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Open and sustainable: An emerging frontier in innovation management?

Jaan-Pauli Kimpimäki [*,a], Iryna Malacina [a], Oskari Lähdeaho [b]

[a] LUT University, School of Business and Management, Yliopistonkatu 34, Lappeenranta 53850, Finland
[b] LUT University, LUT Kouvola Research Unit Industrial Engineering and Management School of Engineering Science, Tykkitie 1, Kouvola, 45100, Finland

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ABSTRACT

The concepts of openness and sustainability have both enjoyed an increasing popularity in recent scientific literature. However, research has yet to fully utilize their combination and the potential carried toward developing strategies and policies toward solving complex sustainability issues. The primary objective of this paper is to identify and describe the theoretical connections between sustainability and open innovation. We investigate the structural and statistical aspects of recent open innovation literature in search of signs of sustainability using bibliometric metadata and perform a content analysis of articles relevant to Sustainable Open Innovation. Our findings indicate that despite a lack of institutionalized use of sustainability-related keywords, circa nine per cent of the sample articles materially discuss aspects of sustainability or societal concerns from various perspectives, but also lack a holistic and unified approach. As our primary contribution, we shift the level of inquiry in Sustainable Open Innovation research from an organizational-level toward a multi-level system understanding, situating our findings regarding open and sustainable forms of innovation present in the literature as a framework containing the individual, organizational, city, and regional levels and their interconnections.

1. Introduction

Concerns around sustainability issues are complex and ever-growing (Bansal, 2019; Whiteman et al., 2013). These problems tend to be systemic, and solving them requires collaborative efforts (Bowen et al., 2018; George et al., 2016; Slawinski and Bansal, 2012). Open Innovation (OI) provides one framework for organizing such collaborative efforts. For several years already, organizations such as OpenIDEO have been organizing OI-based initiatives for solving complex sustainability challenges. Where does the research on this issue stand?

Setting the stage for this line of inquiry Bogers et al. (2020) introduced the concept of *Sustainable Open Innovation* (SOI). They define SOI as *"a distributed innovation process which is based on purposively managed knowledge flows across organizational boundaries, using pecuniary and non-pecuniary mechanisms in line with the organization's business model, thereby contributing to development that meets the needs of the present without compromising the ability of future generations to meet their own needs"* (p. 1507). Their definition combines the core elements of the traditional definitions of OI, linking them with the Brundtland (1987) definition of intergenerationally considerate sustainable development.

OI and sustainability appear to be intrinsically connected through a shared necessity of understanding openness at the broader system level. Although considerable research has been dedicated to both fields separately, their interconnections remain poorly understood. Despite the recent emergence of the SOI concept and other alternative frameworks investigating the connection points between sustainability and open innovation practices—such as *Open Sustainable Innovation* (Cappa et al., 2016) and *Open Social Innovation* (Chesbrough and Di Minin, 2014)—a broader and more general understanding of this area of research remains underdeveloped. To date, research dedicated to this area has mainly focused on the organizational-level regarding e.g., opportunities arising for product development (Cappa et al., 2016), social innovation in non-profit organizations (Chesbrough and Di Minin, 2014), and most recently on "*how open innovation can effectively drive innovation activities to address a stated sustainability objective*" (Bogers et al. 2020, p. 1506). We frame this study on the latter perspective, combined with the potential of openness as a tool for engaging actors to interact across various levels within socio-technical systems (Farla et al., 2012; McMeekin and Southerton, 2012). In doing so, we seek to advance existing understanding of SOI by moving our frame of reference beyond

Abbreviations: LDA, latent dirichlet allocation; LL, living lab; MCN, minimum cost pathfinder network; RWB, random-walk betweenness; SOI, sustainable open innovation; SLL, sustainable living lab.

* Corresponding author.
E-mail addresses: jaan-pauli.kimpimaki@lut.fi (J.-P. Kimpimäki), iryna.maliatsina@lut.fi (I. Malacina), oskari.lahdeaho@lut.fi (O. Lähdeaho).

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the organizational-level toward situating SOI as a component of a broader system of actors, where each system layer individually contains a portion of the seeds necessary to develop solutions for resolving complex sustainability issues.

Our objective is to better describe the theoretical connection points between sustainability and OI. Developing a better understanding of the link between sustainability and OI is needed to address both managerial and policy concerns. Managers are constantly faced with external stakeholder pressures to address sustainability concerns (Kassinis and Vafeas, 2006; Watson et al., 2018) and therefore need to continuously innovate for sustainability. Simultaneously, policymakers need ways to effectively incentivize the right types of (open) innovation activities at various policymaking levels (Söderholm et al., 2019). To date, sustainability issues still tend to be seen more as policy rather than business problems. Regardless, both are valuable perspectives that can be informed through an improved understanding of the dominant links between sustainability and OI. We study this link with a bibliometric approach, measuring both structural and statistical aspects of language-use in contemporary scientific literature using the keyword 'open innovation' and a subsequent content analysis of articles identified as materially relevant to our research focus on SOI.

Based on our empirical findings and content analysis, we develop a multi-level theoretical framework conceptualizing levels of SOI and their interactions. Our findings contribute to advancing the SOI research agenda by displaying the dominant trends in OI research, and by demonstrating which of those OI-trends are primarily associated with addressing various sustainability issues. We also show how SOI practices tend to correspond primarily to open collaborative innovation research within the broader body of OI research. Our findings contribute to the OI literature by underscoring how the open collaborative innovation substream is relatively dominant for addressing sustainability issues.

We structure the paper as follows: in Section 2 we present a brief overview of previous literature related to open collaborative innovation, sustainable open innovation, and a multi-level perspective on OI. In the next Section 3, we describe our methodology. We then present and discuss our findings in Section 4, which we finalize by outlining our theoretical framework under Section 4.2, discussing the limitations of our study and future research opportunities arising from our findings in sub-Section 4.3. Section 5 concludes the paper, including a discussion of the resulting managerial and policy implications.

2. Theoretical background

2.1. Open collaborative innovation

The openness perspective has revealed a different way of thinking about innovation. Successful innovation today is considered more the product of a network of actors than individuals or organizations alone. Chesbrough's (2003) concept of OI is one of the most popular currently studied branches of innovation management. On the firm-level, OI implies that firms should leverage their in-house inventions outside their organizational borders concurrently with exploiting ideas existing in a firm's external environment (Chesbrough, 2003). From this standpoint, firms can not reach superior performance innovating only from within. Instead, to innovate effectively and efficiently they must collaborate with other actors and leverage their networks (Arlbjørn and Paulraj, 2013; Manceau et al., 2012).

OI research is typically classified to inbound or outbound OI (Chesbrough and Crowther, 2006). Inbound OI relates mainly to sourcing and leveraging technologies and knowledge made by others (Spithoven et al., 2010), while outbound OI implies a search for external organizations better suited to commercializing internally developed technologies (Chesbrough and Crowther, 2006; Spithoven et al., 2010). Inbound OI practices include e.g., joint ventures (Enkel et al., 2009), crowdsourcing (Cappa et al., 2019; de Mattos et al., 2018) or innovation contests (Terwiesch and Xu, 2008). In turn, examples of outbound OI practices include out-licensing (Hu et al., 2015) and the sale of innovation projects (Bianchi et al., 2011) among others.

Open collaborative innovation is a sub-type of OI combining knowledge inflows and outflows i.e., inbound and outbound OI processes (Bogers, 2012). In this paper, we concentrate on open collaborative innovation practices involving multiple actors sharing ideas, knowledge, expertise, and opportunities (Kodama, 2015; Sørensen and Torfing, 2016). Examples of such practices include living labs (Leminen et al., 2020), joint R&D projects (Du et al., 2014) and supplier involvement in new product development (Johnsen, 2009). Collaboration with different partners enhance innovativeness due to the diversity of knowledge to be shared and combined, thereby enabling the collaborators to fill out their initial knowledge gaps and skill endowments (Nieto and Santamaría, 2007). All in all, open collaborative innovation carries the potential to drive innovation by combining complementary sets of knowledge, skills, and ideas, sharing the risks and costs associated with the innovation process, and offering more comprehensive results assessments by larger groups of actors.

Although OI has gained much traction at the firm level (Wang et al., 2015), it has also attracted attention at the individual (Locatelli et al., 2021) and ecosystem levels. The latter can be further classified into international systems (Wang et al., 2012), network (Lyu et al., 2019), and geographic clusters (Nestle et al., 2019). Similarly, the narrower concept of open collaborative innovation has also been approached from different levels of analysis. The roots of the individual level of collaborative open innovation lie in ethnography, psychology, and social network analysis. Open collaborative innovation allows for the development of synergetic effects by combining ideas related to distinct pieces of knowledge and experience within teams of individuals (Taylor and Greve, 2006). As at the individual level, actors at the organizational level combine their ideas, knowledge, skills, experience, and resources to achieve innovative products, services, or processes. For instance, Lorenzoni and Lipparini (1999) emphasized that firms possessing the relational capability to interact with other firms can accelerate their access to and transfer of knowledge and—as a result—their innovative performance. Lastly, open collaborative innovation at the system level includes cooperation towards innovation occurring at the larger industry, regional, national, or global levels (Lee et al., 2020; Semitiel-García and Noguera-Méndez, 2012; Shapiro et al., 2010).

2.2. A multi-level perspective on open innovation

Adopting a multi-level perspective opens up new opportunities for theory development and allows for a more holistic and rigorous understanding of innovation processes (Geels, 2005). The standard multi-level perspective on system innovation was introduced by Geels (2002, 2005), according to whom system innovations include simultaneous short- and long-term processes occurring on multiple dimensions. These processes must link and reinforce each other for successful system innovation. Geels' multi-level perspective is closely related to an evolutionary view, which implies unfolding and creating new combinations leading to novel paths and trajectories (Geels, 2002). The traditional multi-level perspective has often been adopted in the conceptualization of path-breaking innovations (e.g. Geels, 2005; Markard and Truffer, 2008; Walrave et al., 2018). From this standpoint, the multi-level perspective is essential for a thorough understanding of technological transitions and socio-technical transformations resulting from introducing radical innovations to the market (Markard and Truffer, 2008).

In contrast to this traditional multi-level perspective, our primary focus is on understanding how innovation processes at different levels converge and combine to create synergies. Drawing on-but differentiating from-the traditional view by Geels, instead of discussing the emergence of new technological regimes, we focus on the transitions of innovation practices across levels of analysis. While the traditional view primarily focuses on processes related to the diffusion of radical

innovation, we adopt a multi-level logic to holistically analyze OI processes and how they span across levels of analysis.

The number of studies adopting a multi-level-like logic on OI is limited (Lee et al., 2020). Chesbrough et al. (2006) proposed five levels of OI analysis that include (i) individuals and groups; (ii) firms/organizations; (iii) inter-organizational value networks; (iv) industries and sectors; and (v) national institutions and innovation systems. These levels have tended to be exploratory rather than explicit requiring further research and conceptualization (Chesbrough and Bogers, 2014). For instance, society at large (Chesbrough and Bogers, 2014), communities (Chesbrough, et al., 2006), or cities (Cohen and Muñoz, 2016) are not mentioned in this classification, but may be considered as separate levels of analysis. While Chesbrough and Bogers (2014) stated the importance of understanding interactions across levels of analysis, they noted a lack of related empirical and theoretical research. In this study we therefore draw on, combine, and refine the Chesbrough et al. (2006) classification of OI levels with our multi-level logic, conceptualizing interactions between levels and diffusion of innovation practices across system levels.

2.3. Sustainable open innovation

Innovation does not automatically lead to societal progress, better quality of life, or sustainable development. In fact, new technologies may aggravate sustainability problems by e.g., magnifying consumer needs (Vollenbroek, 2002). Regardless, innovation has great potential toward sustainability-oriented transformation in individuals, organizations, and communities (Silvestre and Ţîrcă, 2019). There is a growing body of research proposing various ways to combine sustainable development and innovation. For instance, sustainability-*oriented* innovation implies introducing changes to an organization's philosophy and values-as well as to its products, processes or practices-to create and realize social and environmental value in addition to economic returns (Adams et al., 2016). On the other hand, sustainability-*driven* innovation highlights the importance of the stakeholder effect, emphasizing the significance of stakeholder pressures forcing businesses to embrace sustainability (Kiron et al., 2013).

Sustainability challenges have been traditionally understood as related to three standard dimensions of sustainability: economic prosperity, social equity, and environmental integrity (Bansal, 2005). The sustainability perspective has been introduced into the OI context relatively recently. For instance, Cappa et al., (2016) introduced the concept of *Open Sustainable Innovation*, which implies OI principles can be successfully utilized to develop more sustainable products. Bogers et al. (2020) introduced another concept-*Sustainable Open Innovation* (SOI)--building on the notion that innovation processes should be organized in a manner fulfilling the needs of the present without compromising the ability of future generations to meet their own. Chesbrough and Di Minin (2014) proposed an alternative framework of *Open Social Innovation*, concentrating on the relationship between social innovation and OI mainly in a non-profit context. Lastly, a number of empirical studies have attempted to identify the relationships between innovation performance and environmental, social, and economic sustainability (e.g. Michelino et al., 2019; Rauter et al., 2019).

In our study we adopt the Bogers et al. (2020) SOI concept for several reasons. Firstly, collaboration is integral to SOI. Establishing OI practices as sustainable requires the development of win-win solutions, which are difficult to achieve without collaboration among multiple stakeholders (ibid.). Although some SOI solutions can result from single actor efforts, open collaborative innovation is essential for achieving scalable solutions (ibid.) and expansion to other levels. Secondly, the SOI concept demonstrates the transfer of sustainable OI practices from the individual to the organizational level (ibid.), corresponding to our multi-level logic. Finally, although the Bogers et al. (2020) SOI definition implies an organizational level of analysis, we suggest it can be applied on a broader scale, spanning e.g., city or regional levels.

3. Methodology

This section presents a brief account of our methods. We begin with a short introduction describing our analyses and process of triangulation. We then describe our data collection process and follow with a detailed description of the analyses.

In order to expand the current state of knowledge and contribute to a better understanding of the phenomenon, we analyze the empirically identified interconnections between the two literatures. Based on our review of identified past literature and empirical analysis, we propose a theoretical framework combining our findings regarding open and sustainable forms of innovation.

Our methodology consists of two distinct but interrelated stages. Firstly, we conducted a bibliometric analysis to understand how sustainability is positioned in recent OI research. We applied bibliometric methods because of their relative objectivity and ability to sift through results in a more automated and relatively unbiased fashion. Secondly, we performed a content analysis of sample papers that materially discuss both sustainability and OI. Content analysis reduces research bias and enhances the reliability and validity of the constructs under investigation (Yawar and Seuring, 2017).

Our empirical design draws on scientometric approaches of mapping science (Callon et al., 1983) and the sociological underpinnings of linguistics in organizational theorizing (Alvesson and Kärreman, 2000). This approach combines contrasting views arising from the structural characteristics of language (Mohr, 1998) as they occur in network visualizations and metrics to results arising from a topic model representative of a "statistical model of language" (DiMaggio et al. 2013, p. 577).

We triangulate across units of analysis to "obtain corroborating evidence from using a variety of methods" (Scandura and Williams 2000, p. 1249) in two primary ways: (i) by using two related sets of units of analysis arising from the same data, and (ii) "between methods" (Jick 1979, p. 602) by using a combination of structural and statistical representations in our analysis. We do not triangulate over different data sets, but rather analyze one set of data at two distinct levels using multiple methods. This layered investigation of language-use affords insights into distinct levels of cognitive usage-namely over the degree of its institutionalization-allowing us to analyze results on a continuum ranging from specificity to generality.

To do so, we produce two structural (network) representations of text through (i) a co-word analysis (of keywords) and (ii) a term map (of titles and abstracts, referred to as documents throughout). As a statistical representation, we produce a topic model over documents. The triangulation process allows us to compare layers of cognitive structures inhibiting the same space: the institutionalized use of keywords against the more informal terminological choices exercised in documents. The primary purpose of the triangulation process is to increase the interpretive validity of our findings. The end result is an adjusted methodology combining pre-existing methods, mirroring each layer of investigation against two others forming a type of 'interpretive glue' aiding in the assessment of the validity of claims (DiMaggio, 2015; DiMaggio et al., 2013) made based on any of the individual analyses alone. While each of these methods are powerful modes of analysis in their own right, their use in conjunction allows for a more fine-grained analysis strengthening the validity of drawn inferences and interpretations. Fig. 1 shows an overview of the applied methodology including a legend explaining the nomenclature.

We show the resulting structural representations as pathfinder networks (which have further been independently used as a method for cognitive and linguistic mapping among other uses), and display the statistical representation's artefacts as tables and strategic diagrams.

3.1. Data collection

We chose to collect data from ISI Web of Science (WoS) as it

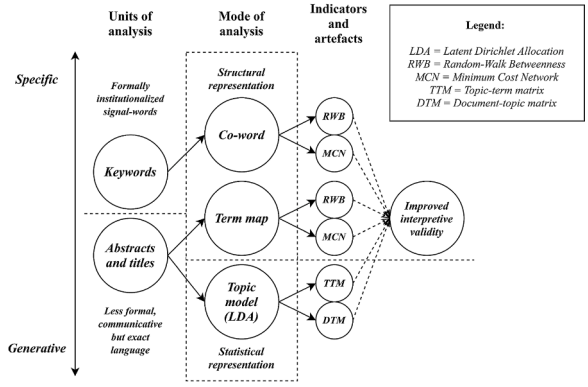

Fig. 1. Overview of the applied methodology.

generally indexes high quality journals with a wide coverage (Martín-Martín et al., 2018). The quality of indexed journals was an important criterion for us as we chose not to restrict the journal set to e.g. top-ranked management journals but focused rather on discovering the adoption of the query term across disciplines. Our sample is therefore representative of a population of multidisciplinary research-utilizing the concept of OI-which has gained early institutional acceptance in various disciplines as indicated by citations received relatively shortly after their publication. We collected the data in June 2019 using the search phrase *"Open Innovation"* in the field "Topic," selecting the 500 most cited articles from the latest five years. Upon confirmatory inspection, we noticed one of the articles was marked retracted and subsequently removed it, resulting in a final sample of 499 records. The sample therefore included circa twenty-five per cent of the most cited articles utilizing the search term in the period as indexed in the WoS Core Collection.

We extracted the full text of all documents identified as sufficiently related to sustainability in the sample based on our empirical findings and retained them for further content analysis. We identified these documents through topic-related keywords, topic distribution associations, and qualitative readings of all 499 abstracts. All three authors read the full texts of the identified articles, and articles were eliminated from content analysis if any of the authors considered them insufficiently related. The main selection criterion was that each article should bear a clear reference to a non-economic sustainability dimension in addition to economic sustainability.

In total we retained 45 documents (≈ 9% of sample), with totals of 477 citations, 503 keywords, and an average of 3.8 citations per year for content analysis. Most of these articles were published in sustainability-focused journals (≈ 47%), with technological or innovation focused journals trailing slightly (≈ 33%). The remaining documents have been published in other general management journals (≈ 7%) or in miscellaneous other publications (≈ 13%).

3.2. Structural representations

3.2.1. Co-word analysis and term mapping

Co-word analysis over *signal-words* (Rip and Courtial, 1984)-such as keywords-extracts co-occurring terms in and between documents (Callon et al., 1983). We perform co-word analysis over keywords yielding an interpretation rooted in institutional formalisms engrained in the professional habits observed in specific fields. The function of signal-words is to guide readers toward a desired direction, but their effective use is contingent on the general acceptance of such words in the field (Rip and Courtial, 1984).

Conversely, text in titles and abstracts is only moderately institutionalized, allowing for a greater variety of generating latent linkages between terms. Term maps visualize the conceptual structures of corpora by displaying relationships of terms, i.e. domain-specific concepts that are not necessarily keywords but can be automatically derived from abstracts (van Eck and Waltman, 2011; 2014; van Eck et al., 2010). As term maps rely on detecting semantic units with a high degree of distinctiveness—i.e. high termhood (van Eck et al., 2010)—they reveal cognitive structures with an arguably increased degree of objectivity in use, offering potentially deeper insights into the underlying substantive meanings and contexts.

3.2.2. Minimum cost pathfinder networks

We produce minimum cost pathfinder networks (Chen and Morris, 2003; Schvaneveldt et al., 1989, MCNs) over both units of analyses as their structural representations. MCNs reduce a network structure to retain only globally optimal links given minimum parameters (Borner et al., 2003; Chen and Morris, 2003). The technique is grounded in graph theory and cognitive psychology, and has been traditionally applied to mapping various knowledge structures consisting of conceptual relations (Schvaneveldt, 1990).

Prior to reducing the networks to MCNs, we calculated the centralities of terms and keywords. To measure centrality, we use random-walk betweenness (RWB)-a variant (Newman, 2005) of the traditionally geodesic-based shortest path measure of betweenness centrality (Freeman, 1978)-to determine the global flow-points enabling and facilitating the exchange of ideas between clusters of terms and keyword topics. We further used modularity optimization (Blondel et al., 2008; Waltman et al., 2010) to cluster the community structures of the co-word and term networks. The resulting clusters can be interpreted as topics arising from the most closely related terms or keywords within the corpora. The interpretation thus varies slightly between units of analysis.

3.3. Statistical representation

3.3.1. Discovering latent topics

As a statistical representation of documents, we produce a *Latent Dirichlet Allocation* (LDA) (Blei et al., 2003) based topic model. LDA is a generative probabilistic model where individual documents are considered random mixtures of latent topics, and individual topics are understood as distributions over terms (Blei et al., 2003). LDA is useful for statistically inferring the 'hidden' topics underlying text corpora (Blei et al., 2003). We use the resulting topic distribution to illustrate how documents qualitatively determined as related to sustainability are distributed across the overall topics.

LDA allows us to group documents of interest within latent topics, as well as to discover terms shared *between* topics and the relevance of terms *within* topics (Sievert and Shirley, 2014). In practice, these two types of mixed membership (Hannigan et al., 2019) distributions allow us to discover relationships at multiple levels of analysis, relating e.g. documents by their topic memberships, or topics by their shared words and terms. The downside of topic models tends to be human interpretability, where statistically optimal models typically do not result in the most meaningfully interpretable topics (DiMaggio, 2015; DiMaggio et al., 2013; Hannigan et al., 2019). The standalone use of topic models is therefore subject to some scrutiny in interpretation, and as there may not be a *best fit* model at all in terms of a single metric to choose the right models from, DiMaggio (2015) suggests the resulting interpretive uncertainty may not always be met with singular enthusiasm.

For ease of interpretation, we further analyzed the model using *pyLDAvis*, a Python-port of the *R*-package *LDAvis* (Sievert and Shirley, 2014). pyLDAvis allowed us to visualize the resulting topic distribution with multidimensional scaling and enabled the exploration of the underlying model in detail at various levels of relevance λ. Various values of λ were used to explore tangents of the vector space underlying the topic-term distribution by alternating between *lift*—i.e. the "ratio of a term's probability within a topic to its marginal probability across the corpus" (ibid., p. 65)—and *saliency*, which weighs terms according to their distinctiveness within a topic (Chuang et al., 2012). $\lambda = 0$ displays

terms strictly according to saliency, while $\lambda = 1$ displays them strictly according to lift. We labelled our topics with the most distinctive theoretical term at $\lambda = 0$ to avoid subjective choices arising from qualitative labelling efforts. Values of λ between 0 and 1 provided mixed and richer representations of topic structure, which we used to derive relevant terms within topics.

4. Results and discussion

In this section we present and discuss the results of our analyses, describe the topics and literature discovered, and visualize the MCNs over keywords and terms. We first briefly describe aspects of the sample in terms of composition and relevance to the investigation. We then display and discuss the keyword and term networks and move on to discuss details of the topic distribution unveiled by LDA. We conclude the section by outlining our multi-level theoretical SOI framework.

4.1. Unfolding conceptual layers

Fig. 2 displays the co-word MCN representing the institutionalized and formal use of keywords over the search space. We find two central keywords of interest that may indicate permeability of sustainability considerations within the network: 'systems' and 'future.' Their closest associations to 'management' and 'design' would suggest that designing efficient management systems is related to the generic notion of future.

In the strongest-link neighborhood, the other closest terms are 'framework,' 'strategy,' and 'networks,' last of which is directly connected to 'innovation management' and 'biotechnology.' This local group may be the closest clue toward sustainability in the co-word MCN. Slightly less relevant keywords are 'value creation' and 'governance' which we find in the context of 'performance.' None of these concepts are particularly central in the network and are not found on key paths between other significant concepts. In addition to these keywords, there appear to be no clear indicators of sustainability in the network. We did not find any occurrences of the identified topic-relevant keywords in this network, suggesting that albeit various aspects of sustainability have been discussed, a single consistent strand is lacking within the space.

Analyzing the co-occurrence of terms over documents, we find more concepts of relevance to our investigation in the term map MCN in Fig. 3. The network contains the explicit term 'sustainability' with strongest associations to 'management,' 'time,' and 'entrepreneurship.' The latter two are therefore likely to be among the core concerns relating sustainability to OI research.

Other notable terms include 'crowdsourcing' and 'co-creation.' This

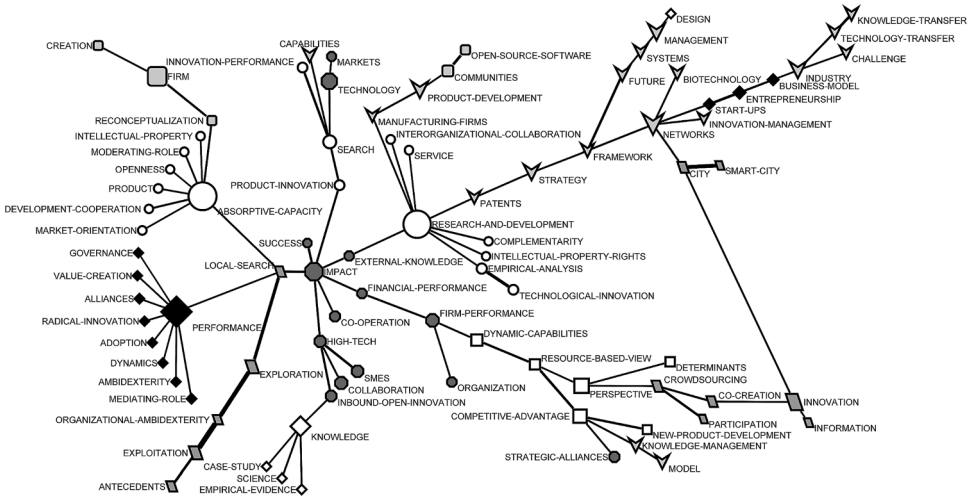

Fig. 2. Co-word minimum cost network. Node sizes represent random-walk betweenness values; node shape and greyscale shade combinations represent clusters of topics.

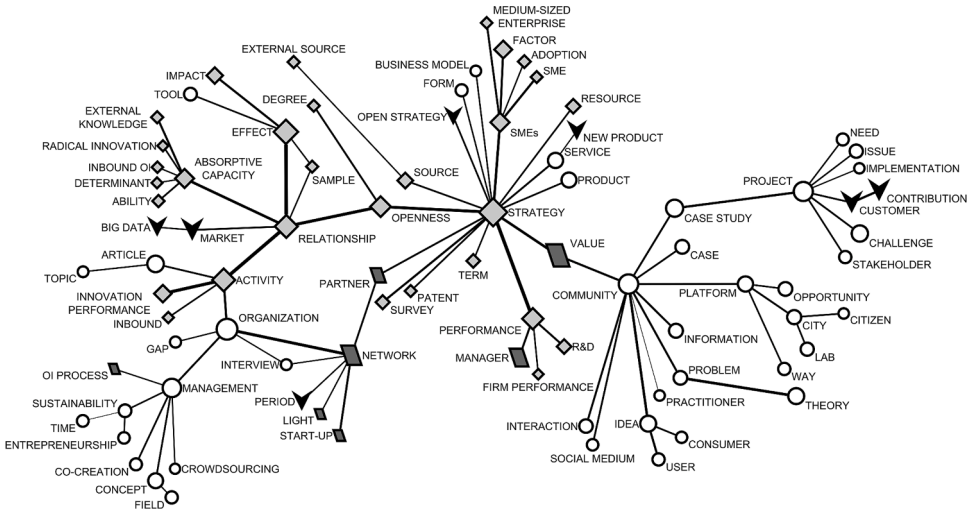

Fig. 3. Term map minimum cost network. Node sizes represent random-walk betweenness values; node shape and greyscale shade combinations represent clusters of topics.

Table 1
Top central terms across networks.

Emerging or informal terms	RWB ratio	Institutionalized formal terms	RWB ratio
STRATEGY	1.00	PERFORMANCE	1.00
EFFECT	0.81	ABSORPTIVE CAPACITY	0.93
VALUE	0.75	R&D	0.90
ACTIVITY	0.73	KNOWLEDGE	0.51
RELATIONSHIP	0.73	FIRM	0.48
ORGANIZATION	0.68	NETWORKS	0.44
PERFORMANCE	0.65	IMPACT	0.42
OPENNESS	0.62	INNOVATION	0.37
COMMUNITY	0.61	TECHNOLOGY	0.32
NETWORK	0.61	PERSPECTIVE	0.28

Note: Informal terms arise from the term map, while formal terms are the product of the co-word network. The columns were normalized by dividing column items with the maximum column value.

subset of nodes is connected to the remainder through 'organization,' which in turn connects alternate paths between 'network' and 'activity.' Another set of terms belonging to the same topic are centered on 'community,' with the notion of 'stakeholders' connecting primarily to 'project.' This term cluster is also characterized by mentions of qualitative methods via included terms such as 'interview,' 'case,' and 'case study.' Other concepts of interest within this cluster are 'platform,' 'city,' 'lab,' 'product,' 'service,' and 'business model.' Table 1 displays and compares the topmost central terms in both networks, showing the differences in focus between formal and less formal representations. Whereas the institutional representation seems to consist of largely R&D performance and absorptive capacity, the abstract suggests that the latent focus in these articles is heavily centered on strategy. Only the terms 'performance' and 'networks' are present among the most central terms in both layers.

Table 3 shows a sampling of the topic-term distribution from the LDA model, where we find that the most prevalent topic by number of assigned documents (5) is both saliently and frequently characterized by the terms 'sustainability' and 'sustainable,' while being centered on the term 'co-creation.' The other salient and contextually relevant topic (4) is centered on the term 'social innovation' and accompanied by 'open business models' and 'open social innovation.'

Table 2 displays the conditional probabilities of documents observed as sustainable (or not) belonging to specific topics, with Fig. 4 displaying these conditional probabilities against each other yielding indicators of their biases with respect to the related documents, classified as *sustainable* with the remaining corpus labelled as *not sustainable*. We find that the topic centered on 'co-creation' (5) includes the majority of the documents discussing sustainability, with topics labelled 'smart city' (1) and 'quadruple helix' (8) also displaying a degree of focus on sustainability-related documents. We further note that the topics labelled 'absorptive capacity' (9) and 'SMEs' (7) appear by far the least concerned with sustainability-related conversations. It is also interesting that the topic labelled 'social innovation' (4) appears largely neutral.

In the aggregate, we find that the institutionalized terminology contains little to no references to sustainability considerations, despite a

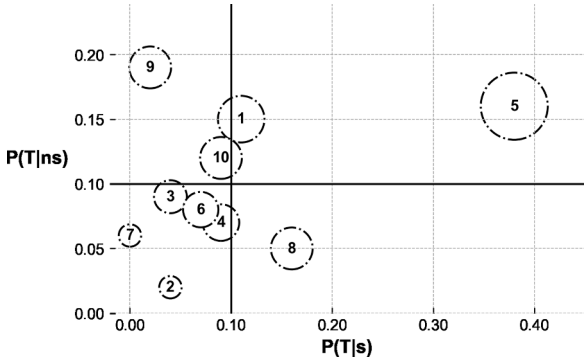

Fig. 4. Strategic diagram of conditional probabilities of documents observed as sustainable (*x*-axis) or not sustainable (*y*-axis) belonging to topics sized by their marginal probability and labelled by topic numbers. Note that the marginal probability of a topic also dictates the maximum shared distance from the axes. The dotted cut-off lines represent two naïve reference assumptions for interpretability: (1) a 1/10 expectation assuming indicators of sustainability are uniformly distributed across topics, and (2) that the topics themselves are uniformly distributed.

≈ 9% representation of qualitatively determined sample documents discussing one or more aspects of sustainability. However, in unfolding the informal contents of the documents through term mapping and topic modelling, we find an inconsistent but relatively diffused use of sustainability-related terminology across the same corpus.

In Fig. 5 we display inductively derived relationships between the identified latent topics (represented as numbered white nodes, numbers standing for the latent topic identifier with its label term as text) and the posited levels (represented as grey nodes) in our SOI framework. The white topic nodes are sized according to each topic's marginal probability, so that larger topic nodes are more prevalent in the sample. We postulate relationships occurring both between latent topics, and between latent topics and levels of analysis. Each relationship is labelled

Table 2
Topic distribution over documents.

Topic (T)	n docs with dominant membership	% of total distribution	n docs sustainable (s)	n docs not sustainable (ns)	$P(T\|s)$	$P(T\|ns)$
1	75	13.27%	5	70	0.11	0.15
2	9	2.49%	2	7	0.04	0.02
3	44	8.95%	2	42	0.04	0.09
4	36	8.39%	4	32	0.09	0.07
5	90	17.03%	17	73	0.38	0.16
6	40	8.27%	3	37	0.07	0.08
7	29	6.13%	0	29	0.00	0.06
8	29	6.48%	7	22	0.16	0.05
9	89	17.26%	1	88	0.02	0.19
10	58	11.72%	4	54	0.09	0.12
	499	100%	45	454	1.00	1.00

Table 3
LDA topic distribution descriptive terms.

Topic	Label term	Salient terms ($\lambda \leq 0.4$)	Frequent terms ($\lambda \geq 0.6$)
1	Smart city	Startup(s), outbound OI, inbound OI, bio-pharmaceutical, OI startups, knowledge leak, OI collaboration, Chinese firm, energy, cluster	OI, technology, startup(s), outbound OI, network, cluster, policy, strategy, knowledge, industry
2	Living lab	Micro-level, monetary, reward, innovative solution, network structure, autonomy, flexibility, crowdsourcing, contest	Crowdsourcing, micro-level, monetary, network structure, collaboration, radical innovation, institution, urban
3	Licensing	Supply network, desorptive capacity, Spanish manufacturing, licensing volume, European firm, enhance innovation, licensing activity, innovation performance, project management, OI performance, inbound OI	Innovation performance, resource, inbound OI, portfolio, desorptive capacity, technology, market
4	Social innovation	Ambidexterity, open social innovation, open business model, energy technology, foresight network, university-industry collaboration, depth (and) breadth, roadmap, planning, governance, proprietary, strategy, patent, social network	Strategy, ambidexterity, collaboration, innovation strategy, network, open strategy, technology, economy, profit, product
5	Co-creation	OI community, Communities of Practice (COP), producer, intelligence, crowdfunding, (open) innovation environment, knowledge creation, vision, value co-creation, architecture, process model, external stakeholder, empowered, user, sustainable, sustainability, evolution, science	Community, user, consumer, network, knowledge, stakeholder, sustainable, sustainability, interaction, crowdsourcing, innovation process, value, product
6	Open data	Open government, family firm, public, citizen, local government, reuse, public sector (OI), public private, end-user, citizen participation, government agency, service innovation, sustainable product (and) service, city government, capability, public private	Public, government, open, sector, service, citizen, capability, public sector, open government, social media, end-user, strategy, service innovation, open strategy, policy
7	SMEs	Intellectual property rights (IPR), sustainable growth, SME engagement, SME innovation, Internet of Things (IoT)	Open, IPR, SME innovation, IoT, OI, process, SME OI, knowledge, technology, activity, data, strategy
8	Quadruple helix	Team member, regional innovation, organizational innovation, economic growth, service/product, triple helix, regional development, territorial, economic development, demographic, inclusive, responsibility, new venture, public policy, high growth, innovation roadmapping, emerging economy, supply chain, ecosystem	University, regional, ecosystem, product, economy, responsibility, supply chain, OI, entrepreneurship, knowledge, strategy, trust, technology, new product
9	Absorptive capacity	Innovation performance, knowledge sourcing, firm performance knowledge acquisition, resource-based view (RBV), external search, search strategy, dynamism, open search, internal capability, product innovation, knowledge-based view (KBV), search breadth, acquisition	Firm, knowledge, external knowledge, OI, relationship, openness, acquisition, firm performance, innovation performance, strategy, impact, industry, financial
10	Knowledge integration	Product development project, tacit knowledge, OI adoption, OI mode, collaborative product development, OI strategy, coordination, complex product, knowledge management (KM), KM practice, new product development (NPD), income, lead user, laggard, supplier, startup, incubator, social media, process, software	Knowledge, technology, OI, project, NPD, startup, design, social media, time, creative, software, customer, practice, KM

with an inferred connection based on a combination of empirical evidence primarily from the statistical representation of abstract-title combinations and the content analysis of the 45 articles identified as materially relevant to SOI.

4.2. Sustainability, innovation and openness: towards a multi-level framework

In this section, we review the relevant literature on *Sustainable Open Innovation* (SOI) discovered based on the analysis detailed in the previous sections. We synthesize the most prevalent concepts and topics from these articles and relate them to the topic distributions from the statistical topic model. Based on the analysis conducted we develop a multi-level conceptualization of levels of SOI intended as a basis for further theoretical advancements and empirical research.

The concepts of sustainability and openness are paired. System-level sustainability requires transparency about its processes and underlying motives. Openness allows us to notice errors and modify strategic choices, as transparency invites feedback and increases reliability. Simultaneously, because of its nature, openness facilitates innovation due to its inseparability from knowledge transfer and creativity. We enhance the understanding of how SOI practices exist at various levels and how they interact across levels. Our framework provides a holistic viewpoint on the SOI phenomena and allows us to analyze the implications of SOI in different systems existing at the individual, organizational, city, and regional levels (Fig. 6).

4.2.1. Sustainable open innovation at the individual level

The root level of SOI identified in our analysis is the individual level. Often, people pursuing innovative activities pave the way for more complex, large-scale OI projects. Individual- and team- based sustainable innovation need not be generated inside the organization's borders (e.g. firm, university), but, the participating individuals may be members of particular social units embedded in organizations. The individual-level of SOI involves open collaboration with a shared aim of innovative co-creation not confined to the boundaries of any specific establishment.

As reflected in the Fig. 5, knowledge integration is an essential process in SOI at the individual level and it implies sharing tacit knowledge, which is often ambiguous, abstract, and rooted in personal values, talents, and beliefs. The peculiarity of SOI at this level is that while individuals innovate on the basis of personal experiences and needs, they also do so for the benefit of others to improve the environmental, social or health condition and well-being of a community or larger society (Nielsen et al., 2016). For example, in the study of sustainable service development, households interested in innovative heating practice development were motivated by the need for an energy efficient solution for warming indoor spaces (Liedtke et al., 2015).

Another interesting SOI practice at the individual level are sustainability jam sessions. This concept-centered on the idea of organizing creative meetings between experts in the form of "jam sessions," similar to jamming used in music to support the composer's creativity for songwriting-was introduced by Carlsson et al. (2015), who argue such sessions are a useful tool for creating an OI space where industry practitioners can share knowledge and experience, while communicating with researchers and sustainability professionals toward solving sustainability challenges.

Lastly, Nahi (2016) highlights the importance of engagement of companies entering the base of the pyramid market into direct personal relationships between nonprofit workers and community leaders. Building upon the notion of level interconnectedness, SOI at other levels may encourage SOI at the individual level (Fig. 5), e.g., social innovation

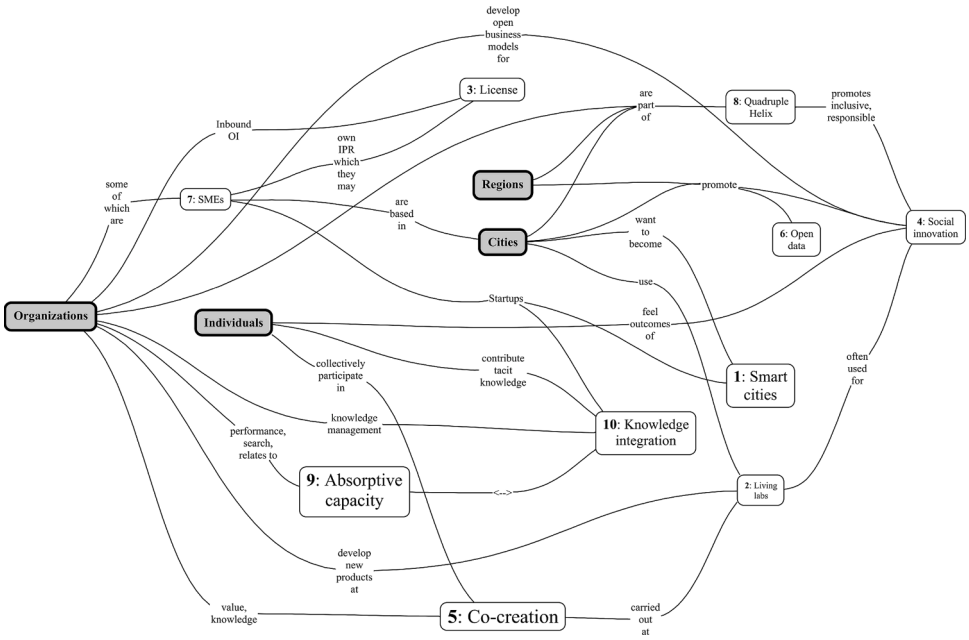

Fig. 5. Mapping theoretical levels to empirical topics. The label texts have been adjusted to maximize readability, so ideally every relationship (*source node-link-target node*) should be readable as a sentence. The conceptual map is organized hierarchically from left to right, so that nodes with most outgoing connections are placed on the left, while those with most incoming connections are on the right.

at the city level may empower citizens to collaborate in municipal projects (Mora et al., 2019a).

4.2.2. Sustainable open innovation at the organizational level

In the rapidly changing economic environment, integrating external partners into the process of new product or service development has become a part of the business strategy for many companies (Kortmann and Piller, 2016). For example, Starbucks' crowdsourcing campaign aimed at developing an innovative solution to reduce waste from paper cups, or Coca-Cola's strategic collaboration with the University of Exeter focused on improving consumers' at-home recycling rates (Arcese et al., 2015). The terms *Open Sustainability Innovation* (ibid.) and *Open Sustainable Innovation* (Cappa et al., 2016) both appear in our sample primarily referring to practices taking place at the organizational level.

Holding shareholders close helps companies not only better meet their requirements and reduce the development risks associated with new product development, but also to react faster to market needs and anticipated business problems. The effects of external integration in co-creation (Fig. 5) and engagement of different types of stakeholders in OI networks are discussed in a number of papers in our sample: e.g. relating to clients (Altuna et al., 2015; Callaghan and Herselman, 2015), public authorities (Schwerdtner et al., 2015), suppliers (Behnam et al., 2018; Kortmann and Piller, 2016), customers (Shim et al., 2017), users (Behnam et al., 2018; Nielsen et al., 2016), and other external stakeholders (Watson et al., 2018). Additionally, business model innovation has been studied as a tool for developing organizationally sustainable business models cognizant of their ecological embeddedness (Carayannis et al., 2017).

Firms adopting SOI strategies must meet the responsibility criteria of their stakeholders and innovate in a manner compliant with their sustainability goals and agendas. SOI-based approaches to innovation may lead to sustainability performance improvements such as total cost reductions, decreases in resource consumption and pollutant emissions, and increased affordability for low-income customers without sacrificing value (Cappa et al., 2016).

A growing number of firms take a step further and open their business models even more by combining value capture and value creation (Kortmann and Piller, 2016). Consistently applying an open and sustainable approach to innovation management may be a challenging task for many firms operating with outdated business models. Thus, novel sustainable business models should be developed using systemic rather than unidimensional innovations: e.g. mobility sharing can be seen as preferable to ownership of an environmentally friendly vehicle (Behnam et al., 2018). Blok (2018) studied the problem of information asymmetries in the context of sustainable business models, noting that although integrating OI into a firm's business model may improve its innovation performance, integrated models carry higher risks of knowledge leakages and may lead to a loss of competitive advantage.

A separate cluster of papers in our sample addresses the topic of open eco/green/environmental innovation (e.g. Ghisetti et al., 2015; Lopes et al., 2017; Watson et al., 2018). The eco-innovation concept encompasses principles of circular economy and organizational sustainability (Lopes et al., 2017) and originates in the work of Fussler and James (1996), who describe it as innovation fueled by ecological issues. A constituent part of eco-innovation-open eco-innovation-refers to environmental innovation utilizing knowledge and expertise originating from outside the firm's boundaries (Ghisetti et al., 2015).

Social innovation is generally understood as a set of activities regarding societal challenges with innovative approaches (Shin, 2016) with further potential to create novel social relationships and opportunities for collaboration (Altuna et al., 2015). Social innovation inherently contains a degree of openness (Unceta et al., 2017), since it should involve extra-organizational stakeholders such as citizens in the process to ensure its effectiveness (George et al., 2015). Open social innovation focuses on inbound OI originating from the general public in order to identify and feasibly serve their needs (Shin, 2016). However, social innovation is accompanied by an obstacle: companies often find it difficult to justify the creation of social value in monetary terms (Altuna et al., 2015). Du et al. (2016) answer these concerns by showing how stakeholder involvement and sustainability focus in innovation activities may enhance new product development cycles, and thus the overall profitability and longevity of companies. Furthermore, engaging in business ecosystem thinking (considering external stakeholders as primary actors within the sphere of business), companies can improve their innovative and financial performance through stakeholder beliefs and their perceived reputation (Joo et al., 2017). The connection between

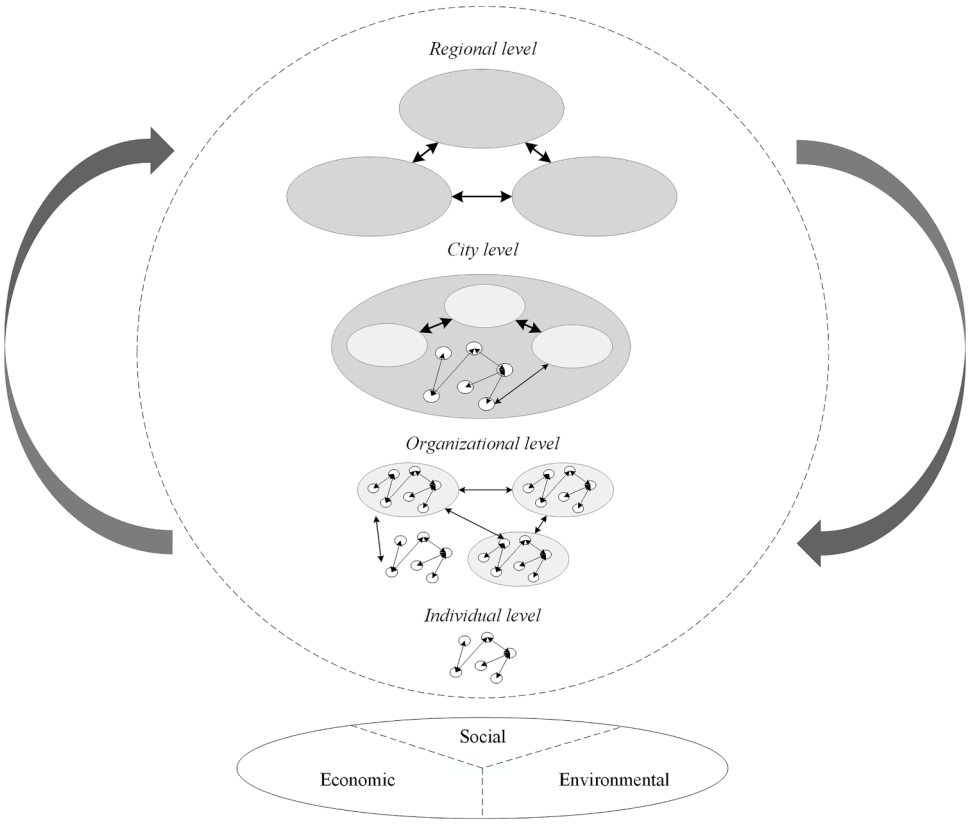

Fig. 6. An illustration of our theoretical framework of the identified levels of SOI. *The arrows indicate the interaction across the empirically discovered levels of SOI.*

open and social innovation has also been investigated in the context of social enterprises (Yun et al., 2017), where standalone OI has been noted as often related to and capable of delivering societal impacts (Schillo and Kinder, 2017).

Inbound OI can originate for the purpose of tackling challenges in social sustainability (Unceta et al., 2017), but also those in environmental sustainability (Hyysalo et al., 2017). Hyysalo et al. (2017) discuss instances where consumers have engaged in innovation activities to produce energy efficient heating systems in residential buildings located in rural areas. These activities have created communities where innovation is shared not only in a peer-to-peer manner, but also in the form of inbound OI from consumers to companies. Cappa et al. (2016) highlight sustainable product development with an example of involving a network of open hardware and software development, peer production, and distributed 3D-printing to create economically affordable products with low environmental impacts.

Lastly, including the broader public (as depicted in Fig. 6) in the SOI process may potentially foster responsible innovation toward rendering innovative products or processes more sustainable and socially desirable (Ceicyte and Petraite, 2018). For instance, NASA has introduced an OI-based business model to advance the health of its astronauts in space (Davis et al., 2015). Notably, in the context of co-creation (Fig. 5), integration of sustainability-oriented customers in the firm's innovation processes and activities may trigger a change toward more sustainable practices (Arnold, 2017).

As shown on Fig. 5, the organizational level has the highest number of connections to topics. The organizational level cluster is the largest in our sample and is directly or indirectly connected to all other levels. As this level is an intermediary to all other levels, the practices implemented at the organizational level appear to carry the highest potential for influence transference across system levels.

4.2.3. Sustainable open innovation at the city level

The concept of a smart city is no longer novel, but has recently taken on a new dimension of ICT architectures applied to bringing together people and locations for the prosperity of citizens and urban neighborhoods. The topic of OI for smart cities and sustainable urban development is discussed in several papers in the sample (e.g. Collier et al., 2016; Mora et al., 2019a). Mora et al., (2019a) conducted a systematic review of the research on smart cities which they followed with an empirical analysis of four European smart city-leaders, revealing how open collaborative environments may enhance the abilities of citizens (users) and local firms to actively participate in ICT-driven initiatives for co-creation, which in turn may lead to improvements and more sustainable urban innovation (Mora et al., 2019b). While discussing the smart cities topic (Fig. 5), special attention is given to the role of social capital for greater trust and cooperation achieved through knowledge exchange among actors in OI structures (Errichiello and Micera, 2018).

Living labs (LLs) (Fig. 5) are a relatively novel phenomena. LLs can be defined as "physical regions, virtual realities or spaces of interaction, where all stakeholders join together to create, develop, test and implement new products and services in a real-life context" (Rodrigues and Franco, 2018, p. 780). Sustainable living labs (SLL) are found in several papers (e.g. Callaghan and Herselman, 2015; Liedtke et al., 2015; Rodrigues and Franco, 2018), with the research by Liedtke et al. (2015) being the second most cited of the sustainability-related articles. SLLs aiming at supporting urban entrepreneurship and enhancing sustainability (Rodrigues and Franco, 2018) can be viewed as user-centered OI ecosystems. The advantage of SLLs is the continuous orientation of innovation towards the end user who is totally integrated in the process of co-creative sustainable innovation. For instance, a case study of a Portuguese living lab concluded that SLLs may enhance the creation of new innovations that address a region's difficulties via the establishment of an OI model, which allows the user to take an active role in the processes of innovation and R&D (Rodrigues and Franco, 2018). In the

context of smart cities, Liedtke et al. (2015) highlighted the particular significance of an SLL infrastructure for sustainable product service systems solutions development. Outside of the concept of SLLs, special attention has been paid to LLs in developing countries as well (Hooli et al., 2016).

The city level emerges in our findings as a rapidly growing SOI research stream. The city level is associated with SOI practices in an ecosystem context. As a higher aggregate, the city level promotes the transmission and integration of SOI practices from the lower individual and organizational levels toward synergetic effects at the ecosystem level.

4.2.4. Sustainable open innovation at the regional level

In addition to sustainable urban development, OI approaches have been applied in the service of wider sustainable regional development under the term "Regional Open Innovation Roadmapping" toward safeguarding continued innovation at the regional level (Schwerdtner et al., 2015; Specht et al., 2016), with other research focusing on regional innovation systems in a sustainability and regional development context (Kutsenko, 2015). Hu et al. (2017) investigate the role of policy and OI in the context of environmental regulations, proposing that OI strategies have a mediating effect on the relationship between regulations and productivity, while Mann (2015) discusses strategies for sustainable policy design using OI-based processes for biodiversity and ecosystem service preservation.

The regional level emerges as the most underexplored SOI level. While this level could also be combined with the city level, we opted to separate the two. Although less present in the literature, practices involving SOI cross-border collaboration between regions are gaining momentum in different parts of the world between regional authorities, universities and companies (e.g. Nauwelaers et al., 2013). Fig. 5 shows the regional level as the least connected level in our sample. This level is directly related to the latent topics of "open data" and "Quadruple Helix". Similarly to the city level, the regional level is associated with processes occurring in a broader ecosystem context, requiring the SOI practice experience to be collected and aggregated from the lower system levels.

4.2.5. Implied levels of sustainable open innovation

All of the levels discussed so far also aggregate nationally and globally, within and between levels as complex networks of interactions. Although these levels did not surface from our findings directly, we infer and discuss them here by conjecture. We believe that it is reasonable to complete the multilevel SOI framework with overarching contexts setting the boundaries for the applicability of our framework.

The existence of these levels implies that SOI practices can be dispersed and unified with a global view toward addressing contemporary grand challenges (e.g., poverty or climate change) or toward collectively developing holistic action frameworks and governance norms in contexts characterized by broader societal influences (e.g., democratization of science or policy-making).[1] Recent studies have demonstrated applications of SOI in the grand challenges context (e.g., through nudging and citizen science (Cappa et al., 2020) or through international hackathons (Bertello et al., 2021)).

In addition, national (and other broader political regime) contexts introduce further contextual boundaries to the applicability of our framework. For instance, the varied regulatory styles over which select systems are governed in distinct states may carry strong impacts on the types of SOI tools that may be applicable in that specific context. SOI practices designed for improving the sustainability of health care systems in a specific state of the U.S. would presumably have quite a different set of tools on hand than a similar effort in, for instance, France or Denmark. Similarly, broader regulatory bodies such as the European Union or the U.S. federal government also provide an additional meta-level of governance imposing additional constraints and enablers concerning SOI practices. These nuances across contexts are an important factor when considering the applicability and potential uses of SOI.

4.3. Limitations and future research

Our sampling procedure introduced some limitations to our analysis. As our focus was on uncovering multidisciplinary patterns existing over the conceptual ground of open forms of innovation, our results are not reflective of any specific individual research field or subfield with clearly defined boundaries. Rather, our findings reveal patterns of adoption and use of the OI term across various contexts. Our approach is an atypical one for conducting bibliometric research, with more typical approaches relying on studying well-bounded fields of study in order to reveal their intellectual or conceptual structures.

The initial sample of 499 articles with 45 articles identified as relevant to our research objectives limits the external validity of our findings. Future studies could address this issue by adopting a larger sample focusing on the breadth the history of the development of these ideas covering all of past literature, rather than current patterns of adoption. In addition, the sampling procedure excluded research that was not yet well cited, as well as other OI-related research that did not contain the keyword "open innovation" (OI) in the Web of Science core collection, likely leading to the omission of otherwise relevant articles in the initial sample. We chose to use the OI concept in order to avoid introducing artificial biases due to the required subjective selection of additional theoretical terms as proxies, keeping the initial sample as objective as possible. As we ranked our sampling search by citations received, some emerging literature—and typically less cited grey literature (Rojon et al., 2021)—may have been excluded from our sample. Despite its unorthodox nature, we believe our methodological approach is fit-for-purpose in this instance.

Further, our topic model is relatively crude per its function as a statistically produced counterpart to the structural network analyses. The sufficiency of the dataset is quite limited, as topic models tend to perform better with more data. This tendency also reveals an opportunity, as a broader and more up-to-date dataset over the same space may yield rather different results, allowing for a comparison of the evolutionary developments of the studied adoption. In addition, future studies could focus entirely on topic modelling both the OI and SOI literatures as the volume of the latter grows, making use of more sophisticated representations such as dynamic (Blei and Lafferty, 2006), structured (Roberts et al., 2019), or joint sentiment/topic models (Lin and He, 2009). Such models might reveal the more intricate underlying patterns a simple LDA model may not be capable of identifying.

Despite the apparent relevance of several documents identified as sustainable by the presence of keywords, we found some of them displayed little substantive theoretical relevance to SOI. Such a discrepancy suggests the possibility that topics may be at times connected due to their overarching simultaneous popularity rather than their theoretical fit or relevance to each other. Future research could benefit from a thorough conceptual review of the underlying dimensionality of the interconnections between sustainability and OI, agnostic of their conceptual origins. As it currently stands, we find a multitude of conceptualizations that use distinct terminologies in discussing similar aspects with reference to SOI. A conceptual unification might add to the resilience of the underlying ideals and contribute to their wider diffusion.

Our multi-level framework consists of the broader patterns empirically identified from existing literature. As such, the levels identified are a function of the data fed into the model, and may omit implied levels of importance. For instance, a national, rather than regional, level of investigation may involve distinct ideals not revealed by our analysis. Similarly, sustainability challenges, the more complex they are, tend to necessitate a global perspective, which a perspective stopping at the

[1] We would like thank an anonymous reviewer for pointing out the importance of these issues.

regional level may betray. Too limited a focus on sustainability issues may result in a myopic view regarding the broader impacts at a global scale. Engaging more deeply with SOI regarding specific global sustainability challenges is therefore an interesting area for future inquiry. Such research could focus on the various exogenous contexts on issues such as climate change (globally) or health care (nationally). Developing such contextualized views may yield deeper insights into how SOI could be leveraged at a system-level toward solving specific sustainability challenges. We therefore see this line of inquiry as a particularly fruitful area for future research, especially from a more qualitative perspective.

5. Conclusions

In this study, we set out to explore the extent of and better describe the conceptual connection points between open innovation (OI) and sustainability. We did so with a bibliometric methodology focused on statistical and structural aspects of language used in 499 contemporary article abstracts employing the keyword 'open innovation'. We found 45 of the sample articles as materially related to sustainability by their full text, which we content analysed. Based on our empirical findings and content analysis, we developed a theoretical multi-level framework building on the concept of Sustainable Open Innovation (Bogers et al., 2020).

Our structural analysis shows that the usage of *keywords* does not point to the permeability of sustainability or societal concerns in OI related research, but relevant signals start to emerge when using structural or statistical techniques over *titles and abstracts*. The difference implies that researchers utilizing the OI concept have not broadly and officially recognized the importance of sustainability as a connection, but may be beginning to do so as indicated by the late emergence of these topics in moderately formalized language use. In addition, although innovation scholars concerned with open approaches may not have explicitly positioned sustainability at the core of their research, we find that sustainability focused research has more so adopted OI-based approaches in the service of sustainability. Our results further suggest discussions unifying openness and sustainability are more often taking place in journals focused on sustainability than innovation. This finding indicates that innovation research to date has likely had more to contribute to the study of sustainability than vice versa.

Our primary contribution is a multilevel framework that describes four levels of SOI-namely individual, organizational, city, and regional levels-and interactions between them. The *individual* level implies collaboration between individuals who may-but are not required to-be members of a particular social unit. SOI at this level is closely related to knowledge integration and co-creation activities. The organizational level is the most researched and interconnected between discovered levels. At the *organizational* level, SOI includes a variety of inbound and outbound practices allowing organizations to enhance their sustainability performance, such as external integration, business model innovation, and sustainability-oriented innovation management. The *city* level is related to collaboration between individuals, firms, universities and research centers, as well as municipalities. SOI practices at the city level target smart city design, the establishment and functionality of sustainable living labs, and sustainable urban development. The *regional* level is the most underdeveloped of discovered levels. Although this level is present in the sample papers to a smaller extent, practices necessitating SOI cross-border collaboration between regions appear to be building momentum.

Our secondary contribution arises in highlighting the importance of the sub-stream of open collaborative innovation and its relevance to sustainability within the broader open innovation research. Our findings suggest that out of the existing OI frameworks, open and sustainable innovation practices appear to be theoretically closest to open collaborative innovation (Bogers, 2012). In line with Bogers et al. (2020), we further found collaboration as an essential component of SOI through our content analysis, finding that sustained long-term win-win innovative solutions are seen as difficult without collaboration among stakeholders by proposing that such collaboration occurs among actors within and between identified SOI levels.

Our findings regarding the topics and their distributions of open innovation research not only model the field as it appears in search of sustainability, but also reflects the cognitive structure of recent and cited multidisciplinary research on open innovation at large. The empirical artefacts produced offer a modest contribution as a temporal snapshot of the general state of OI research, offering insights toward modelling it further and more extensively.

In sum, our multilevel framework and related discussion contributes to the development of a better understanding of the interfaces between sustainability and openness in innovation research.

5.1. Managerial and policy implications

Managers are continuously under stakeholder pressures to address sustainability issues. Our study contributes to advancing managerial practices for doing so by showing how OI and sustainability research have intersected in recent literature. Our empirical findings lend managers a detailed description of studied activities linking openness and sustainability. Managers may draw on the individual links in Fig. 5 to find underexploited areas of activity in their own organizations, as well as discover links from their companies' activities to other levels of their embedded systems, so that e.g., companies engaged or interested in co-creative product development may seek to find living labs in their cities as a means of doing so more effectively.

Policy-wise, the prevalence of smart cities, urban and regional development, and living labs, suggests a widespread focus of SOI on various interfaces with regional policymaking. Considering the two latent topics (4 and 9) respectively centered on the concepts of *Quadruple helix* and *social innovation*, it appears that considerable OI research has been dedicated to the interface between societal impacts and governance structures. In addition to traditional stakeholder integration, user-centric approaches and various forms of openly engaging local communities in local development efforts may therefore be an emerging normal in innovation-based development of societal policies. Policymakers can draw on our literature synthesis to discover detailed subjects and recent studies of academic relevance in creating socially oriented, sustainable innovation policies. Doing so may yield insights into which types of incentive structures should be developed for—and which directions taken—for developing effective innovation policy considering openness for developing more sustainable cities, regions, and broader governance structures.

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CRediT authorship contribution statement

Jaan-Pauli Kimpimäki: Methodology, Software, Conceptualization, Data curation, Formal analysis, Writing – original draft, Writing – review & editing, Visualization, Investigation, Validation. **Iryna Malacina:** Methodology, Conceptualization, Writing – original draft, Writing – review & editing, Visualization, Investigation. **Oskari Lähdeaho:** Methodology, Conceptualization, Writing – original draft, Writing – review & editing, Investigation, Validation.

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Supplementary material

Supplementary material associated with this article can be found, in the online version, at 10.1016/j.techfore.2021.121229

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Jaan-Pauli Kimpimäki is a junior researcher and a Ph.D. candidate at LUT University School of Business and Management. His research interests include the interface of strategy and sustainability considerations with secondary methodological interests in natural language processing and networks of all shapes and sizes.

Iryna Malacina is a researcher and a Ph.D. candidate at the School of Business and Management, LUT University, Finland. Her main research interests relate to supply network innovation and urban logistics innovation.

Oskari Lähdeaho is a junior researcher in LUT University, School of Engineering Science, Kouvola unit. His doctoral studies focus on environmental sustainability in multimodal logistics.