EV users going on holidays. One of the most active threads on the forum is the “holidays” thread, with also separate threads dedicated to specific countries. The virtual community works hard to enable the EV users to also drive their EV in other geographical contexts, by sharing information, charge plugs and passes. In terms of circulation, the practice of EV driving is hence brought to places where it is less or differently embedded. This also affects the local establishment of other system elements, for example when users lobby for specific charging points at their holiday destinations throughout Europe. Notably, users send requests for the placement of specific Tesla-sponsored chargers to hotels throughout Europe. No particular local charging passes or plugs are needed for these chargers.

4.4. Reconfiguration of the existing socio-technical regime

The electric vehicle emerges in the context of the existing socio-technical regime of the fossil fuel car. Some regime parts simply carry over to the EV (e.g. the status attached to personal vehicle ownership). Other regime elements however, are in conflict with EV. The virtual community participates in reconfiguration with the mechanisms of empowerment to challenge the regime and regime-adapting activities.

4.4.1. Empowerment to challenge the regime

The virtual community users are often reminded that the innovation they have adopted does not conform to the existing regime. For example, they are told that their car is not a real car, because it makes a different sound or only has a limited range. The EV users often get into discussion with conventional vehicle owners about how EVs fare compared to fossil fuel cars. The forum then empowers them by offering a series of possible arguments that can be used in such discussions. For example, a forum user develops an excel sheet that can be used to demonstrate that EVs are not more expensive than comparable fossil fuel cars if costs in the long run are considered. Another user develops a detailed post about the CO₂ emissions of electric vehicles, after media reports have appeared that



***U blokkeert een laadplaats
voorbehouden aan ladende
elektrische wagens! Dank U!***

***You are blocking a charge
spot reserved for charging
electric vehicle's! Thank you!***

***Vous bloquez un emplacement
de recharge réservé au
chargement de véhicules
électriques! Merci!***

***Eine verladestelle für
elektroautos wird durch
sie blockiert. Diese verladestelle
dürfen nur von
elektroautos verwendet werden,
die auch am laden sind! Danke!***

Fig. 3. Leaflets shared in the virtual community to be used for the policing of EV charging spots.

they have no or only limited benefits for the environment as compared to fossil fuel cars. Users discuss strategies for answering critical questions about EVs.

"I use the following answer for questions about charging time: 'I don't know. It is just always full when I need it.' This is not entirely true, but it comes closer to the truth than when I say: 'well if it is totally empty, about 9 h.' Because people then start looking worried, and you have to explain that it occurs very rarely that you arrive at your destination totally empty. Most of the time charging only takes a few hours at the end of the day."

Forum members employ these strategies in their own social circles, but also to comment on other sites and blogs, as well as by sending letters to newspapers that according to them are too much on the side of the fossil fuel car regime.

4.4.2. Regime-adapting activities

As EVs scale up, some conflicts with the existing regime emerge. A good example are dedicated parking spots for EVs, equipped with chargers. These were mostly parking places for fossil fuel cars before. Fossil fuel car users still park on these spots, preventing EVs to charge. Formal signifiers such as road signs are often not yet available, making the parking places even more contested. On the internet forum the virtual community develops some activities to make these parking places more accepted. Leaflets (Fig. 3) are shared to make conventional car owners aware of their behaviour. Such leaflets are printed out by virtual community members, and put on the fossil fuel cars that block EV parking places every time a virtual community member sees one. Additionally, a wide variety of activities (ranging from press action to calling the police) and their effectiveness are discussed.

The virtual community also works on reconfiguring some highly institutionalized associations of the current regime. Most notably, this concerns the idea that a car that is able to drive long distances has to be a fossil fuel car. Virtual community members organize various activities that demonstrate that EVs are also able to drive long distances. For example, there is a yearly EV rally, which attracts national media attention. Then there are various international road trips organized among forum members, which are enthusiastically reported on the forum and blogs. These mostly do not receive large-scale media attention but can help people interested in EV "cross the line". They are also found to stimulate existing EV owners in the virtual community to make longer trips, including their yearly holiday, with an EV instead of a fossil fuel car.

5. Discussion

5.1. Roles of virtual user communities in upscaling

Approached from a socio-technical perspective, a case study has been conducted of an Electric Vehicle (EV) user community. The

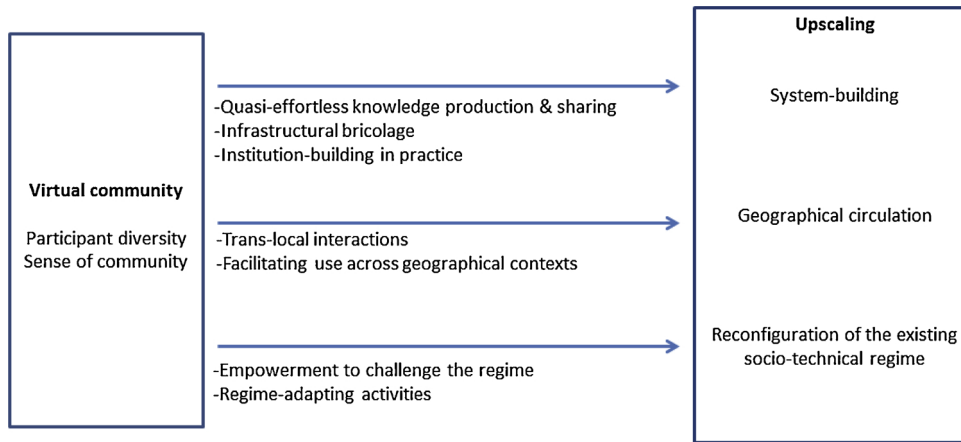


Fig. 4. The participation of the virtual community in the upscaling of systemic innovation.

results describe key community characteristics as well as core mechanisms by which users participate in upscaling (summarized in Fig. 4). Distinctive characteristics of the virtual community are not only a strong sense of community but also large diversity in terms of participants ranging from “pure user” to professional actor, as well as in terms of knowledge levels about EV. Three core mechanisms have been identified by which the user community contributes to system-building. The introduction of digital technology has facilitated knowledge-related activities for users and hence quasi-effortless knowledge production and sharing is a main virtual community occupation. Although they do not engage in large-scale charging point development, users provide their contribution to developing the material dimension of the innovation system in the form of infrastructural bricolage. By engaging in institution-building in practice, users contribute to the development of shared rules, for instance about how an EV should be used, that help to hold the scaling system together. In terms of geographical circulation, on the internet forums fruitful trans-local interactions occur and users are active in facilitating use across geographical contexts. Two ways were identified in which users play a role in reconfiguration of the existing socio-technical regime. Community members are empowering each other in the process of challenging the existing regime. Additionally, various regime-adapting activities, aimed at changing some taken-for-granted institutions of the regime, emerge from the forum.

These findings add to the emerging work on virtual communities in sustainability transitions. One of the few cases hitherto described in this regard is that of virtual communities related to heat pumps in Finland (Hyysalo et al., 2013a, b; Hyysalo et al., 2017; Hyysalo et al., 2018). The quasi-effortless knowledge development and sharing process we observe is well in line with Hyysalo et al.’s (2018) findings on the heat pumps case. It demonstrates how the community provides more balanced market information, develops solutions to upscaling barriers, and articulates demand to other market actors. Hence, it reduces uncertainties for more mainstream users during upscaling. As a difference, in the case of the Finnish heat pumps, the virtual community shared much knowledge regarding physical adaptations to the heat pumps. Such classical “tinkering” was hardly observed in the virtual community we studied. This is probably due to the EV being a highly technologically advanced product. Tinkering might also lead to loss of warranty, deterring users of expensive products (Hyysalo et al., 2013b). There was nonetheless some digital tinkering going on, with users making apps for the Tesla screen. It should be noted that on the American Tesla forums, which we did not study in detail, classical tinkering occurs, enabled by the presence of some highly technologically skilled users and the availability of spare Tesla parts.

For the virtual community we studied, it was most noticeable that users contributed beyond simple knowledge sharing, and participated in system-building activities in the domains of infrastructure and institutions. In their own ad-hoc way, which we describe as infrastructural bricolage, the user community contributes to infrastructure development, for example by lobbying for chargers when people go on holidays. These findings fit well with recent work that stresses the importance of bottom-up processes driving infrastructure development, contrasting the dominant view on infrastructure development as resulting from top-down and centralized steering processes (Egyedi and Mehos, 2012). Most users in our study had a Tesla model S, which is a luxury EV with higher performance than other EVs. This being a limitation of our research, we performed a basic cross-check with the Nissan Leaf internet forum (a more middle class EV) and included people active on other forums among the interviewees. It emerged that the issues addressed in other EV communities are largely similar, except that for other EVs, there is more activity related to infrastructure, because the low range of these EVs makes charging a more important issue. By means of institution-building in practice, the virtual community helps to establish and disseminate rules and practices among EV users. This role has particular relevance in the upscaling phase, in which many new users join. It also seems hard to be taken up by other intermediary actors, which lack the shared experiences and trust that emerge in the user community.

More user activity in infrastructure and institution-building was reported than in the case of heat pumps in Finland. These differences can be related to the nature of the technologies involved. The heat pumps are stationary and their deployment is heavily influenced by national institutions such as energy laws. Electric vehicles, on the other hand, can and do cross national borders while in use. As a result, international institutions, such as charging standards, are highly important for further diffusion of EVs during

upscaling. In line with this, we also observe online user activity regarding these issues, even lobbying across countries. In general, the relative importance of local, national and supranational institutions will differ per innovation type. These differences are likely to be reflected in the roles online communities take up and the degree of interaction between users across geographical locales. Future comparative research would be useful for investigating the relationship between, on the one hand, the relative importance of local, national and supranational institutions for the innovation, and on the other hand, the role of online user communities and geographical patterns of interactions between users.

The virtual user community also participates in the reconfiguration of the existing socio-technical regime. In their study of Finnish heat pump forums, Hyysalo et al. (2018) note there is hardly discussion about sustainability. The heat pump is instead discussed in economic and technological terms. On the EV forum, this is only partly the case. Although EV users go to great lengths to demonstrate that their EV is on par with fossil fuel cars in terms of price and performance, they also discuss environmental sustainability and question the sustainability of regime actors such as car companies. Yet, following the user typology of Schot et al. (2016), we had expected to see more activity of the EV community in “hollowing out” the existing regime than we actually observed. This lower activity might reflect that the electric vehicle transition is still in an early stage of the upscaling phase and has not yet enough momentum to take on the existing regime. The underlying question here is about the extent to which virtual communities activities in regime reconfiguration tend more to what Smith and Raven (2012) call “fit and conform” to the existing regime or “stretch and transform” of its fundamental values and structures. This is a valuable question to explore further, as it will give insight into the extent to which users are able to accelerate large-scale sustainability transitions rather than contributing to incremental changes.

5.2. The specific nature of virtual user communities

Our case study suggests that a virtual user community differs in two ways from other user communities in terms of ability to engage in upscaling. First, digital platforms facilitate knowledge sharing and thus the collective production of knowledge among a wide variety of participants. In our case, the knowledge developed is taken up by users who already have an EV, prospective EV users and market actors active in the sector. It is also remarkable that during the influx of new users a relatively strong sense of community is maintained for a considerable group of users. This contrasts with accounts of tensions between initial users and more mainstream users in the literature on local grassroots communities (Truffer, 2003; Hossain, 2016). An explanation might be that, paradoxically, in a virtual community it is much easier to opt out of community activities if one is not interested, which is also accepted.

Second, as expected, the virtual community is able to build bridges between otherwise geographically isolated user groups. This is a major difference with local communities as described in the grassroots literature, which are heavily embedded in specific socio-spatial contexts and hence have difficulties to engender more widespread sustainability transitions. It is noticeable that the trans-local interactions on the internet forum do not only concern knowledge sharing but can also result in international collective action, for example related to charging standards. During upscaling, national subforums become more dominant, which reduces the frequency of international contacts between users. On these national forums, there is still considerable activity related to the use of EVs in different geographical contexts. Certain users take up a gatekeeper role as they are active on multiple forums with different geographical focus areas, or on multiple mediums, such as Facebook, WhatsApp, YouTube and blogs.

Before the virtual user community is hailed as the panacea for the upscaling of systemic innovation, two main limitations of its role have to be acknowledged. The first of these concerns the development and sharing of knowledge. While the virtual community is undeniably a valuable source of knowledge for (aspiring) EV drivers and other system actors, the knowledge sharing process is also far from perfect. This is partly for technical reasons. In contrast to what Grabher and Ibert (2013) have observed, the “archival” function of the internet forum does not function well, and users have to go through large amounts of texts to find useful knowledge. (This problem is even worse on other social media, such as Facebook, on which the virtual community has also become increasingly active.) Also, the context-specific and subjective nature of the practice-based and experiential knowledge shared hampers its aggregation during upscaling. Second, users mostly do not solve upscaling barriers permanently. They are relatively unorganized and rather work around the problems with whatever resources at hand in their everyday lives. In the Dutch context of our study there are policy-makers who recognize the potential of virtual communities, but the unorganized, ad-hoc, and subjective nature of these communities makes it very hard to better include them in the policy development process.

5.3. Users in sustainability transitions and innovation processes

At a more general level, our study provides some insights in overall sustainability transition dynamics and the role of users herein. Following the growth of various sustainable innovations beyond initial niche exploration, transition scholars have started to explore upscaling (Naber et al., 2017; Geels and Johnson, 2018; Hyysalo et al., 2018). If there is one thing on which these studies agree, then it is that niches after initial development will not simply continue to grow smoothly, as suggested by the diffusion of innovation model of Rogers (2010). To highlight differences with diffusion, Hyysalo et al. (2018) proposed to use the term “innofusion” (Fleck, 1988), defined as “the development of the sociotechnical characteristics of technology during its diffusion” (Hyysalo et al., 2018, p. 882).

Even more than in the innofusion pattern as described by Hyysalo et al. (2018), the activities we observed the user community performing concerned the system, practices and institutions around the technology rather than the technological artefact of the vehicle itself. Accordingly, the dimensions of the upscaling pattern we used as starting point, namely *system-building*, *geographical circulation*, and *reconfiguration of the existing socio-technical regime* proved useful for capturing the variety in upscaling activity. At a more general level, the sustainability transition perspective allowed for analyzing the breadth of user activities as well as the way

users handle the embeddedness of the innovation in existing geographical and institutional environments. Regarding the latter, the sustainability transitions lens particularly had value in enabling us to point out how EV users deal with the socio-technical regime of the existing technology of fossil fuel cars.

As an explicit sustainability-oriented perspective was adopted in this study, it is worthwhile to reflect on the applicability of our findings to non-sustainable technologies. User involvement has also been observed for transitions towards non-sustainable innovations. For example, Kanger and Schot (2016) demonstrate the involvement of users in the transition towards automobility. Regarding the internal dynamics of the online community we studied, there is a large similarity to “non-sustainable” virtual innovation communities as described by Grabher and Ibert (2013). A difference might be the extent of user activity that is devoted to institutional barriers. Such barriers are higher for sustainable innovations, as sustainability values are not yet deeply engrained in society. Hence, we observe user activity in demonstrating that EVs are on par with normal cars in economic and performance terms, as well as attempts to promote more sustainable living in general.

A lively debate has emerged regarding the possibility of accelerating sustainability transitions (Sovacool, 2016; Grubler et al., 2016; Sovacool and Geels, 2016). In this debate, users still overwhelmingly figure as passive actors or as actors that hamper transitions. However, as we have shown, users, empowered in online communities, can also contribute to acceleration processes. Another point to note is that new roles and actors emerge during upscaling. As Schot et al. (2016) have described, users take up various roles in the different phases of a transition. Additionally, we should not forget that broad societal trends and technological developments change divisions of roles between actors and create new ones. In our case, because of a coming together of the rise of EV from niches and developments in social media technology, the virtual community we studied emerged. It altered the role of users in upscaling, most notably by increased blurring of the role of user-producer and user-intermediary (knowledge development and sharing among a wide variety of participants), as well as enhancing the role of user-intermediary (contributions in terms of institutions and infrastructure).

6. Conclusion

Following increased debate in recent years over the role of users in sustainability transitions (Schot et al., 2016), as well as the virtual nature of user communities (Grabher and Ibert, 2013; Hyysalo et al., 2013a; Hyysalo et al., 2018), this paper set out to explore the role of the virtual user community in the upscaling of systemic innovations. An internet ethnography was conducted of a large community of electric vehicle users. A socio-technical perspective was taken to identify upscaling dimensions: system-building, geographical circulation, and reconfiguration of the existing socio-technical regime.

Our research demonstrates the participation of the virtual user community in the upscaling of innovation in sustainability transitions. The virtual user community makes a distinctive contribution to the work needed in the upscaling process. It is able to perform a broad scope of upscaling work, ranging from infrastructure development to institution-building. Knowledge is more easily developed and shared among a wide variety of participants than in local user communities. In terms of geography, the virtual community enables interactions between dispersed users in a variety of geographical contexts. The virtual user community also empowers its members to challenge the socio-technical regime of fossil fuel cars. At the same time, the virtual community also acts in an ad hoc manner, is unorganized and subjective, and generates solutions to upscaling barriers that are often only workarounds. Still, the uncertainty around EV that it reduces, the driving practices that it establishes and explains, and the empowerment vis-à-vis fossil fuel car proponents that it brings make that more mainstream users can “cross the line” and become EV users as well.

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References

- Aguirre, K., Eisenhardt, L., Lim, C., Nelson, B., Norring, A., Slowik, P., Tu, N., 2012. Lifecycle Analysis Comparison of a Battery Electric Vehicle and a Conventional Gasoline Vehicle. Retrieved from. <http://www.ioe.ucla.edu/perch/resources/files/batteryelectricvehiclelca2012.pdf>.
- Baker, T., Nelson, R.E., 2005. Creating something from nothing: resource construction through entrepreneurial bricolage. *Adm. Sci. Q.* 50 (3), 329–366.
- Bakker, S., Leguijt, P., van Lente, H., 2015. Niche accumulation and standardization—the case of electric vehicle recharging plugs. *J. Clean. Prod.* 94, 155–164.
- Bergek, A., Jacobsson, S., Carlsson, B., Lindmark, S., Rickne, A., 2008. Analyzing the functional dynamics of technological innovation systems: A scheme of analysis. *Res. Policy* 37 (3), 407–429.
- Bergek, A., Hekkert, M., Jacobsson, S., Markard, J., Sandén, B., Truffer, B., 2015. Technological innovation systems in contexts: conceptualizing contextual structures and interaction dynamics. *Environ. Innov. Soc. Transit.* 16, 51–64.
- Coenen, L., Benneworth, P., Truffer, B., 2012. Toward a spatial perspective on sustainability transitions. *Res. Policy* 41 (6), 968–979.
- de Vries, G., Boon, W.P., Peine, A., 2016. User-led innovation in civic energy communities. *Environ. Innov. Soc. Transit.* 19, 51–65.
- Dewald, U., Truffer, B., 2011. Market formation in technological innovation systems—diffusion of photovoltaic applications in Germany. *Ind. Innov.* 18 (03), 285–300.
- Dewald, U., Truffer, B., 2012. The local sources of market formation: explaining regional growth differentials in German photovoltaic markets. *Eur. Plann. Stud.* 20 (3), 397–420.
- Edquist, C., Johnson, B., 1997. Institutions and organizations in systems of innovation. In: Edquist, C. (Ed.), *Systems of Innovation: Technologies, Institutions and Organizations*. Pinter Publishers, London, pp. 41–63.

- Egyedi, T., Mehos, D. (Eds.), 2012. *Inverse Infrastructures: Disrupting Networks from Below*. Cheltenham. Edward Elgar Publishing.
- Feola, G., Butt, A., 2017. The diffusion of grassroots innovations for sustainability in Italy Great Britain: an exploratory spatial data analysis. *Geogr. J.* 183 (1), 16–33.
- Fleck, J., 1988. Innofusion or diffusion? The nature of technological development in robotics. ESRC Programme on Information and Communication Technologies. Working Paper Series. University of Edinburgh.
- Fuenschiilling, L., Truffer, B., 2016. The interplay of institutions, actors and technologies in socio-technical systems—an analysis of transformations in the Australian urban water sector. *Technol. Forecast. Soc. Change* 103, 298–312.
- Füller, J., Jawecki, G., Mühlbacher, H., 2007. Innovation creation by online basketball communities. *J. Bus. Res.* 60 (1), 60–71.
- García, A.C., Standlee, A.L., Bechhoff, J., Cui, Y., 2009. Ethnographic approaches to the internet and computer-mediated communication. *J. Contemp. Ethnogr.* 38 (1), 52–84.
- Geels, F., Deuten, J.J., 2006. Local and global dynamics in technological development: a socio-cognitive perspective on knowledge flows and lessons from reinforced concrete. *Sci. Public Policy* 33 (4), 265–275.
- Geels, F., Johnson, V., 2018. Towards a modular and temporal understanding of system diffusion: Adoption models and socio-technical theories applied to Austrian biomass district-heating (1979–2013). *Energy Res. Soc. Sci.* 38, 138–153.
- Geels, F., Sovacool, B.K., Schwanen, T., Sorrel, S., 2017. The socio-technical dynamics of low-carbon transitions. *Joule* 1 (3), 463–479.
- Grabher, G., Ibert, O., 2013. Distance as asset? Knowledge collaboration in hybrid virtual communities. *J. Econ. Geogr.* 14 (1), 97–123.
- Grabher, G., Ibert, O., Flohr, S., 2008. The neglected king: the customer in the new knowledge ecology of innovation. *Econ. Geogr.* 84 (3), 253–280.
- Grubler, A., Wilson, C., Nemet, G., 2016. Apples, oranges, and consistent comparisons of the temporal dynamics of energy transitions. *Energy Res. Soc. Sci.* 22, 18–25.
- Hansen, T., Coenen, L., 2015. The geography of sustainability transitions: Review, synthesis and reflections on an emergent research field. *Environ. Innov. Soc. Transit.* 17, 92–109.
- Hargreaves, T., Hielscher, S., Seyfang, G., Smith, A., 2013. Grassroots innovations in community energy: the role of intermediaries in niche development. *Glob. Environ. Chang. Part A* 23 (5), 868–880.
- Hekkert, M.P., Suurs, R.A., Negro, S.O., Kuhlmann, S., Smits, R.E., 2007. Functions of innovation systems: a new approach for analysing technological change. *Technol. Forecast. Soc. Change* 74 (4), 413–432.
- Hillman, K.M., Suurs, R.A., Hekkert, M.P., Sandén, B.A., 2008. Cumulative causation in biofuels development: a critical comparison of the Netherlands and Sweden. *Technol. Anal. Strateg. Manag.* 20 (5), 593–612.
- Hossain, M., 2016. Grassroots innovation: a systematic review of two decades of research. *J. Clean. Prod.* 137, 973–981.
- Hyysalo, S., Juntunen, J.K., Freeman, S., 2013a. Hyysalo, Juntunen & Freeman: internet forums and the rise of the inventive energy user. *Sci. Technol. Stud.* 28 (1).
- Hyysalo, S., Juntunen, J.K., Freeman, S., 2013b. User innovation in sustainable home energy technologies. *Energy Policy* 55, 490–500.
- Hyysalo, S., Johnson, M., Juntunen, J.K., 2017. The diffusion of consumer innovation in sustainable energy technologies. *J. Clean. Prod.* 162, S70–S82.
- Hyysalo, S., Juntunen, J.K., Martiskainen, M., 2018. Energy internet forums as acceleration phase transition intermediaries. *Res. Policy* 47 (5), 872–885.
- IEA, International Energy Agency, Bunsen, T., Cazzola, P., Gorner, M., Paoli, L., Scheffer, S., Schuitmaker, R., Tattini, J., Teter, J., 2018. *Global EV Outlook 2018*. Paris, France.
- Kanger, L., Schot, J., 2016. User-made immobilities: a transitions perspective. *Mobilities* 11 (4), 598–613.
- Kozinets, Robert V., 2015. *Netnography: Redefined*. Sage, London.
- Latour, B., 1993. *The Pasteurization of France*. Harvard University Press, Cambridge, MA.
- Lincoln, Y., Guba, E., 1985. *Naturalistic Inquiry* Vol. 75 Sage, Beverly Hills, CA.
- Markard, J., Raven, R., Truffer, B., 2012. Sustainability transitions: an emerging field of research and its prospects. *Res. Policy* 41 (6), 955–967.
- Naber, R., Raven, R., Kouw, M., Dassen, T., 2017. Scaling up sustainable energy innovations. *Energy Policy* 110, 342–354.
- NEA Netherlands Enterprise Agency (Dutch: Rijksdienst Voor Ondernemend Nederland), 2014. *Cijfers Elektrisch vervoer tm maart 2014*.
- NEA Netherlands Enterprise Agency (Dutch: Rijksdienst Voor Ondernemend Nederland), 2018. *Elektrisch Rijden – Personenauto's en laadpunten Analyse over 2017*.
- Ornetzeder, M., Rohrer, H., 2006. User-led innovations and participation processes: lessons from sustainable energy technologies. *Energy Policy* 34 (2), 138–150.
- Ornetzeder, M., Rohrer, H., 2013. Of solar collectors, wind power, and car sharing: comparing and understanding successful cases of grassroots innovations. *Glob. Environ. Change* 23 (5), 856–867.
- Peters, A.M., van der Werff, E., Steg, L., 2018. Beyond purchasing: Electric vehicle adoption motivation and consistent sustainable energy behaviour in The Netherlands. *Energy Res. Soc. Sci.* 39, 234–247.
- Randelli, F., Rocchi, B., 2017. Analysing the role of consumers within technological innovation systems: the case of alternative food networks. *Environ. Innov. Soc. Transit.* 25, 94–106.
- Rogers, E.M., 2010. *Diffusion of Innovations*. Simon and Schuster, New York, NY.
- Ruggiero, S., Martiskainen, M., Onkila, T., 2018. Understanding the scaling-up of community energy niches through strategic niche management theory: insights from Finland. *J. Clean. Prod.* 170, 581–590.
- Rullani, F., Haefliger, S., 2013. The periphery on stage: the intra-organizational dynamics in online communities of creation. *Res. Policy* 42 (4), 941–953.
- Schot, J., Kanger, L., Verbong, G., 2016. The roles of users in shaping transitions to new energy systems. *Nat. Energy* 1, 16054.
- Sengers, F., Raven, R., 2015. Toward a spatial perspective on niche development: the case of Bus Rapid Transit. *Environ. Innov. Soc. Transit.* 17, 166–182.
- Seyfang, G., Longhurst, N., 2016. What influences the diffusion of grassroots innovations for sustainability? Investigating community currency niches. *Technol. Anal. Strateg. Manag.* 28 (1), 1–23.
- Seyfang, G., Smith, A., 2007. Grassroots innovations for sustainable development: towards a new research and policy agenda. *Env. Polit.* 16 (4), 584–603.
- Seyfang, G., Hielscher, S., Hargreaves, T., Martiskainen, M., Smith, A., 2014. A grassroots sustainable energy niche? Reflections on community energy in the UK. *Environ. Innov. Soc. Transit.* 13, 21–44.
- Smith, A., Raven, R., 2012. What is protective space? Reconsidering niches in transitions to sustainability. *Res. Policy* 41 (6), 1025–1036.
- Smith, A., Fressoli, M., Thomas, H., 2014. Grassroots innovation movements: challenges and contributions. *J. Clean. Prod.* 63, 114–124.
- Sovacool, B.K., 2016. How long will it take? Conceptualizing the temporal dynamics of energy transitions. *Energy Res. Soc. Sci.* 13, 202–215.
- Sovacool, B.K., Geels, F.W., 2016. Further reflections on the temporality of energy transitions: a response to critics. *Energy Res. Soc. Sci.* 22, 232–237.
- Sun, N., Rau, o., Ma, L., 2014. Understanding lurkers in online communities: a literature review. *Comput. Human Behav.* 38, 110–117.
- Suurs, R., Hekkert, M., 2009. Cumulative causation in the formation of a technological innovation system: the case of biofuels in the Netherlands. *Technol. Forecast. Soc. Change* 76 (8), 1003–1020.
- Takahashi, M., Fujimoto, M., Yamasaki, N., 2003. The active lurker: influence of an in-house online community on its outside environment. November. *Proceedings of the 2003 International ACM SIGGROUP Conference on Supporting Group Work* 1–10.
- Temenos, C., Nikolaeva, A., Schwanen, T., Cresswell, T., Sengers, F., Watson, M., Sheller, M., 2017. Theorizing mobility transitions: an interdisciplinary conversation. *Transfers* 7 (1), 113–129.
- TMC, 2016. *Tesla Motors Club Homepage*. Retrieved, June, 15 2016. www.teslamotorsclub.org.
- Truffer, B., 2003. User-led innovation processes: the development of professional car sharing by environmentally concerned citizens. *Innov. Eur. J. Soc. Sci. Res.* 16 (2), 139–154.
- Van Bree, B., Verbong, G.P., Kramer, G.J., 2010. A multi-level perspective on the introduction of hydrogen and battery-electric vehicles. *Technol. Forecast. Soc. Change* 77 (4), 529–540.
- Yin, R., 2013. *Case Study Research: Design and Methods*. Sage Publications, Beverly Hills, CA.