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Sustainable User Innovation from a Policy Perspective

A Systematic Literature Review

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Title: Sustainable user innovation from a policy perspective: A systematic literature review

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Abstract:
Sustainable innovation is typically viewed through the lens of the producer innovator, whereas end-users (or consumers) are perceived to play only a peripheral role in the development of sustainable products and services. A growing literature stream, however, sharply departs from this view by suggesting that end-users often play a critical role with regard to sustainable innovation. To further consolidate this field, the purpose of this paper is threefold. First, the paper summarizes and synthesizes key insights within the field based on 84 papers published from 1992 to 2015. Second, we offer a framework to understand the current observed barriers and drivers to this innovation process, suggesting two distinct end-user innovation types: independent and facilitated. The end-users' motivation, ability and opportunity to innovate serve as the deductive analytical tool utilized for discerning these drivers and barriers. Third, the paper suggests how this form of innovation may be ameliorated from a policy perspective. The paper reveals that the literature on end-user innovation within sustainability is both diverse and compartmentalized. Hence, policy mechanisms designed to support this type of innovation process need to be tailored to the independent or facilitated framework in which the end-user resides and to take into account how each framework is necessitated by a different actor logic and motivation, resulting in the pursuit of different innovation types. It is concluded that the literature focusing on independent end-user innovation typically highlights policy aimed at enabling end-users with the necessary skills and resources to innovate, whereas literature focusing on facilitated end-user innovation typically emphasizes creating platforms that enable the effective introduction of end-user knowledge into an already existing framework.
The paper offers an overview and a framework for researchers to further explore this diverse and compartmentalized field. Practitioners may especially benefit from the proposed policy tools, including the overview of potential tools for drawing on end-user competences and resources.

1. Introduction

The importance of end-users within innovation is an increasing mainstay within the traditional innovation literature, identified both independently and in a facilitated fashion as a major source of innovation (von Hippel 2005; Chesbrough et al. 2006). However, in contrast, within the sustainable innovation literature, the involvement of the end-user remains a "neglected site of innovation for sustainability" (Seyfang & Smith 2007, p. 585), whereas producer-led innovation remains "the mainstay of both empirical research and theoretical development" (Hargreaves et al. 2013, p. 869). The end-user's role within sustainable innovation is often relegated to that of a passive recipient of innovation (Belz 2013). Nonetheless, an increasing number of articles within sustainable innovation research challenge this conception (Feola & Nunes 2014) and – although diverse, compartmentalized and typically single-case based – illustrate the multitude of ways in which end-users innovate for sustainability ends (Hoffmann 2007; Hyysalo et al. 2013b). These end-user innovators represent a type of niche innovation actor who insulates novel ideas and prototypes against the dominant socio-technical regime and tolerates uncertainty and initial low product performance levels (Geels 2002; Kemp & Rotmans 2004).

The purpose of the present paper is to garner the insights of this research utilizing a systematic literature review method. The primary goal is to summarize and synthesize the state of knowledge of this nascent research field that we label "Sustainable End-User Innovation" (SEI) (Nielsen et al. 2014). A second goal is to develop recommendations on how innovation policy, which is currently primarily aimed at producer-led innovation (Henkel & von Hippel 2005), may be adapted to better meet the needs of end-user innovators. Hence, the paper's dual contribution is to provide an overview of the key identified barriers and drivers to this form of innovation process and to propose a policy framework and toolset for fostering and facilitating this promising type of sustainable innovation.

To conceptualize and delimit the scope of the review, the following subsection introduces the background literature for the review, drawing especially on literature on user and open innovation. Section 2 introduces the research method for the literature review, and Section 3 presents some key descriptive observations derived from the identified literature. Section 4 introduces the deductive categories for the qualitative content analysis of the literature. Finally, Sections 5 and 6 present the results and discussion of the qualitative content analysis of the literature, respectively.

1.1 Conceptualization and demarcation

The fields of user innovation and open innovation are well-developed within the innovation literature, where it has been observed that the knowledge relevant for innovation is widely dispersed and hence often falls outside the realm of any one individual person, firm or organization (West & Bogers 2014). External sources of knowledge are therefore often employed to ameliorate the innovation process which end-users are regarded as one such potential source. However, the two research fields diverge on their actor-focused vantage point, with open innovation typically focused on firms and other organizations, whereas user innovation focuses on individual users (von Hippel 1988; Chesbrough 2003).

In conceptualizing the term "user", the present study draws upon the work of Eric von Hippel (2005), who distinguishes between two ideal types of users: intermediate users and end-users. An

intermediate user typically represents a firm that utilizes equipment and components from other producers (i.e., upstream products) to produce further products and services, whereas an *end-user* represents the end-consumer (or groups of consumers) of a given product or service. The present study is deliberately focused on and limited to end-users. Additionally, from an open innovation perspective, the focus is on the so-called "interactive coupled model" (Chesbrough et al. 2014), which conceptualizes innovation as a collaborative activity between the end-user(s) and a given firm, organization or project. In this model view, end-users partake in all or multiple phases of the innovation process rather than purely in the refinement phase (Weber 2003). The paper therefore seeks to uncover not only how end-users themselves innovate but also how they may be co-opted and involved in a firm or project-driven sustainable innovation process.

Against this backcloth, the present study characterizes the role of the end-user within sustainable innovation as either facilitated or independent in nature. Facilitated end-user innovation is characterized by the integration of the end-user into a company or project-driven sustainable innovation process. Independent end-user innovation conversely reflects innovation by the end-user, which is not facilitated by outside involvement (Nielsen et al. 2014).
Sustainable innovation is understood as an advance in a product, service, or process system that offers an improved or the same economic performance with less externalities in the form of social and environmental hazards (Halme & Laurila 2009; Bos-Brouwers 2010). Following Smith et al. (2014, p.115) sustainable end-user innovation processes should not be seen "as a blueprint for the future, but rather as a resource for debating and constructing different pathways to sustainable futures." This is what the present study intends to nourish. Figure 1 below illustrates the demarcation of this literature review.

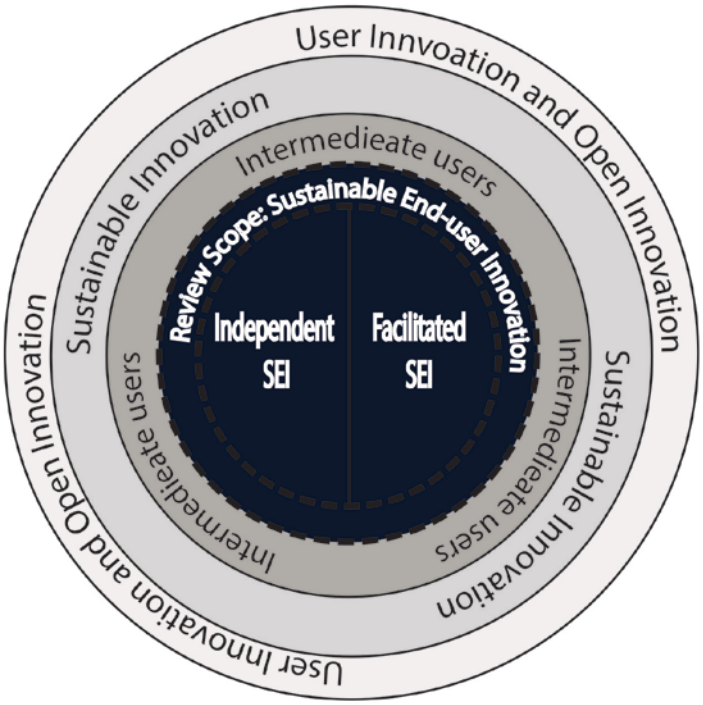


Fig. 1. Demarcation of the literature review

It should be noted that many of the innovations reported in the literature have not been diffused beyond the end-user or a small community of end-users and should hence more correctly be

labeled inventions rather than innovations (Schumpeter 1942). This lack of diffusion might be due to the limited capabilities of (small groups of) end-users to commercialize and disseminate their inventions, but perhaps also sometimes due to uneasiness amongst end-user inventors about the thought of commercializing their ideas. Be that as it may, following the practice in most of the reviewed literature, the present paper does not distinguish between inventions and innovations. Limiting the focus to only research dealing with commercialized SEIs – i.e., innovations in the narrow sense – would have greatly hampered the study's ability to reach its goals, especially because the dissemination and commercialization of end-user inventions has been identified as one of the main barriers for this type of innovation in general (Hienerth & Lettl 2011).

The present paper argues that SEI systematically differs from traditional users and open innovation in two key characteristics: the goal and the tasks. The goal of end-user innovators is to innovate for themselves based on their experience with a given product or service (von Hippel 2005). Uniquely for SEI, however, is that although users innovate on the basis of personal experiences and needs, they do so (also) for the benefit of others – to improve the environmental, social or health condition of a community or larger society. The level of focus is therefore not only personal wants and needs, but potentially also the needs of others (Belz & Binder 2015), including social and environmental concerns (Elkington 1997). When pursuing a triple bottom line[1] of sustainability, the end-user arguably needs to tackle more complicated tasks because products and services must live up to not only economic criteria but also social and environmental criteria as well (Choi & Gray 2008). This has consequences for the tools of effective policy making to foster sustainable innovation led by end-users.

2 Method

The literature on sustainable innovation has been characterized as disjointed, distributed and skewed (Adams et al. 2012). To expedite an orderly and reproducible review, the present study adopted a systematic literature review approach, as increasingly applied in management research (Tranfield et al. 2003). First, a systematic review method was applied to identify relevant articles from the EBSCO databases, and second, the Scopus and Web of Science (WoS) databases[2] were searched to identify relevant articles that might have been missed by our initial data collection. As noted in Section 1, the extant SEI research to date has not been approached systematically (Feola & Nunes 2014).

2.1 Systematic Literature Review

A systematic literature review is a structured approach to reviewing published academic research, as opposed to the more common narrative-based review (Tranfield et al. 2003). The systematic literature review approach allows other researchers to replicate the literature review for the sake of revisions and updates, thus providing an audit trail on the reviewers' procedures and decisions (Cook et al. 1997).

[1] Conceptualized as "Planet, People and Profit" or "Environment, Social and Economic Dimension".

[2] EBSCO Database: http://web.b.ebscohost.com.esc-web.lib.cbs.dk/ehost/search/basic?sid=156a9332-b6ee-4609-ae0d-0988346183f6%40sessionmgr115&vid=0&hid=123
Scopus Database: http://www-scopus-com.esc-web.lib.cbs.dk/
Web of Science Database: http://apps.webofknowledge.com.esc-web.lib.cbs.dk/

In the present study, the first stage of the systematic literature review was an initial scoping exercise: an iterative process of defining, clarifying and refining the literature search parameters. The iterative process included contacting recognized experts within the field for their insights and scoping their recommended readings. A number of initial scoping literature searches were also conducted to identify search strings (i.e., combinations of keywords) that would adequately capture relevant peer-reviewed articles.

The initial scoping exercise focused on the keywords "user innovation" AND "sustain*", which resulted in nine hits in EBSCO, of which only two were within the scope of this review (Date: 25.07.2014). In subsequent attempts to maintain this narrow band of keywords, the number of databases was expanded; however, search results remained too low to start an analysis (e.g., 8 from WoS and 22 from Scopus). These results may be due to the subsequently observed multiplicity of research streams studying this phenomenon resulting in a lack of one overarching terminology for SEI. The limited search keywords failed to capture this diverse and compartmentalized literature. Widening the search to full-text rather than title, abstract and author-supplied keywords increased the number of hits but did not yield significantly more articles within the scope of this review.[3] Following Adams et al.'s (2012) systematic review on innovation for sustainability, the search parameters were therefore broadened in the next round, resulting in the addition of multiple keywords associated with end-user innovation, sustainability and policy for our review. Like Adams et al. (2012), we also delimited the time period of the review to 1992 to the present (incl. articles in press),[4] primarily because of the significance of the year in terms of sustainability due to the United Nations Conference on Environment and Development in Rio de Janeiro (the "Rio Summit").

Table 1.
Keywords and search strings for the systematic literature review

Search string themes	Keywords (Synonyms and alternatives)
End-user innovation	innov* AND (user OR "end-user" OR "user-centered" OR "lead user" OR customer OR consumer OR participat* OR collaborat*) OR co-innovat* OR co-design* OR co-produc* OR co-creat* OR prosumer OR "do-it-yourself"
Sustainability	sustain* OR environment* OR "eco-innovation" OR green OR renewable* OR "triple bottom line" OR eco-efficien* OR eco-effectiv* OR "cradle to cradle" OR biomimicry OR frugal OR ecolog* OR "circular economy"
Policy	governance OR policy OR "policy instrument" OR incentiv* OR regulat* OR "choice architecture" OR nudge OR "behavioural policy" OR patent* OR toolkit

This approach resulted in more relevant articles being identified but also considerably increased the number of captured articles that fell outside the scope of this research. When searching the full text, this resulted in an unmanageable number of hits, and the search criteria were therefore limited to the title, abstract and author-supplied keywords. In addition, the search was initially limited to a single database – Business Source Complete by EBSCO – which was chosen for three reasons: First, the broad search parameters necessitated a narrowing of databases to keep the number of articles collected to a manageable size. Second, the EBSCO database includes a large range of relevant journals such as the Journal of Cleaner Production, Ecological Economics

[3] E.g., 195 in EBSCO, of which 7 were within the scope of our review (Date: 31.07.2014)
[4] Articles in press at the time of the final review of the paper: 17. October 2015.

and Research Policy. Third, many databases limit the number of hits that can be shown and exported, whereas EBSCO does not; this is a major advantage regarding the technical and practical handling of large datasets stemming from a systematic literature review. Table 2 below provides the full criteria of the initial literature search.

Table 2.
The criteria for the literature search - the inclusion and exclusion parameters

Criterion	Inclusion	Exclusion
Search scope	EBSCO – Business Source Premier	Other databases
Source	Peer reviewed journal articles	Any other source
Empirical approach	No restrictions	
Time period	1992 to present (incl. articles in press)	Any source before 1992
Search parameters	Keywords appearing in the title, abstract and author-supplied keywords	Keywords appearing in other parts of the article*
Language	English	Any other language
Relevance	Literature focused on sustainable innovation and end user(s)	
* Keywords appearing in the full article text were rejected because it resulted in an unmanageable number of search results (also due to the broad search parameters adopted).		

The application of the keywords to the EBCSO database was conducted utilizing three search string combinations, as illustrated in Figure 2. This variation in the combination of search strings was applied to obtain a fuller overview of the literature.

Fig 2. The search string combinations of keywords

The initial database search, utilizing the three separate search strings, led to 1,471 hits for Search string 1, 4,805 hits for Search string 2, and 5,121 hits for Search string 3. Of these 11,397 hits, 2973 overlapped, reducing the number to 8,424 potentially relevant articles. Recognizing the challenge of working with this number of articles, a designated reference manager program (RefWorks) was used to sort the articles, rather than doing so on the EBSCO platform itself. The review process itself consisted of an initial title screening followed by an abstract and finally a full text review to narrow down the search results to include only articles within the scope of this study. In case of doubt, the article was kept in the dataset for subsequent more thorough (abstract and/or full-text) screening (e.g. Jones 2004). The initial title screening narrowed the number of possibly relevant articles to 446, whereas the subsequent screening of the abstracts resulted in a further reduction to 93 articles. The abstract review focused first on the sustainability component of the innovation process and second on whether these remaining articles had either an independent or facilitated end-user innovation component. Finally, the full-text screening reduced the number of articles to 35 that are within the scope of this systematic literature review. Figure 3 below offers an overview of the review process.

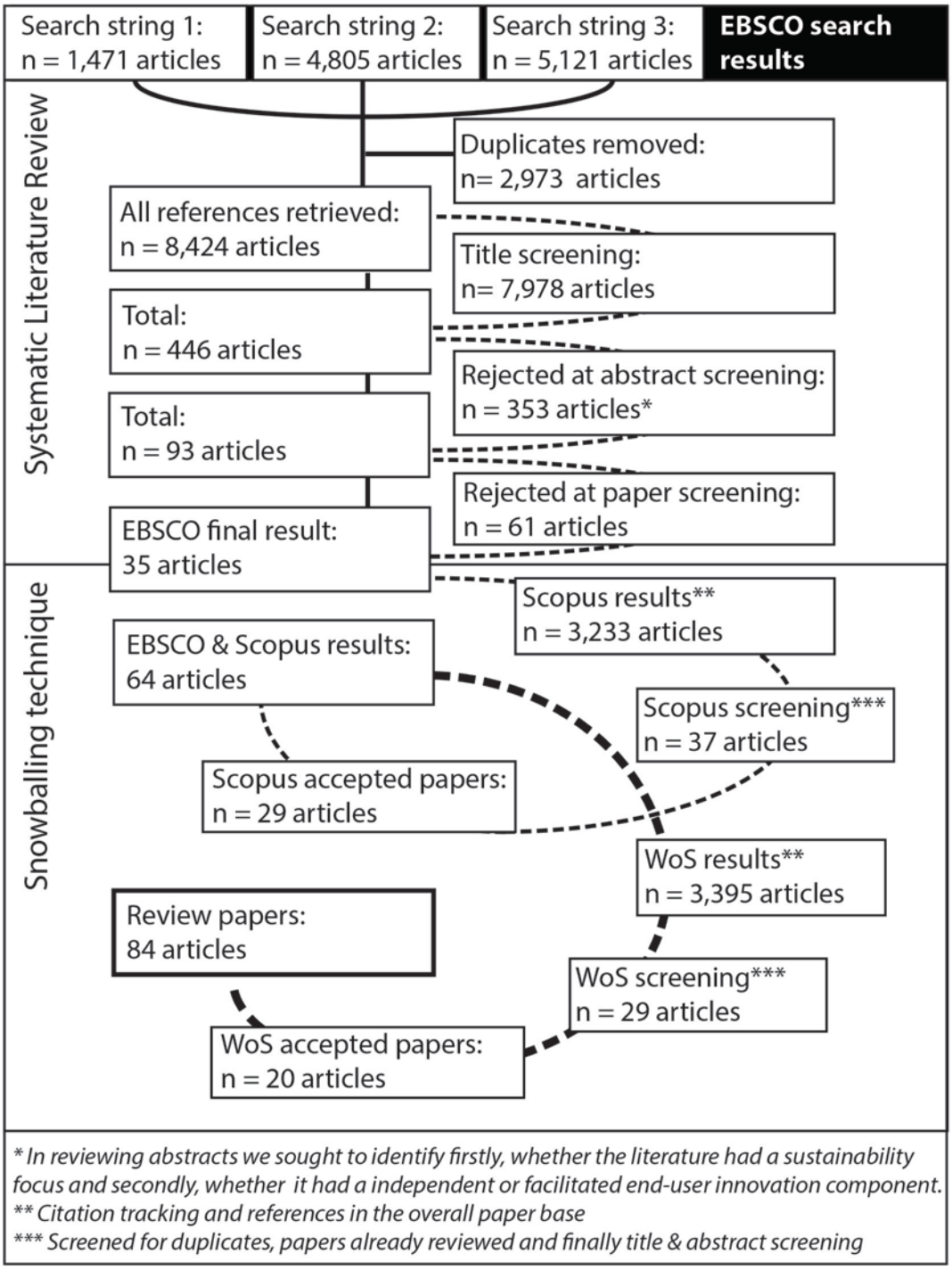


Fig 3. An overview of the literature review process

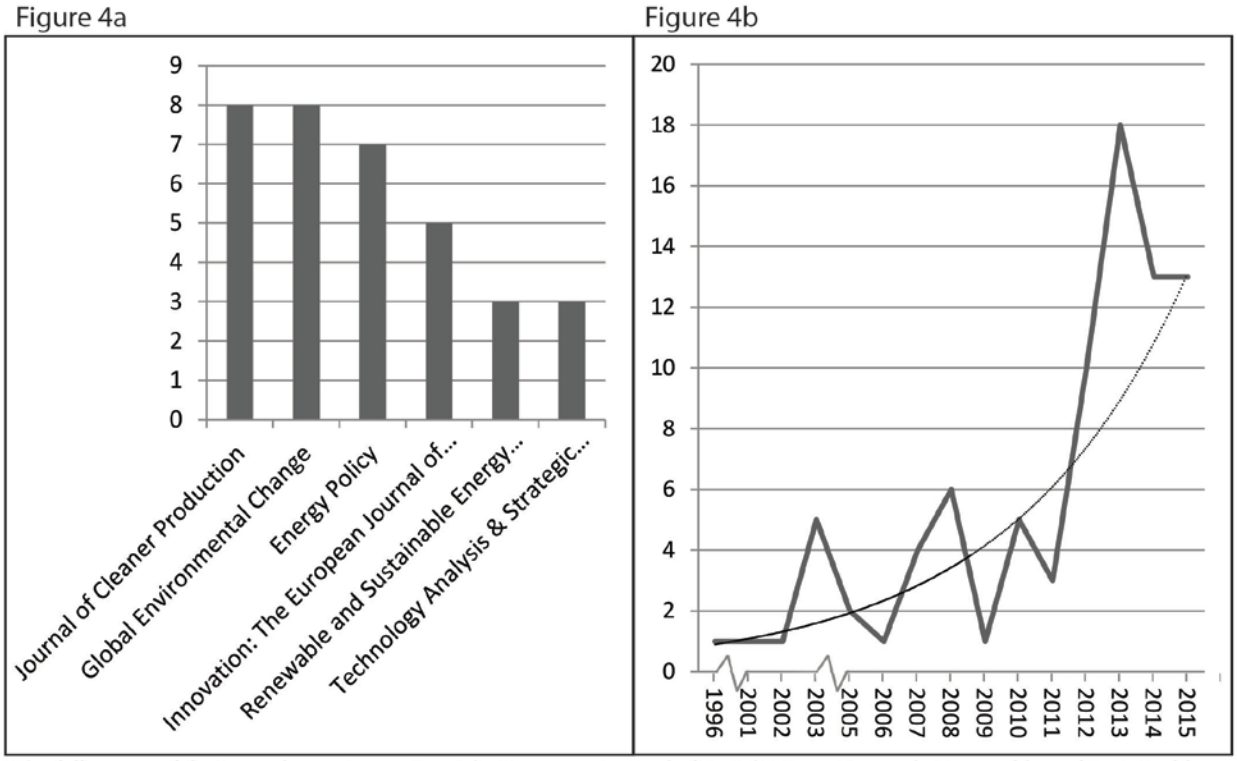
2.2. Snowball sampling

Given the lack of a concise terminology and the diversity of fields studying SEI as well as the limited success at grasping the relevant studies even with broad search parameters,[5] an additional step was introduced next: The 35 articles identified in the first round were subjected to "snowball sampling" using citation tracking as well as the references in the overall paper base. The initial search for citations in Scopus resulted in a total of 3,233 papers. These 3,233 papers were first screened for duplicates and papers already reviewed in the previous systematic review stage. A subsequent title and abstract screening further narrowed the number of possibly relevant articles to 37 papers, of which 29 proved to be within the scope of this literature review when reviewed in full. A second search for citations in Web of Science based on the now 64 in scope articles resulted in 3,395 papers. Similarly, duplicates and already reviewed papers from the previous systematic review stage and the Scopus review stage were first removed. Next, a title and abstract screening narrowed the number of possibly relevant articles to 29, of which 20 proved to be within the scope of the review again when reviewed in full. The final 84 articles represent the core of the review (see Figure 3).

[5] For example: In the field of community currencies, a subcategory of SEI, many different terms are used such as local currencies, alternative currencies, parallel currencies, community currencies or complementary currencies (see Michel & Hudon 2015, p.160).

3 Descriptive analysis

The descriptive characteristics of the final literature sample reflect the diversity of this research field, with a total of 50 different journals represented in the review. However, as Figure 4a illustrates, three journals are particularly prominent in this research field, accounting for nearly one-third of the total literature base on SEI: the Journal of Cleaner Production (8 articles), Global Environmental Change (8 articles) and Energy Policy (7 articles). Also apparent from Figure 4b is that the field is growing rapidly, especially within the last five years (2010–2015), during which 62 out of the total 84 articles were published.



The full names of the journals are: Innovation: The European Journal of Social Science Research; Renewable and Sustainable Energy Reviews; Technology Analysis & Strategic Management.

Figure 4a and 4b. Overview of the core journals and a distribution of publications per year across the period studied.

The descriptive analysis also confirms the observation by Feola and Nunes (2014) that the literature on SEI is predominantly case-based. Of the 84 identified articles, 56 in one form or another build on a case-based approach. These empirical cases draw on a varying number of cases, which also vary in both scale and focus, including, for example, a specific user innovation (Juntunen & Hyysalo 2015a), a specific user innovation locality or neighborhood (Yalçın-Riollet et al. 2014), and several end-user driven grassroots innovation movements (Seyfang & Haxeltine 2012). This diversity creates a multiplicity of narratives, and although there have been attempts to place some of these cases in an overall theoretical framework – e.g., strategic niche management (Hargreaves et al. 2013) – this research field remains arguably empirically rich but theory poor.

In the next step, major areas of SEI as presented in the literature were identified. Based on Tukker and Jensen's (2006a) Environmental Impact of Products (EIPRO) approach, SEI was

grouped into different product and service fields with a high environmental impact: food, energy and heating, living[6] and mobility. Moreover, three subcategories discerned from the literature that fell outside this general product-centric characterization were added: citizen science, development and civic engagement. Citizen science is research on how end-users' abilities are utilized to collect observations, study natural phenomena and, in the example of Cornwell and Campbell (2012), even assist in the documentation and conservation efforts of endangered species. Development refers to research on end-user innovation within the fields of sustainable development, for example, through co-innovation of knowledge between scientists and farmers to increase the productive capabilities of the respective farms and improve their sustainability (Dogliotti et al. 2014). Civic engagement refers to research on end-user innovation and how this results in individual and communal behavior and value shifts. Figure 5 illustrates the distribution of the literature based on these subcategories – the numbers for each subcategory referring to the number of articles on topics in this subcategory.[7]

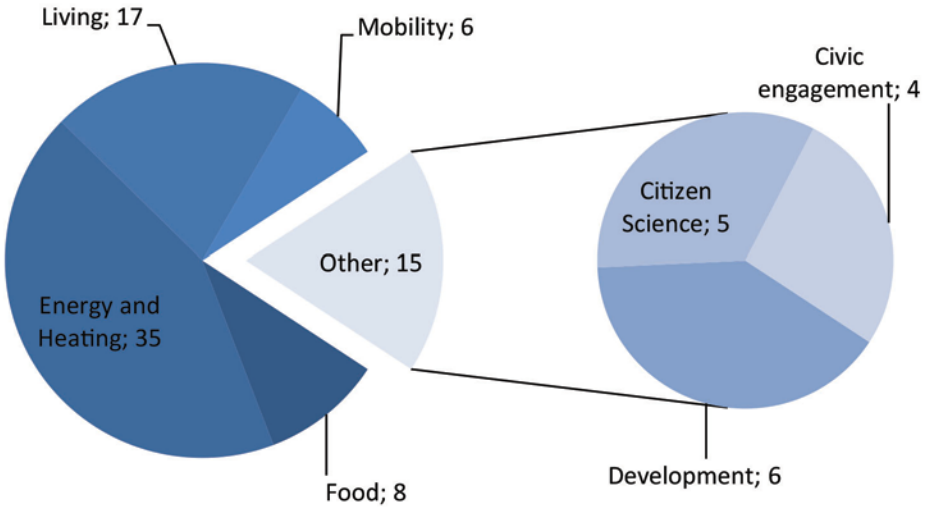


Fig 5. Overview of the major subcategories of the SEI literature

The strong focus on end-user innovation within the field of energy and heating – the largest share of all – illustrates the potential innovativeness of end-users even within fields often characterized as complex and top-down from both an institutional and technical perspective .

4 Categories for analysis

Drivers for and barriers of SEI are discussed in the framework of Ölander and Thøgersen's (1995) Motivation–Ability–Opportunity–Behavior (MOAB) model. The MOAB model conceptualizes the determinants of consumer behavior in relation to sustainability, and although not particularly tailored for understanding SEI, the model is well suited for studying SEI. First, the MOAB model has a broadly applicable coding tool for identifying potential drivers and

[6] "Living" refers to products and services utilized in residential homes apart from electricity and heat production, e.g., kitchenware.

[7] Certain articles touch upon multiple subcategories and are hence represented more than once in the figure above - e.g., Ornetzeder & Rohracher (2013) focus on solar collectors, wind power, and car sharing and hence qualify as a paper focused both on 'Energy and Heating' and 'Mobility' – however, overall, the degree of overlap was minimal, with only a small portion of articles focusing on more than one of the mentioned subcategories.

barriers to end-user behavior that also accounts for the observed attitude-intention-behavior gap, not adequately covered by most other behavioral models (Zanna & Fazio 1982; Devinney et al. 2010). Second, the MOAB model focuses on the end-user and has previously been effectively applied to studying sustainable consumption, production and investment behavior, as well as policy design (Jackson & Michaelis 2003). In the present study, the MOAB model served as the initial deductive coding scheme for classifying key barriers and drivers of SEI identified in the reviewed articles. Additionally, the key variables, motivation, ability and opportunity allowed for stylized coding to identify how and where policy instruments can be implemented to facilitate SEI. The three coding variables are defined as follows:

- *Motivation* represents the underlying reason(s) for a given action that drive(s) the individual's recognition of wants and the subsequent action to satisfy them.
- *Ability* captures the individuals' personal competences and resources and thus includes elements such as end-user knowledge, the ability to carry out this knowledge in practice and access to resources.
- *Opportunity* captures the external conditions supporting or impeding intended action and the connection between intent and action.

Given the lack of an innovation component within the MOAB model and the need to later link to potential effective innovation policies, the coding scheme was extended with three additional innovation specific variables: first, and as already illustrated, the environmentally most relevant product and service fields (Tukker & Jansen 2006b); second, the original driver of the innovation process (facilitated or independent SEI); and third, the type of innovation pursued (incremental, novel or system) based on work by Carrillo-Hermosilla et al. (2010). Incremental end-user innovation refers to any improvement on existing products/services (e.g., improving energy efficiency). Novel end-user innovations are novel products or services, including reorienting an existing product/service in a new direction (e.g., car sharing service, electric bicycles). System end-user innovations are novel products or services that alter an established sociotechnical regime (e.g., localized food system, community power production).

Grounded in the case-based literature (n =56), Figure 6 below illustrates that the original driver of the innovation process appears to influence the type of innovation pursued. The numbers for each subset of the two pie-figures refer to the number of case-based articles covering each.

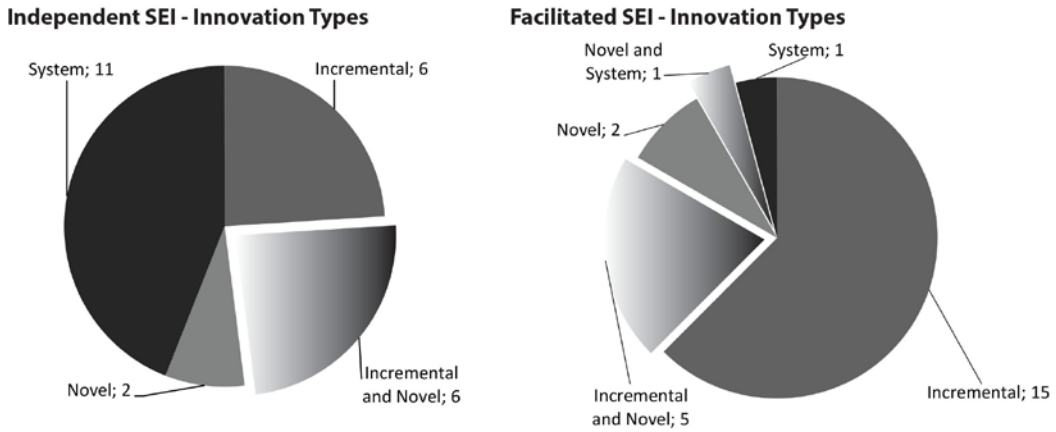


Fig 6. Overview of the innovation pursued by independent and facilitated SEI

Based on the case-based literature, it appears that although system innovation dominates in independent SEI literature (n = 11), incremental innovation appears to be the norm within facilitated SEI literature (n = 15). Although this may be due to biases in the source literature itself, it is also consistent with earlier observations by Seyfang and Smith (2007) when studying grassroots innovation. They suggested that bottom-up initiatives operating outside a market-based framework pursue more radical system innovation, whereas market-based initiatives pursue more incremental market-fit oriented innovation. Hence, it seems relevant to make a distinction between independent and facilitated SEI when considering policy barriers and drivers.

5 Results

The initial descriptive analysis of the literature suggests that end-users in many cases engage actively in sustainable innovation, in multiple capacities and within a diversity of fields, contributing with novel and technically sophisticated designs (Mattinen et al. 2015). Research aiming to map the extent of user innovation suggests that up to eight percent of end-users engage in some type of innovation (Flowers et al. 2010; de Jong & von Hippel 2013); and it is highly likely that some of this activity is in the field of sustainability innovations. Hence, it seems safe to assume that end-users are important innovating actors, also with regard to sustainable innovation, and that it is worth designing policies that specifically foster and facilitate these innovation processes.

5.1. Drivers and barriers to SEI

Using the categorization tools presented in Section 4, key barriers and drivers to SEI from both an independent and a facilitated perspective have been distilled. Table 3 illustrates the initial observations structured according to the MOAB model. It is important to note that the variables of the model should not be perceived as isolated from one another but rather as interdependent. An increased ability to perform a certain task, for example, often also positively influences the motivations to do so (Thøgersen 2005).

Table 3.
The drivers and barriers to independent and facilitated SEI

		Driver(s)	Barrier(s)
Independent SEI	Motivation	- Personal investment in project. - Project has a visible impact. - Collaboration with others (social component). - Community support (real world or internet enabled). - Effective and dynamic leader or group of individuals.	- Feeling of disenfranchisement from the “system”. - Lack of necessary skills leads to a feeling of impotence. - Frustration with innovation process and feeling of isolation. - Dissemination of the innovation is perceived to contradict the innovator’s ideals.
	Ability	- Having enough resources (time, skills, money and materials) and information to carry out the project idea. - Knowledge partnerships with others. - Early access to finance and other resources.	- Lack of technical know-how resulting in stalled or uninitiated projects. - Trouble identifying technical experts willing to help. - Innovation and/or modifying existing products is too expensive for end-users.

	Opportunity	- Open source platforms and online communities. - Support from an NGO, cooperative or other external intermediary. - Access to volunteer help (especially "expert" volunteers with either technical skill or an understanding of economic management)	- Complex grant scheme(s), bureaucracy surrounding grants, and the fluidity of the external funding landscape. - Failure to fit into classical funding criteria and confusion regarding eligibility. - Loss of warranty and insurance on products or services modified. - Lack of specialized tools required to alter products. - Dependence on unstable volunteer base undermines small projects.
		Driver(s)	**Barrier(s)**
Facilitated SEI	Motivation	- Clear specification of expectations and goals. - Seeing that ideas and feedback result in actual adjustment and changes. - Feeling that insights are valued and not ridiculed or taken for granted. - Interactive group meetings.	- Skepticism from the firm or project managers regarding end-user knowledge and intentions – some view end-users as troublemakers.
	Ability	- Users experience needs that producers may not be aware of.	- End-user and expert opinion may diverge due to information gaps.
	Opportunity	- Users offer multiple testing sites for the given product or service.	- Many tools for incorporating end-users into the innovation process remain novel and untested. - Projects focused on end-user innovation require flexibility on behalf of funding regimes that is currently not offered.

As revealed in the user innovation literature (von Hippel 1976), end-users primarily innovate for personal reasons and only secondarily, if at all, for commercial gains (Gabbott & Hogg 1999; Lettl 2007). Therefore, the general perception is that many end-user innovators have no intentions to achieve commercial success and only do so by accident, along the way (Shah & Tripsas 2007). The key characteristics shared with user innovation in general therefore include innovating due to the personal enjoyment of the process (Hertel et al. 2003; Jalas et al. 2014), the social capital gained by doing so (Ornetzeder & Rohracher 2013; Seyfang & Longhurst 2013) and, in certain circumstances, the financial element at stake (Ross et al. 2012). As opposed to traditional user innovation, however, end-users involved in SEI innovate (also) for others as opposed to (only) for themselves. Independent SEI is therefore often characterized as being driven not by market forces but rather by personal interests, passion and idealism (Seyfang & Smith 2007; Seyfang & Haxeltine 2012).

The "historical disenfranchisement of lay people from centralized systems" (Jalas et al. 2014, p.90) seems to be a central motivational barrier to independent SEI. End-users often perceive themselves as incapable of causing change or as lacking the necessary skills to do so (Ross et al. 2012; Jalas et al. 2014). This is also translated into a sense of frustration faced by a significant number of independent SEI due, for example, to a sense of isolation and failure to obtain funding from overly complex and shifting funding regimes (Kirwan et al. 2013; Hargreaves et al. 2013;

Feola & Nunes 2014). Furthermore, the often idealistic (or even activist) approach to sustainable innovation characterizing many independent SEI also creates issues with regard to the diffusion of the innovation(s) (Seyfang & Haxeltine 2012). Often, independent SEIs want to create their project as a counterpoint to the mainstream and therefore do not wish to "integrate" it into the dominant regime (Seyfang & Smith 2007). This internal dynamic, although understandable, can act as a barrier to the dissemination of especially system innovations because any step towards the mainstream could be conceived of as "selling out".

From a facilitated SEI perspective, end-users are often highly motivated to take part in an innovation process, provided that their role in the process is clear and that they feel that their views are taken seriously (Rohracher 2003; Hoffmann 2007). A lack of motivation by the end-user seems to be a less important barrier for end-user integration than skepticism by the facilitators regarding the competences of the end-users involved (Rohracher & Ornetzeder 2002; Cornwell & Campbell 2012). Rohracher (2003) notes that some experts view end-users as "troublemakers" or "irrational" in their comments. This divergence between expert and end-user opinions has also been observed in citizen-led conservation, where local knowledge can be in conflict with expert knowledge (Cornwell & Campbell 2012). Hence, the major challenge for facilitated SEI is to identify platforms that can bridge this gap between facilitator experts and end-users.

The major ability barriers to independent SEI identified in the literature can be broadly classified into two types: lack of end-user competences and lack of resources. The lack of competences includes a lack of technical expertise (Heiskanen et al. 2011; Jalas et al. 2014), difficulties with finding and organizing suitable collaborators (Feola & Nunes 2014), and issues concerning where and how to access potential external resources (Seyfang & Smith 2007; Ross et al. 2012). The importance of a lack of resources is, for example, highlighted in Heiskanen et al.'s (2011) case study on end-user innovation regarding heat pumps that cost up to EUR 20,000. The financial risks involved when tinkering with such an expensive system would seem to be a natural barrier to many potential end-user innovators (Hyysalo et al. 2013b). Time constraints are also a major barrier for many end-users. Maintaining micro-generation of heat and power, for example, is time consuming (Juntunen & Hyysalo 2015b). In addition, a significant number of the independent SEI reviewed in the literature depend on the labor resource of volunteers for their survival and consequently struggle to secure and maintain their access to a stable volunteer base (Hoffman & High-Pippert 2005; Seyfang & Smith 2007).

As sketched above, within facilitated SEI, expert and end-user knowledge and opinions may conflict. This could be due to the previously discussed motivational component and/or due to information gaps between end-users and experts. These gaps arise because information sharing is often hampered by the "stickiness" of information – referring to the often costly acquisition and transfer of information from one location to another (von Hippel 2005). This makes the sharing of information "highly contextual, tacit and difficult to transfer from one site to another" (Heiskanen et al. 2013, p.242). End-users often simply speak a different "language" than experts within their respective fields. Although incorporating end-users into a facilitated SEI process is meant to ease the stickiness of information transfer, this remains an issue.

From an opportunity perspective, independent SEI remains challenged by the fact that the project is either wholly financed by their own income, and innovators therefore view the process as a personal project or reliant on shifting funding landscape (Hyysalo et al. 2013b; Hargreaves et al. 2013). Seyfang and Smith (2007) noted, with reference to Church (2005) and Wakeman (2005), that many of these initiatives spend 90% of their time simply surviving economically, thus leaving little time for their focal activity. These projects also remain enormously dependent on key individuals in the group, and when these individuals inevitably leave the project, the projects often fail to receive additional funding (Kirwan et al. 2013). Consequently, limited access to finances remains a significant opportunity barrier to the independent SEI process, driven by a number of issues. The first issue relates to the grant funding process itself, which a significant number of independent SEI note as being overly complex and therefore a source of considerable frustration (Seyfang & Smith 2007; Ross et al. 2012). This relates to identifying eligibility but also to the bureaucracy and requirements usually associated with the application process (Smith 2007; Walker 2008). In addition, some independent SEI, especially within system innovation, face issues with regard to matching the currently available grant and funding schemes, especially because they fall between "the interstices of traditional social, economic, and environmental issue boundaries" (Seyfang & Smith 2007, p. 596). The inaccessibility of some government institutions has also been noted as a barrier to independent SEI (Ross et al. 2012; Seyfang & Haxeltine 2012). Hence, the lack of opportunity for end-users to alter or change existing products or services in a simple fashion is currently a significant barrier to SEI (Hyysalo et al. 2013b). The fact that modifying a product or service often leads to an immediate loss of warranty and insurance is another external constraint on end-users' willingness to engage in user innovation (ibid). Additionally, many producers actively attempt to prevent end-users from tampering with their products by, for example, requiring specialized tools to disassemble the product (Ornetzeder & Rohracher 2006; Heiskanen & Lovio 2010). Finally, the often isolated nature of end-user innovators has been noted as greatly endangering the survivability of many projects as isolated independent SEI (Feola & Nunes 2014).

According to the reviewed literature, facilitated SEI especially faces two practical issues, one with regard to funding constraints and the other with regard to identifying methods for effectively co-opting end-users. End-user involvement and co-design requires a flexible project planning environment, and current funding regimes have been found to be too inflexible to properly facilitate end-user integration and involvement (Heiskanen et al. 2013). Most government-funded projects require detailed plans that cannot easily be altered to fit new information or end-user feedback gained during the project. Coupled with this, there is also the issue of identifying the correct tools to use to effectively integrate the end-user into different facilitated processes.

5.2 Policies supporting independent SEI

Despite the novelty of the field, a number of policy tools for supporting independent SEI have been identified in the literature. These include formal and informal education initiatives, supportive intermediaries, microloans and alternative finance, and data access and co-location.

Policy makers can pursue the incorporation of sustainable innovative ideas into a formal education setting (Smith 2007; Kiros-Meles & Abang 2008). An example is the introduction of organic farming techniques into the curriculum at agricultural colleges in the UK (Smith 2007), a

move that not only led to increased end-user competences within the given area but also helped to increase the legitimacy of organic farming in the eyes of the general public (Ibid). Do-It-Yourself (DIY) and self-building courses and groups are other educational instruments used to overcome some of the stated barriers to independent SEI. They seem to be especially effective in building competences, empower end-user action, facilitate group creation and learning, and even aid in the dissemination of both end-user competences and the innovation itself. These groups can either be organized as real-world events (Ornetzeder & Rohracher 2006) or via online fora and websites (Hyysalo et al. 2013a).[8] In both cases, they aim to empower end-users with the necessary tools and competences to repair, alter and even build products or services. It has been observed that by integrating end-users into a group-learning process, their technical know-how quickly increases (Hyysalo et al. 2013b). These gains in know-how and the success with the process itself often also results in increased end-user empowerment and a sense of personal fulfillment. These groups additionally establish a sense of belonging to a group and encourage social learning (Ornetzeder & Rohracher 2013; Jalas et al. 2014). The dissemination and legitimacy of a given sustainable innovation can also be strengthened by DIY and self-building groups. This could be observed, for example, with regard to the spread of solar collectors in Austria (Ornetzeder 2001). These groups and courses could both be organized at a local level, as recommended by Jalas et al. (2014), or policy makers could facilitate the creation of online forums either by supporting the running costs or by offering minor remuneration "to the moderators and key users for the voluntary helping behaviors these users already do" (Hyysalo et al. 2013b, p.499).

Intermediary actors representing "boundary organizations" engaging in "relational work" between varying independent initiatives have also been identified as important actors in supporting the overall independent SEI process (Moss 2009). These intermediary actors work between communities to support fledgling localized independent initiatives, specifically by helping to grow, consolidate and spread initiatives (Kemp & Rotmans 2004; Hargreaves et al. 2013). Intermediary actors can also help to support independent SEI achieve funding either via direct participation or by assisting in the process (Feola & Nunes 2014; Hargreaves et al. 2013; Seyfang & Smith 2007). Examples highlighted in the literature include various localized cooperatives (Ornetzeder & Rohracher 2013), national organizations such as Communities and Climate Action (Hargreaves et al. 2013) and the Transition Town movement (Seyfang & Haxeltine 2012), as well as international networks such as Ashoka (ashoka.org) (Partzsch & Ziegler 2011). In addition to potential funding support, these organizations can also facilitate pooling of resources between various smaller independent SEIs. The success of the Austrian solar collector case was facilitated, for example, by the fact that the self-building groups coordinated purchases and bought in bulk (Ornetzeder 2001, p. 109). This pooling of resources can also be seen with regard to attracting new members and sharing skills (Hoffman & High-Pippert 2005; Ornetzeder & Rohracher 2013). Finally, intermediaries can also grant end-user innovators a common voice for ensuring the continued commitment of policy makers (Ross et al. 2012; Hargreaves et al. 2013). The success of wind turbine and car sharing innovation was, for example, partly attributed to the traditional culture of cooperatives in Denmark and Switzerland, which "gave grassroots innovations a well-proofed means of organizing action" at a local level

[8] Organized events include "repair cafes" (e.g., repaircafe.org), which give end-users the tools necessary to repair their products and which also have specialists at hand to assist the end-user. Websites such as IFixit (www.ifixit.com/) offer free repair guides to a variety of everyday products.

(Ornetzeder & Rohracher 2013, p. 862). Additionally, the successful coordination of the Danish "wind meetings" allowed end-user innovators to meet with regulators and utilities and to lobby them to create a framework through which wind power could be effectively coupled to existing electrical grids (Karnøe & Garud 2012).

Despite the near unanimous observation that current funding regimes need to be improved, there is a surprising lack of recommendations on how exactly they could be improved. Ross et al. (2012, p. 488) suggest the establishment of a "one-stop shop for advice and funding that covers all categories of innovator" for not only entrepreneurs but also end-user projects. Other possibilities include micro-grants with less labor-intensive funding schemes, as often "small amounts of money at the right time can make a huge difference to lone innovators and micros" (Ross et al. 2012, p. 487). A more open framework within grant and funding regimes has also been suggested. However, how this should be practically executed in policy remains unclear from the literature. An alternative source of funding for social and sustainable innovation noted in the literature is the emerging field of crowdfunding (Lehner & Nicholls 2014; Zhang et al. 2014). Here the aggregated power of the "crowd" is drawn upon with small contributions from a diverse number "crowd-investors" accumulating to create sufficiently large totals (Bruton et al. 2015). The scale of alternative financing, like crowdfunding, is already significant, with a few but growing number of policy entities utilizing it as a tool to engage in co-financing (Zhang et al. 2014; Greater London Authority 2015). In addition, several researchers suggest that crowdfunding could be a potentially significant financier of social and sustainable innovation. For example, Lehner and Nicholls (2014) note that crowd investors are often driven to invest by the idea, core values and legitimacy of the product or service, as opposed to its business plan. This is in unison with the fact that crowdfunding, which typically draws on many small investments or donations rather than larger single actor investments, could facilitate more responsibility-oriented investments (Idelchik & Kogan 2012; Lehner & Nicholls 2014).

Finally, increasing free access to enabling data, such as public transit timetables, geographical data and pricing, has been suggested as a means to support independent SEI. This is especially relevant for the design of "smart green" travel apps[9] because the availability of travel data permits end-users to make their own public transit apps (Ross et al. 2012). Policy initiatives that have attempted to accomplish this include the UK Midata initiative (Gov.UK 2011) and the US data.gov project (US Data.Gov 2014). However, many government datasets remain compartmentalized and non-standardized, creating hurdles for independent SEI. Data availability and standardization are therefore important tools for supporting these types of initiatives. Additionally, co-locating independent SEI among other start-ups has also been noted as an external opportunity facilitator. In co-locating various entrepreneurs and independent SEI, a number of spill-over opportunities arise. These include networking opportunities, increased access to knowledgeable people and an increased potential for collaboration (Horwitch & Mulloth 2010; Ross et al. 2012). The last opportunity is seen as particularly important because of the potential for collaboration viewed "as an essential enabler for successful innovation" (Ross et al. 2012, p.481). As a positive side effect, it becomes easier for local and national governments to host workshops and organize get-togethers because there is a present and identifiable target group.

[9] Smart green travel apps facilitate travel by public transit by offering the user easy, one-step, on-the-spot and up-to-date access to time schedules, prices and connection information.

5.3 Policies supporting facilitated SEI

The primary issue facing many facilitated SEI processes is ameliorating end-user and expert (project leader) motivations, expectations and divergences. Although the need for more flexible funding schemes has been noted (Heiskanen et al. 2013), the literature remains unclear on how this should be achieved. Methods for ameliorating facilitated SEI should therefore include platforms that can bridge the gap between experts and end-users. Such platforms include open source platforms, awards and competitions, crowdsourcing, toolkits, the lead user method and living labs.

Open source platforms have already been studied in depth within the open innovation literature and have shown in practice to be a successful means of facilitating innovation within a variety of sectors (Hertel et al. 2003). The basic concept is that individuals, organizations and governments make a given product design or blueprint universally available to be used freely by anyone. End-users can subsequently utilize the given product or modify it to better suit their needs. Typically, this includes making these modifications freely available for others to mimic. As within the DIY and self-building community, end-users find a sense of joy in the process itself and the linked reputational gains (Lakhani & von Hippel 2003). The full potential of open source within sustainability remains less explored in the reviewed literature. However, examples including open source water management systems (Chen et al. 2010) and e-participation platforms within sustainable tourism (Chiabai et al. 2013) illustrate a latent potential that arguably has been far from fully exploited.

In addition, awards and competitions are effective facilitators of SEI because they trigger a number of enabling drivers, including exposure and public awareness, credibility, encouragement, and of course a financial incentive (Ornetzeder & Rohracher 2006; Füller et al. 2012). Additionally, competitions typically bring together many like-minded people as well as investors and therefore present networking opportunities and innovation spill-over prospects. Furthermore, these types of awards and competitions allow policy makers to steer the direction of sought-after innovation. Although there is a danger of discouraging innovation after losing a competition, the benefits appear to outweigh the risks (Ross et al. 2012). A key emergent type of competition available to policy makers is to utilize the interconnectivity of the Internet as a means to mobilize “crowd” knowledge and ideas. The success of the Harvard Crowd Innovation Lab and NASA Tournament Labs illustrate the complexity of problems that a “crowd” can solve. Several reviewed papers thus note that a similar process could also be utilized with regard to sustainable innovation (Füller et al. 2012; Idelchik & Kogan 2012). Füller et al. (2012) note that crowdsourcing has a strong non-monetary incentive structure from the point of view of the end-user, and therefore, it is possible to get more with less, if the aim of the SEI is legitimate in the eyes of the end-users participating in the process (Zhang et al. 2014).

The lack of opportunity for end-users to alter or change existing products or services in a simple fashion is currently a significant barrier to SEI (Hyysalo et al. 2013b). The immediate loss of warranty and insurance on modified products or services is a very real external constraint on end-users’ willingness to take on user innovation (Ibid). Von Hippel (2001, p.247) proposed equipping end-users with toolkits as a promising way for manufacturers to permit “users real freedom to innovate, allowing them to develop their custom product via iterative trial-and-error”.

Such toolkits could, for example, be tools to freely manipulate aspects of a computer game, such as Garry's Mod (garrysmod.com), allowing end-users to modify the game. Facilitating innovation via toolkits has also been proposed within the reviewed literature (Ornetzeder & Rohracher 2006; Heiskanen & Lovio 2010). Currently, however, research remains centered around traditional user innovation, most typically within IT and the service industry (von Hippel 2001; Franke & von Hippel 2003). Policy makers could encourage producers and service providers to make specific sustainability-oriented toolboxes available to consumers to help them innovate. Granting end-users easier access to modify products or services could allow project leaders to facilitate better end-user and expert learning, ideally allowing end-users to create more efficient products for themselves (Hyysalo et al. 2013b).

Finally, LivingLabs (LL) represents a systematic approach to integrating end-users into the innovation process via direct end-user involvement. Specifically, LL seeks to involve end-users not within an external context, via, for example, workshops at a university, but instead within their own everyday context. LL is therefore "a user-centric innovation milieu built on every-day practice and research, with an approach that facilitates user influence in open and distributed innovation processes engaging all relevant partners in real-life contexts, aiming to create sustainable values" (Bergvall-Kåreborn et al. 2009, p.3). The aim is not to test modules against end-user requirements but instead to bring end-user "explorational learning" to bear with regard to the creation of new ideas and insights (Ibid). Liedtke et al.'s (Liedtke et al. 2015) approach to LivingLabs, or Sustainable LivingLabs (SLL), is a real world example of how this method can be applied in practice. In utilizing the SLL method, Liedtke et al. (2012) pursue a better understanding of energy and resource efficiency within sustainable buildings, specifically by studying and incorporating the insights of end-users living in these buildings. Furthermore, Liedtke et al. (Liedtke et al. 2015) study both the technical feasibility of these buildings and also whether end-users accept the given living conditions that these technical specifications dictate to remain sustainable. The LL approach reflects an opportunity for researchers to better understand end-user behavior and to draw upon end-user insights via the approach suggested by Liedtke et al. (2015). From a policy perspective, SLL could offer policy makers and researchers the tools necessary to overcome, for example, behaviorally driven rebound affects.

6 Discussion

As noted in the descriptive overview, research on SEI has grown significantly, particularly in the last five years. The compilation and synthesis of this literature has revealed its immense diversity and multiplicity, both empirically and theoretically. The review also revealed a nuanced literature with many insights and perspectives and, at the same time, an emergence of research "silos" working independently from each other, where one stream of researchers seems unaware of others covering similar topics from the same actor perspective. Although conceptual differences exist, these literature streams may still garner insights from one another. For example, the literature on grassroots innovation within community energy could draw insights from the literature on user innovation within sustainable home energy technologies and vice versa (Seyfang et al. 2013; Hyysalo et al. 2013b).

As noted, there is a paucity of theory in this research field, which can in part be explained by the novelty of this literature. Another contributing factor might be the diversity of academic disciplines contributing to the exploration of the role of end-users in the sustainable innovation

process. The literature on grassroots innovation (Seyfang & Smith 2007), for example, builds on a different theoretical tradition than the literature on LivingLabs (Liedtke et al. 2015) or user-led innovation (Ornetzeder & Rohracher 2006). Indeed, even researchers studying the same phenomenon and drawing on common literature often use different terminology. For example, Staggenborg and Orgodnik (2015), studying the Transition Town movement in Pittsburgh, US, refer to it as 'new environmentalism', whereas previous studies on the Transition Town movement in the UK by Seyfang and Haxeltine (2012) refer to it as grassroots innovation. Hence, not only is the field arguably theory poor, but the theories and frameworks that are applied stem from different research traditions. In sum, a coherent theoretical perspective in this field is lacking yet needed.

The results suggest that there is a need to examine the overall role that the end-user plays within innovation because increased end-user innovation is not necessarily a dividend from a sustainable innovation perspective. In fact, more end-user innovation could result in more rather than less unsustainable practices because it leads to more niche products and services for consumption. Hence, end-user innovation is not in and of itself a solution to our current unsustainable practices. Young end-users, for example, arguably do not typically modify their cars with fuel efficiency or sustainability in mind. In more extreme cases, end-users pursue wholly unsustainable ends, exemplified by the fad known as rolling coal or rolin' coal (Grenoble 2014). In this case, end-users modify the amount of fuel injected into the car engine combustion chamber so that the fuel is only partially combusted. The result is a highly inefficient engine, with visible black soot exuded from the exhaust. Although this is an extreme case, it illustrates that we should be wary of seeing end-user innovation as always a positive development. Understanding the motivations for SEI is at the heart of this issue, and it is therefore safe to argue that this is an area where there is an urgent need for additional research. We need to understand not only what drives an end-user to innovate, as with traditional user innovation literature (West & Bogers 2014) but also why they innovate for sustainable ends. The literature on sustainable entrepreneurship could be a point of departure for this research, in addition to current behavioral science research on pro-environmental behavior in general (Gifford & Nilsson 2014; Thøgersen 2014; van Vugt et al. 2014).

The near uniform critique of current funding regimes should also translate into research on how these regimes may be improved. One might draw on the authoritative advice of behaviorally informed public policy as the starting point for further exploration (Mullainathan & Shafir 2013; Ölander & Thøgersen 2014). In the US, for example, the simplification of college information sheets, so-called College Scorecards, offers an example of how to simplify and make more accessible complex information (Sunstein 2013). The paper proposes that a similar approach could be employed to simplify current funding schemes. However, further research is needed to explore how funding schemes can be simplified while remaining conducive to both end-user and policy maker needs. An important caveat is that, whether designing college information sheets or funding schemes, "a minimum requirement is that one takes heed of the heuristics people use when processing information" (Ölander & Thøgersen 2014, p.343). In addition, crowdfunding might be both an initial source of funding for SEI and help support the transitory step that some, primarily independent, SEI make from government sources of finance to commercial sources. This could be especially relevant for independent SEI projects that have become overly dependent on government funding schemes for their survival (Karnøe & Garud 2012). It is

therefore suggested that, despite relevant discussions regarding issues of investor protection in the US (SEC 2014) and EU (EC 2014), crowd-funding might in the future become a new and potentially large financier of sustainable innovation. One could even imagine that policy makers could draw on crowdfunding as a type of co-financing for projects via end-user involvement.[10] Understanding what motivates end-users to participate seems to be the key to tapping into this potential resource for co-financing sustainable innovation.

Overall, when reflecting on the policy options suggested in the literature to support independent SEI, it appears that these policy options are primarily aimed at enabling end-users with the necessary skills and resources to innovate. Promising approaches in this regard include tailored DIY workshops, resources, networks and knowledge access. Policies aimed at facilitated SEI appear to be primarily focused on creating platforms that enable the effective introduction of end-user knowledge into an already existing framework. This might be done, for example, through the lead user method, crowdsourcing, open source and sustainable living labs.

Finally, the results of this review confirm the observations by Ornetzeder and Rohracher (2013, p. 866) that there is a need for more research focusing "on missed opportunities and discontinued initiatives," specifically because it would enable a better understanding of how local settings and structural conditions influence the success or failure of SEI. In exploring these areas, a better understanding of the arguably growing role of the end-user within sustainable innovation and how policy can create a context more conducive for this type of innovation process may be gained.

7 Conclusion

The present review shares the observation with Seyfang and Smith (2007) that sustainable innovation and end-user action are in general viewed as separate issues, both from a policy and research perspective. This division inhibits sustainable innovation because end-users evidently can and do play a key role within the innovation process. In systematically reviewing the literature, this paper has aimed to summarize and synthesize this available knowledge, providing an evidence base for developing more effective policy tools that might facilitate SEI. The latter presents an innovation niche that at the moment remains largely ignored by policy and is hence an untapped source in a world that urgently needs smart sustainability innovations of all types.

From an academic perspective, this paper contributes to the field of sustainable innovation by synthesizing the compartmentalized literature focusing on the active role of end-users within sustainability-oriented innovation. Another important contribution is the overview of key barriers and drivers to SEI, while also highlighting areas for potential future research. Hence, the paper hopefully will act as an overview and resource for scholars interested in pursuing this line of research.

From a practitioner's perspective, the recommended policy tools offer insights into how to both encourage SEI and also bring end-user abilities to bear within an institutional framework. A

[10] The German crowdfunding platform EcoCrowd (https://www.ecocrowd.de/en) represents an example of how policy makers could help facilitate end-user involvement in sustainable innovation. In this case, the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety co-finances the sustainable crowdfunding platform.

good example is the mobilization of crowd-knowledge and resources to help solve and co-finance sustainability challenges. Overall, the paper suggests that end-users combined with other innovation actors represent a major resource for achieving multiple pathways towards a more sustainable future – a source that should be tapped systematically by innovation policy. This seems to be advisable particularly because radical innovation often starts in small protected niches where uncertainty and low product performance levels and efficiency are tolerated (Kemp et al. 1998; Caniëls & Romijn 2008).

The literature on end-users within sustainable innovation remains multifaceted, diverse and widely distributed with multiple terminologies and empirical cases. The rapid growth of this literature within the last five years does suggest that this phenomenon is increasingly also becoming more common within sustainable innovation. If we assume that up to eight percent of end-users innovate for themselves, as one study suggests (Flowers et al. 2010), and if just a fraction of them innovate for social or sustainable ends, the aggregated potential could be substantial.

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