

# Geography of Innovation and Sustainability Transitions

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## Geography of eco-innovations vis-à-vis geography of sustainability transitions: Two sides of the same coin?

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# **Geography of eco-innovations vis-à-vis geography of sustainability transitions: Two sides of the same coin?**

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## **Keywords**

geography, eco-innovations, sustainability transitions, green technologies, socio-technical systems, systematic literature review

## **Abstract**

The need to develop and disseminate solutions to address environmental challenges such as climate change or resource depletion is more urgent than ever. However, the spatial dimension of pathways towards sustainability has only attracted scholarly interest in recent years, particularly through largely parallel research on the geography of eco-innovations and the geography of sustainability transitions. By systematically reviewing the literature, this article aims to compare both lines of research, devoting special attention to the role of regions and actors. While the geography of eco-innovations field focuses on local and regional conditions that enable the emergence of environmentally friendly technologies and industries, research on the geography of sustainability transitions highlights the place-specific but multi-scalar nature of socio-technical change, taking into account the role of different actor groups. The review identifies numerous complementarities between both fields that may serve as starting points to further integrate geographical work on eco-innovations and transformative change.

## 1. Introduction

The development and diffusion of innovations aimed at reducing environmental burdens are essential to make socio-technical systems more sustainable (Boons and McMeekin, 2019; Smith et al., 2010). Against this background, scientific research approaches are increasingly addressing issues around desirable, i.e. sustainability-focused, innovation (Barbieri et al., 2016; Rennings, 2000) and system transitions (Köhler et al., 2019; Markard et al., 2012). This “*orientation towards [a] directionality of innovation*” (Edler and Boon, 2018, p. 433) is not only gaining importance in the scientific domain, but also in the political sphere, where transformative innovation policies have come to complement the prevailing paradigms around economic growth and competitiveness (Schot and Steinmueller, 2018; Weber and Rohracher, 2012).

Within this normative turn in innovation studies and innovation policy (Sjøtun and Njøs, 2019; Uyarra et al., 2019), however, the spatial dimension of transformative, innovation-based change has initially remained unaddressed. Only recently, conceptual and empirical studies have started to provide useful insights on spatial conditions, their interdependencies and the resulting geographical unevenness of environmental sustainability (Boschma et al., 2017; Cooke, 2011; Gibbs and O’Neill, 2014; Grillitsch and Hansen, 2019; Strambach, 2017).

In general terms, the related research effort can be divided into two main streams that, so far, remain largely unconnected and poorly informed about research insights from the respective other: geographical research on sustainability-oriented innovations, i.e. eco-innovations (e.g. Cainelli et al., 2012; Costantini et al., 2013) vis-à-vis research on the geography of sustainability transitions (e.g. Binz et al., 2020; Coenen et al., 2012). While the latter primarily emphasises spatial specificities of socio-technical change (Hansen and Coenen, 2015; Strambach and Pflitsch, 2020), research on the geography of eco-innovations highlights spatially bound determinants of environmental innovation activities (Perruchas et al., 2020; Trippl et al., 2020). Put differently, the eco-innovation literature lacks explicit references to the spatiality of broader sectoral changes, while the transitions literature hardly produces generalizable knowledge on the extent to which certain spatial conditions influence socio-technical change (Hansen and Coenen, 2015; Strambach, 2017) At the same time, both lines of research do focus on the system level of eco-innovation or transformation processes, consisting of institutions, technologies and (networks of) actors (Dawley, 2014; Markard et al., 2012; Rohe and Chlebna, 2021).

Against this background, this paper aims to compare both lines of research and to provide a comprehensive overview of the last decade’s rich literature on the geography of eco-innovations and the geography of sustainability transitions (Binz et al., 2020; Krupoderova and Portnov, 2020). Despite the above mentioned differences, I argue that the identified complementarities will be beneficial for reciprocal learning and further convergence in scientific discourses.

To identify where relevant differences and commonalities exist, special attention is devoted to regional and actor-oriented perspectives that are characteristic of the respective approaches. The former is relevant as the emergence and diffusion of eco-innovations and transitions are shaped by factors on the sub-national level, so that studies' prevalent regional focus – and concept of space – is of particular importance to assess the comprehensiveness of either line of research (Losacker and Liefner, 2020; Rohe, 2020). The latter is relevant as innovation systems are characterized by a plurality of actors (Markard and Truffer, 2008), so the comprehensiveness and pertinence of each line of research is reflected in the degree to which dynamics in all known actor groups are addressed. In addition, significant differences may occur with a view to methodological issues which may either be the reason for or the consequence of differences in conceptual approaches.

Accordingly, the review is guided by the following research questions:

- What do the research streams say about the role and conceptualisation of regions?
- Which roles and functions of actors are the focus of research interest?
- What potential complementarities can be identified between the two research areas that can offer valuable leverage points for future research?

The structure of the paper is as follows. After contrasting conceptual and theoretical features of geographical work on eco-innovations and sustainability transitions, the methodology applied to conduct a systematic literature review is outlined in detail. Subsequently, the results sections shed light on similarities, differences and complementarities between the two research streams regarding their conceptual perspectives on regions and actors. Finally, the overarching findings are discussed, with particular reference to opportunities for future research and policy implications.

## 2. A first overview: geographical work on eco-innovations and sustainability transitions

A variety of labels and definitions are connected with eco-innovations due to a widespread use in various research disciplines and the fact that innovation itself is a polysemic and programmatic concept (Godin and Gaglio, 2019). Also framed as sustainable innovations, environmental innovations, the greening of technological change, i.e. green innovations (Kemp et al., 2019), eco-innovations range from additive environmental measures in order to minimize negative impacts to eco-effective systemic changes in production and consumption (Carrillo-Hermosilla et al., 2019). Eco-innovations can thus be defined as *“all measures of relevant actors [...] which develop new ideas, behaviour, products and processes, apply or introduce them and which contribute to a reduction of environmental burdens or to ecologically specified sustainability targets”* (Rennings, 2000, p. 322).

Compared to conventional types of innovations, eco-innovations are characterised by several peculiarities (Horbach, 2008). Firstly, eco-innovations reflect a desired direction and content of change and thus have a more normative character that might foster controversy and debate on the innovation paths to be taken and the sustainability targets to be addressed (Godin and Gaglio, 2019; Rennings, 2000). Secondly, related to the evolutionary theory of technological change (Kemp and Soete, 1992), eco-innovations depend to a higher degree on a range of context-specific and temporal conditions, comprising a variety of different activities like organisational change and green technology development which represent resource-saving alternatives and contribute to the protection of natural resources (Kemp et al., 2019; Strambach, 2017). Against this backdrop, studies have shown that eco-innovations are more complex and rely to a higher degree on diverse knowledge inputs from various actors in the innovation system (Barbieri et al., 2020; De Marchi, 2012). Thirdly, the incentive to invest in eco-innovation is rather low due to double externalities. These illustrate that eco-innovations are connected with positive spillovers to actors in the innovation phase as well as positive spillovers in the form of causing a socially desired outcome in the diffusion phase. Environmental policies and regulatory frameworks are therefore especially important determinants of this innovation type (Rennings, 2000; Strambach, 2017).

Sustainability transitions go beyond eco-innovations, as they involve fundamental changes in all system-constituting elements: networks of actors (firms, investors, users etc.), institutions (regulations, markets, norms etc.) and artefacts (technologies, materials, products etc.) (Markard et al., 2012). At the same time, eco-innovations essentially drive the transition of socio-technical systems such as energy and transportation because they reduce environmental impacts from unsustainable production and consumption practices (Boons and McMeekin, 2019). Together with changes of institutional structures and user practices, they have a decisive influence on the rapidity, direction and scope of sustainability transitions (Markard et al., 2012; Smith et al., 2010). Given the complexity of socio-technical systems and the interdependencies of the systems' elements, Köhler et al., 2019 illustrate that sustainability transitions are characterized by contestation and disagreement between multiple actors, making them open-ended, long-term and non-linear processes.

An important thematic focus that has attracted burgeoning scholarly interest in recent years is the geography of both sustainability transitions and eco-innovations. With this ‘spatial turn’ in each field, the “*inattention to space*” (Gibbs and O’Neill, 2014, p. 212) is increasingly being challenged (Coenen, 2015; Rinkinen et al., 2016). Instead, it has been recognised that eco-innovation and transformation processes, as well as their heterogeneity and disparity (Coenen et al., 2012), imperatively requires an inclusion and understanding of the spatial context. Interestingly, research on the geography of sustainability transitions has so far hardly been linked to geographical work on eco-innovations and vice versa. This is also due to different research approaches and logics. Therefore, it seems necessary to characterise and compare the two fields in more detail below.

## **2.1 The geography of eco-innovations**

Research on the geography of eco-innovations recognises that the generation and adoption of eco-innovations varies across places, due to spatially distinct supply and demand side characteristics as well as regulatory support and institutional structures to overcome the above mentioned externality problems (Horbach, 2014; Perruchas et al., 2020). As a heterogeneous field of research, it mainly encompasses spatial (regional) perspectives on green technology and industry development (e.g. Barbieri et al., 2020b; Perruchas et al., 2020), determinants of eco-innovations and green entrepreneurship (e.g. DiVito and Ingen-Housz, 2019; Horbach and Rammer, 2018) and environmental policy (e.g. Dawley, 2014; Fabrizio et al., 2017).

Although eco-innovations can be explicitly technological, organisational, social or institutional in nature (Rennings, 2000), research on this topic is strongly influenced by the literature on economics of innovation and technological change. Particularly influential in this regard is the field of evolutionary economics (Barbieri et al., 2020a; Boons and McMeekin, 2019). Its basic assumptions are that technological change and innovative activities are primarily shaped by organisational routines, i.e. regular and predictable business behaviour. Since routines have persistent and heritable features (Nelson and Winter, 1982), historical trajectories of economic development are likely to result in spatially uneven innovation activities. These general findings form the basis of evolutionary approaches within economic geography (Boschma and Frenken, 2011). In parallel, the relationship between economic development and environmental problem solution associated with eco-innovations originated from ecological modernisation theory (Boons and McMeekin, 2019; Spaargaren and Mol, 1992). Accordingly, technological change has to be guided by environmental policy and regulation to enhance both economic competitiveness and sustainable development (Gibbs, 2000).

The understanding of geography in the context of eco-innovations often results from positivistic research paradigms as a set of major philosophical approaches in human geography (Kitchin, 2015). Following positivism, sustainability-oriented processes are considered as real, highly structured and empirically observable phenomena (Zolfagharian et al., 2019). Hence, eco-innovation activities and

their interrelationships are typically investigated at the level of clearly definable spatial units (Hansen and Coenen, 2015). Against this backdrop, empirical analyses mainly draw on administrative territories that have a certain degree of political capacity and policy making (Cooke et al., 1997), such as districts, federal states or countries (e.g. Barbieri et al., 2020b; Corradini, 2019).

The operationalisation of space is in turn reflected in methodological approaches. Although research on eco-innovations was initially dominated by qualitative case studies (Florida et al., 2001), systematic comparative approaches relying on quantitative research methods now prevail. These studies primarily use large samples of patent, publication, firm-level and/or socio-economic data obtained either from official administrative databases or surveys in order to investigate eco-innovative activities of regions or countries over time (Horbach et al., 2014; Santoalha and Boschma, 2021). Important to note is that the explanation of spatial differences focuses rather on supply side determinants of eco-innovation generation and development.

Research on eco-innovations and its spatial characteristics explicitly refers to core concepts from economic geography and innovation studies that have been developed and widely applied in recent decades. On the one hand, evolutionary approaches such as spatial path dependency and regional branching are included (e.g. Perruchas et al., 2020; Trippl et al., 2020). On the other hand, studies involving systemic concepts and frameworks like territorial innovation systems highlight the role of different (regional) actors and institutional framework conditions (e.g. Colombelli and Quatraro, 2019; Giudici et al., 2019). However, both emphasise the importance of geographical proximity for knowledge spillover and interactive learning processes which are seen as essential to innovation capacities of territories. These factors are particularly significant due to the higher complexity of eco-innovations, which is why empirical studies especially focus on external knowledge sources, network relations, (socio-institutional) embeddedness and technological relatedness (e.g. Antonioli et al., 2016; Corradini, 2019; Horbach, 2014; Quatraro and Scandura, 2019).

## **2.2 The geography of sustainability transitions**

Geographical perspectives have only recently been given greater attention in transition studies (e.g. Boschma et al., 2017; Truffer et al., 2015). This is also evidenced by the geography's recent addition to the STRN research agenda (Binz et al., 2020; Köhler et al., 2019). To explain spatially heterogeneous transition dynamics and geographical peculiarities, the majority of studies refer to place-specific factors such as visions and policies, institutional settings, natural resource endowments, technological and industrial specialisations and market formation (Hansen and Coenen, 2015; Losacker and Liefner, 2020).

Sustainability transitions research has its origins in the sociology oriented science and technology studies (STS). With the technology turn in STS during the 1980s, the field started to embrace core perspectives from innovation studies like evolutionary approaches of technological change and

innovation (Boons and McMeekin, 2019). The disciplinary crossover was enriched by ideas of ecological modernisation (Spaargaren and Mol, 1992), which call for adapted (economic) behaviours to reduce environmental damages (Boons and McMeekin, 2019; Hansen and Coenen, 2015). In this regard, research on sustainability transitions initially foregrounded the role of technologies (Kemp and Soete, 1992). However, due to the interdependencies of actors, institutions and technologies within sustainability dynamics, the notion of socio-technical systems has become increasingly central (Kemp et al., 1998; Markard et al., 2012). Consequently, studies on transitions towards sustainable modes of production and consumption adopted a multi-dimensional and systemic understanding of transformation processes (Smith et al., 2010).

Far from being a homogenous research field, diverse geographical perspectives on sustainability transitions exist that pay attention to scales, places and spaces (Binz et al., 2020; Hansen and Coenen, 2015). In line with the social constructivist thinking of technology and innovation development dominant in STS (Boons and McMeekin, 2019), the conceptualisation of space often builds on relational geographical perspectives (Binz et al., 2020). These suppose that individual and collective actors create knowledge through social interactive learning and action processes across spatial scales (Fuenfschilling and Binz, 2018; Strambach, 2017). Since places, scales and spaces are socially constructed, sustainability transitions are seen as multi-scalar and interconnected processes in which territories form holistic rather than atomistic categories (Binz et al., 2020; Murphy, 2015; Späth and Rohrer, 2012).

Given that transitions comprise socially constructed processes, experiences and practices, the actors' narratives, stories, perceptions and interpretations are essential for the generation of transformational knowledge (Zolfagharian et al., 2019). In fact, to date, most empirical studies draw on case studies using qualitative research methods like expert interviews to uncover the spatial unevenness, systemic interdependencies and spatially distinct patterns of transitions (e.g. Martin, 2020; Strambach and Pflitsch, 2020). However, methodological challenges arise on how to gain generalizable insights on the complex and multi-scalar geography of sustainability transitions (Hansen and Coenen, 2015). To address this shortcoming, some recent empirical contributions draw on quantitative comparative analyses (Meelen et al., 2019) or social network analyses (Binz et al., 2014; Fontes et al., 2016).

Because the geographical dimension of sustainability transitions has long been neglected, the prevailing transition frameworks can be rather seen as spatially naïve or a-spatial (Coenen et al., 2012; Lawhon and Murphy, 2012). In order to increase context and space sensitivity, much of the previous research on geography of sustainability transitions has contributed to adjust or reframe the transition frameworks, especially the multi-level perspective (MLP) and technological innovation system approach (TIS) (Bergek et al., 2015; Coenen, 2015). Although initially setting system boundaries at the national level (Coenen, 2015; Wiczorek et al., 2015a), geographical studies increasingly acknowledge that TIS as well as sectoral niche and regime structures emphasised in MLP, are characterized by local variations and globally interconnected transition dynamics (Boschma et al., 2017; Dewald and

Fromhold-Eisebith, 2015). These findings led on the one hand to the elaboration of frameworks that stress the spatially interrelated character of innovation processes such as the global innovation systems (GIS) framework (Binz et al., 2016) or global socio-technical regimes (Fuenfschilling and Binz, 2018). On the other hand, work on national and regional lead markets for environmental innovation (Losacker and Liefner, 2020; Quitzow et al., 2014) and the regional facet of GIS (Rohe, 2020) emphasise the important role of regions as drivers for transformative change.

Despite the conceptual progress that has been made to further advance the geography of sustainability transitions research field, Binz et al. (2020) call for a deeper integration, i.e. theoretical bridging, of spatial concepts from related disciplines. The authors also propose a stronger focus on regional conditions that lead to more sustainable development trajectories. Against this backdrop, there are direct references to the geography of eco-innovations, especially since both lines of research analyse (innovation) systems' elements, i.e. actors, institutions and technologies (Edquist, 1997; Markard et al., 2012), which have a distinct regional manifestation. This "*meso level of system analysis*" (Markard and Truffer, 2008, p. 444) helps to explain the spatial development dynamics without explicitly referring to individual actions (micro-level perspective) or developments at the macro-level such as political or economic systems (Köhler et al., 2019).

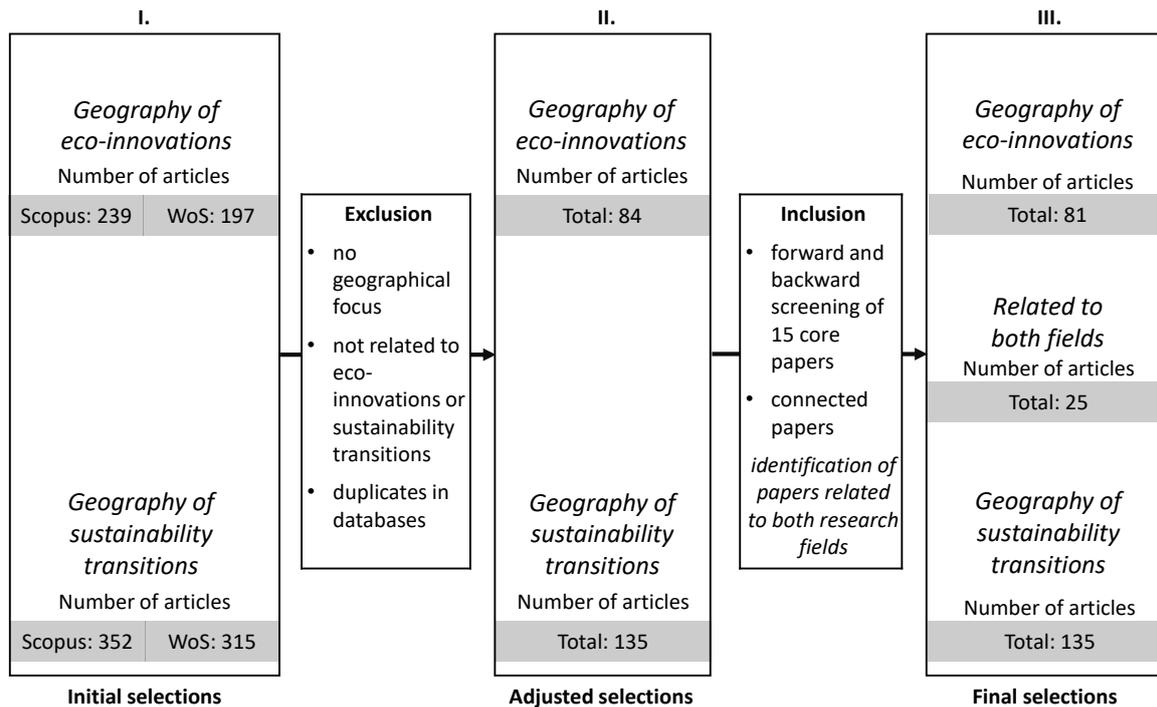
There is widespread agreement among the studies of both literature streams that the emergence and diffusion of eco-innovations, such as renewable energy technologies (RETs) or efficiency techniques in buildings (Perruchas et al., 2020), are necessary to cope with environmental challenges. Equally emphasised is the role of institutions - rules, norms, regulations and standards – that reinforce (reduce) information and power asymmetries, interactions between organisations and (dis-)incentivise both innovation activities (Edquist, 1997) and transition processes (Strambach, 2017). A more heterogeneous picture emerges, however, between both lines of research with regard to the role and function of actors (networks), from whose interactions innovative and socio-technical change is seen to emerge (Markard and Truffer, 2008; Raven et al., 2012). Due to their prominent role in both research streams, regions and actors will thus be the central subject of the following review.

**Table 1:** Features of geographical work on eco-innovations and sustainability transitions

<b>Research strand</b>	<b>Research focus</b>	<b>Origins</b>	<b>Understanding of geography</b>	<b>Methodological approaches</b>	<b>Concepts and frameworks</b>
<i>Geography of eco-innovations</i>	<ul style="list-style-type: none"> <li>• Spatially bounded factors as determinants for the emergence of eco-innovations</li> </ul>	<ul style="list-style-type: none"> <li>• Evolutionary economics of innovation and technological change</li> <li>• Ecological modernization</li> <li>• Geography of innovation</li> </ul>	<ul style="list-style-type: none"> <li>• Based on positivist assumptions</li> <li>• Definable spatial units</li> </ul>	<ul style="list-style-type: none"> <li>• Mostly quantitative research methods</li> <li>• Comparative analyses and generalizable knowledge</li> </ul>	<ul style="list-style-type: none"> <li>• Territorial innovation systems</li> <li>• Regional branching, (diversification and specialisation)</li> <li>• Regional path development</li> </ul>
<i>Geography of sustainability transitions</i>	<ul style="list-style-type: none"> <li>• Place-specificity and multi-scalarity of socio-technical system transitions</li> </ul>	<ul style="list-style-type: none"> <li>• Science and technology studies (STS)</li> <li>• Ecological modernization</li> <li>• (Evolutionary) Economic Geography</li> </ul>	<ul style="list-style-type: none"> <li>• Based on constructivist assumptions</li> <li>• Place, space and scale are socially constructed</li> <li>• Territories as holistic categories</li> </ul>	<ul style="list-style-type: none"> <li>• Mostly qualitative case studies</li> <li>• Stressing particularities of distinct places</li> </ul>	<ul style="list-style-type: none"> <li>• (Contextual) TIS</li> <li>• Global Innovation Systems</li> <li>• (Regional) lead markets</li> <li>• Global socio-technical regimes</li> </ul>

### 3. In-depth review of the existing literature

The rationale for further reviewing the literature on the geography of eco-innovations and the geography of sustainability transitions in-depth, is to provide better and clearer insights into these related but still largely unconnected strands of research. Beyond affirming the more generic differences outlined above, it is proposed, that a comprehensive identification and more detailed analysis of all relevant literature (Petticrew and Roberts, 2006) can help to better understand overlaps and potential opportunities for integration. Given the (considerable) conceptual and methodological differences, this summary will try to elucidate their respectively distinctive perspective on regions and actors. In itself, this in-depth review represents a more structured, transparent and replicable procedure than the more prevalent narrative reviews (Tranfield et al., 2003). It can thus be considered a better foundation for tackling the challenging task of scouting for synergies in two epistemologically rather separate strands. In principle, the analysis follows the systematic approach suggested by Petticrew and Roberts (2006), illustrated in Fig. 1.



**Fig. 1.** Procedure for identifying the relevant literature (author’s own figure based on Kivimaa et al. (2019))

To identify the relevant corpora of literature of both research lines separately, the systematic review started by defining characteristic keywords for each field. Search terms referring to the eco-innovation field were gathered from the seminal paper by Rennings (2000) and the review by Barbieri et al. (2016). To delineate the sustainability transitions research field, search terms were used from reviews by Kivimaa et al. (2019) and Hansmeier et al. (2021). Each search query has been expanded by geographical/spatial keywords to ensure sensitive searches. Using combinations of these terms, titles, abstracts and keywords of documents listed in both the Scopus and Web of Science (WoS) databases were sourced. Since document types such as books, conference proceedings and reports are underrepresented in Scopus and WoS (Mongeon and Paul-Hus, 2016), the search only included peer-reviewed journal articles. As of June 23, 2021, a total of four search strings – two databases, two research streams – were performed (see Table A1 in the appendix). These initial selections comprised 239 Scopus-listed articles (WoS: 197) related to the geography of eco-innovation and 352 Scopus-listed articles (WoS: 315) related to the geography of sustainability transitions.

The next step involved the exclusion of irrelevant work leading to adjusted selections. By screening the abstracts - or, in case of ambiguity, the entire study - those articles were excluded that had neither a distinct geographical focus, nor a connection to the broader eco-innovations or sustainability

transitions research fields respectively<sup>1</sup>. Merging the results from Scopus and WoS separately by research stream also led to the exclusion of duplicates, which reduced the preliminary number of studies on the geography of eco-innovation to 84 and on the geography of sustainability transitions to 135 (see Fig. 1).

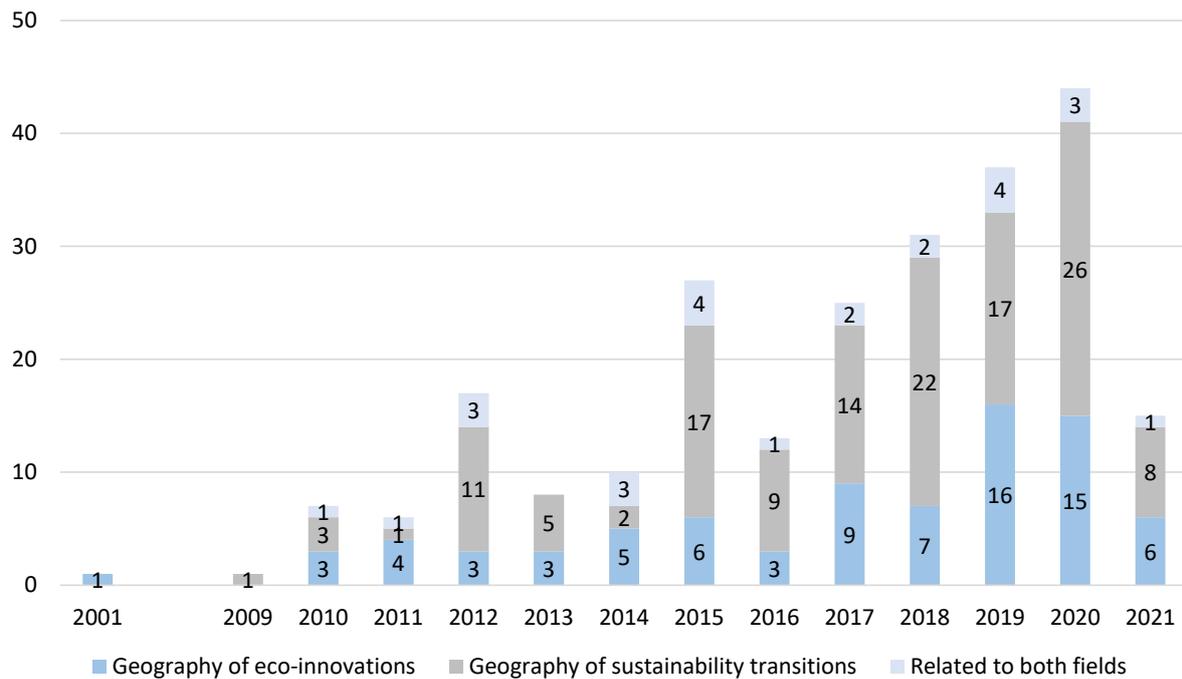
Due to the heterogeneity of both fields, not all relevant studies could be identified with the initial search queries. Following the approach of Kivimaa et al. (2019), further articles were searched by using forward and backward citations. As this step builds on established work (Petticrew and Roberts, 2006), the focus was on the 15 most cited articles in each field. As a second search strategy, the ‘connected papers’ visual tool<sup>2</sup> was used, which draws on the literature graph of Ammar et al. (2018) and identifies papers that are strongly connected to a given paper. Unlike building a citation tree, the algorithm uses co-citation and bibliographic coupling, thus clustering similar papers together. This approach was again applied for the 15 most cited papers of each field. The final selection for the research on the geography of eco-innovations comprises a total of 81 journal articles, 135 journal articles that refer to the geography of sustainability transitions and 25 papers that can be assigned to both (see supplementary data for overview of the articles).

When looking at the development over time (see Fig. 2), it becomes apparent that both lines of research started to emerge in the late 2000s. Interestingly, however, a pioneering paper by Florida et al. (2001), which was published a few years earlier, did not immediately lead to further research on the geography of eco-innovations. While the years after 2009 were shaped by a rather moderate development, the annual publication output has risen sharply since 2017. This dynamic is also evident in the literature on the geography of sustainability transitions, which is also in line with the overall development of transition studies (Hansmeier et al., 2021; Köhler et al., 2019). Journal articles that can be assigned to both fields, on the other hand, appear only sporadically, highlighting that the two fields do not yet converge (see appendix for more detailed descriptive and textual analyses). In the following sections, I analyse and discuss the characteristics of both research streams with regard to regions and actors in more detail (cf. overview in Table 2).

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<sup>1</sup> These include, for example, studies on urban planning and urban sustainability, political and educational transitions as well as literature on green and post growth without references to eco-innovations/transitions.

<sup>2</sup> [www.connectedpapers.com](http://www.connectedpapers.com)



**Fig. 2.** Number of articles published by year and research stream

#### 4. Regions in eco-innovation and transition processes

Studies on both eco-innovation and transition processes do not make use of a coherent and clearly defined term for ‘region’. Yet, there are parallels in that ‘region’ or the ‘regional level’ refers to a sub-national territorial unit, with the exception of Bai et al. (2009) and de Haan et al. (2021) who conceive several Asian countries as a region. The conceptual pluralism leads to the fact that the terms ‘regional’ and ‘local’ are sometimes used synonymously (e.g. Cainelli et al., 2011; Mattes et al., 2015; Rohe, 2020; Späth and Rohrer, 2012). The prominence of a small-scale -mostly regional- focus, can be explained by the fact that despite nationally or globally dominant technologies and institutions, regions can show considerable variance from these overarching patterns (Gibbs and O’Neill, 2017; Skellern et al., 2017). In this way, the research partly connects to the distinction made in geography of transitions between *place*, *scale* and *space* (Binz et al., 2020), which serve to implicitly structure the following analysis.

First, *place*-specific impacts on innovation and socio-technical development processes are directly related to the concept of embeddedness, which is central to both research streams. Hence, it is assumed that sustainability-oriented pathways are embedded in social and institutional relations within specific places and geographical settings that essentially explain their spatial heterogeneity (Coenen et al., 2012; Truffer and Coenen, 2012). Second, studies in both fields conceive the development towards sustainability as a process that goes beyond territorial boundaries. Rather, interdependencies and relationships exist across regions and spatial *scales*, which necessitates a trans-regional perspective of analysis (Coenen and Truffer, 2012). Third, to explain the spatial variation of eco-innovation and

transition processes, the influence of *space* and spatially bound determinants is of crucial importance (Binz et al., 2020).

#### **4.1 Embeddedness**

In its original sense, the concept of embeddedness refers to the fact that economic activities are embedded in broader social relations and institutional structures. According to the fundamental work by Granovetter (1985), it is less about the embeddedness of entire (economic) systems but rather about actors being embedded in networks of interpersonal relations. Following on from this, studies applying a geographical focus have added a spatial perspective to the embeddedness concept.

Previous research contributions evaluating geographical aspects of eco-innovations confirmed the embeddedness of actors and processes in socio-institutional structures within specific places (e.g. Chapple et al., 2011; DiVito and Ingen-Housz, 2019; Grillitsch and Hansen, 2019). Accordingly, eco-innovations shape and are significantly shaped by regionally embedded actors, their interrelations and learning dynamics (Cainelli et al., 2011; Carvalho et al., 2012). The actors considered in this literature stream are mostly from the economic sector such as firms or supplier networks (e.g. Corradini, 2019; Quitzow et al., 2014). Studies find that the institutional embeddedness of actors' capabilities is conducive to the regional eco-innovative performance, for example in the context of the emergence of green start-ups (Corradini, 2019) or the increase of the lead market potential (Quitzow et al., 2014). Moreover, when embedded in regional contexts, even multinational companies seem to gain competitive advantages in eco-innovation development over national companies (Cainelli et al., 2012). The extent of regional embeddedness, however, strongly depends on the forms of knowledge creation, actor networks and institutions (Binz et al., 2016) explaining why some technologies or industries are embedded more strongly in certain regional contexts than others. The spatial variation of environmental innovations and socio-technical change is thus also a result of the extent of regional embeddedness (Tödtling et al., 2020).

In contrast to the eco-innovation research field, geographical transition scholars additionally emphasise the socio-institutional embeddedness of transitions in broader technological and sectoral environments beyond specific places (Truffer and Coenen, 2012). Therefore, both the place-specific institutional arrangements and the wider network configurations are of research interest as they are important for understanding the spatiality of the emergence and stability of industries and technologies (Coenen and Truffer, 2012; Dewald and Fromhold-Eisebith, 2015; Truffer and Coenen, 2012). At the same time, Barnes (2019) points out the alignment of socio-technical configurations as a precondition to embed new technologies into the local context. Hence, region-specific alignments of technologies, actors and institutions are necessary to achieve systemic change. These findings partly reflect those of Longhurst (2015) who shows that local actors of alternative milieus are indispensable in the translation, i.e. embedding, of innovation and transformative activities. In the context of onshore wind energy, Rohe

(2020) also provides empirical support for the importance of actors embedded in regional networks, as this significantly accelerates planning processes. Consequently, the embedding of potentially transformative innovations in the energy sector at the local level is facilitated (Loorbach et al., 2020).

Drawing on the finding that socio-technical systems are embedded in geographical settings (Bridge et al., 2013; Van Boxtael et al., 2020), studies also recognise the role of historical alignment processes of organisations and institutions (Binz et al., 2016; Murphy and Smith, 2013; Veldhuizen, 2020). In this regard, Strambach (2017) confirms the embeddedness of knowledge bases and learning processes of actors in evolving institutional settings and paths. Since the actors' embeddedness is to a certain degree place-specific, this leads on the one hand to embedded competences and knowledge bases. On the other hand, however, the formation of different logics of action and capabilities also creates barriers and tensions in combining knowledge bases across territories. In line with these findings, Boschma et al. (2017) illustrate that place dependence emanating from the socio-spatial embeddedness of actors (Truffer and Coenen, 2012) is likely to hamper the unrelated diversification of regions. The emergence of new potentially more sustainable industries are accordingly unlikely if regions not only have dominant regime structures, but if these are also strongly embedded in localised knowledge, institutions and vested interests.

In accordance with these considerations, Vermunt et al. (2020) and Hawkey (2012) find for the agro-food and energy sector that the place-based embeddedness of actors increases the complexity in transition dynamics, accompanied by blocking mechanisms and a slower upscaling of more sustainable technologies. Bridge et al. (2013) equally argue that limited spatial embeddedness around fossil fuels can be beneficial to accelerate the uptake of renewable energy technologies and create opportunities for place-based solutions. Interestingly, the role of regional embeddedness in destabilising incumbent regime structures (Kivimaa and Kern, 2016) is far less the focus of research on the geography of transitions. The only study identified on this topic shows, contrary to expectations, that spatial embeddedness does not tend to have direct effects on the shutdown decisions of nuclear power plants (Meyer, 2021).

## **4.2 Trans-regional linkages**

Although actors' resources, competencies and synergies show a decidedly regional facet, they are accordingly influenced by broader economic and political network structures that are crucial to explain region-specific pathways towards sustainability (Bai et al., 2009; Coenen et al., 2012; MacKinnon et al., 2019b). Based on systemic (innovation) approaches, both literature streams emphasise the importance of trans-regional linkages and access to global networks for the innovation and transformation capacity of regions (e.g. Bergek et al., 2015; Grafström, 2018).

A general distinction can be made between horizontal and vertical linkages, the former referring to interdependencies on the same spatial level and the latter to multi-level linkages and activities (Rohe,

2020). It is interesting to note that the geographical research on eco-innovations focuses predominantly on horizontal interdependencies in and between regions, while the geography of transitions research focuses on vertical linkages across scales, i.e. adopting a multi-scalar perspective (Hansen and Coenen, 2015). These characteristics could be partly explained by the transitions research's traditional interest in stability and change of globally institutionalised system structures (Boschma et al., 2017). The geography of eco-innovation research, then again, mainly analyses regional characteristics of green industrial or technological change (Krupoderova and Portnov, 2020). Against this backdrop, studies find that environmental performance and innovation of neighbouring regions are likely to influence eco-innovation activities and environmental performances in a given region, suggesting the presence of interregional knowledge spillovers (Benedetti et al., 2020; Costantini et al., 2013; Quattraro and Scandura, 2019). Likewise, the diffusion is assumed to be enhanced by similar regional implementation conditions (Noseleit, 2018), facilitated by various forms of (non-)spatial proximity (Hansen, 2015)

Many studies evaluating vertical structures and linkages of eco-innovation and transition processes observe mixed results on whether higher spatial scales mainly drive regional systems change or, in turn, regions trigger change on the national and global level. Hess et al. (2018) and MacKinnon et al. (2019b) suggest that these differences may also be the result of interfering or orchestrating levels of governance that create case-specific transition patterns. On the other hand, Radinger-Peer and Pflitsch (2017) indicate that both bottom-up and top-down activities rather result from the dynamic interplay of actors. This supports the arguments of Binz and Truffer (2011) who point to the difficulty of characterizing a system's 'core' due to spatial interactions. It seems therefore likely that the role of regions is to spatially bridge and translate transformative activities, which explains why these might differ from global structures (Späth and Rohracher, 2012).

The successful upscaling of eco-innovations and transformative practices, both from niches to the regime and from lower to higher spatial levels, has been widely confirmed in the literature (e.g. Cooke, 2010a; Gibbs and O'Neill, 2014; Späth and Rohracher, 2012). The decisive factor here is seen in actor networks at the regional level, which, flanked by supporting policies and institutions, develop successful strategies, technologies or experiments that can be implemented and used across scales (Carvalho et al., 2012; Gibbs and O'Neill, 2017; Jiusto and McCauley, 2010; Sengers and Raven, 2015). Similar to these ideas, Losacker and Liefner (2020) developed the regional lead market framework and empirically demonstrate that regions can indeed drive national and international diffusion of eco-innovations when a competitive advantage is achieved through an early market formation. These regions could also be called 'transition regions', as they "*act as (...) lighthouses for eco-innovation to other regions and countries*" (Cooke, 2011, p. 106).

Conversely, downscaling dynamics seem to be equally emphasised in the literature. Dewald and Fromhold-Eisebith (2015) therefore characterise the emergence of new environmental technologies and transitions rather as a scale-transcending process, with temporary convergence of systemic functions on

one spatial scale. Scientific work highlights different channels through which the national and international level influences regions, such as policy and agenda setting (Lovio and Kivimaa, 2012; Mazzanti, 2018; Njøs et al., 2020), dominant rationalities (Fuenfschilling and Binz, 2018) and flows of knowledge (Chiarvesio et al., 2015; Rohe, 2020). Whether and to what extent eco-innovative and sustainable systemic change is fostered also depends on the regional absorptive capacity which is seen as crucial for the identification, assimilation and exploitation of external information and developments (Bento and Fontes, 2015; Blum et al., 2015).

Territorial dynamics – top down vs. bottom up – seem to be additionally determined by the type of region as well as technological and industrial characteristics. The latter also resonates with different innovation and valuation modes as illustrated in the GIS framework (Binz and Truffer, 2017). Accordingly, Njøs et al. (2020) find for the carbon-capture and storage technology a rather top-down development, while maritime battery technology emerged largely bottom-up within the region. A similar pattern is reported by Roesler (2019) who shows a rather small-scale dimension and value creation for bioenergy villages. With regard to the type of regions, it can be assumed that well-connected regions are more likely to be a nucleus of change towards more sustainable configurations than peripheral regions that are more attached to current regimes (Fuenfschilling and Binz, 2018). Grillitsch and Hansen (2019) argue, therefore, that peripheral, metropolitan and specialized regions require different policy measures. This also accords with the scenario of Tödting et al. (2020) who show that regions might differ in the application and production of green technologies.

### **4.3 Regional conditions**

Spaces and spatial conditions decisively influence eco-innovation and transition dynamics (Hansen and Coenen, 2015; Horbach, 2014). In reviewing both research streams and taking stock of previous reviews on geographical aspects of eco-innovative and transformative change (Capasso et al., 2019; Hansen and Coenen, 2015), it is found that the discussions mainly emphasize three sets of (intertwining) topics: technological specialisation and capabilities, market formation and demand as well as policies and regulatory frameworks.

Regarded as a supply-side determinant (Horbach, 2008), several research studies reveal that new eco-innovative activities depend on pre-existing regional structures, giving rise to place and path dependencies of sustainability processes (e.g. Colombelli and Quatraro, 2019; Corradini, 2019; Giudici et al., 2019; Santoalha and Boschma, 2021). At the heart of this scholarly debate are the processes of regional branching stressing the influence of technological relatedness on the diversification of regions towards sustainability (Boschma et al., 2017; Montresor and Quatraro, 2020), and thereupon regional knowledge spillovers within and across sectors and industries (Antonioli et al., 2016; Colombelli and Quatraro, 2019; Losacker, 2020). Previous studies confirm that green technologies and industries develop mainly in those territories where related skills and capabilities are available (Cooke, 2010a;

Orsatti et al., 2020; Perruchas et al., 2020). Trippi et al. (2020) show, however, that this does not happen automatically, but rather that opportunities need to be transformed, while Corradini (2019) points out that too much technological relatedness is likely to cause regional lock-ins. At the same time, Barbieri et al. (2020b) indicate that unrelated variety positively predicts eco-innovative activities in the early stages of the respective technology life cycle. Contrary to what is often assumed in the transitions literature, data of Santoalha and Boschma (2021) and van den Berge et al., (2019) suggest that a specialisation in unsustainable technologies does not necessarily hamper the green development of regions and may even provide necessary capabilities for it.

The structure of (regional) markets is a second crucial determinant for systemic change towards sustainability (Bento and Fontes, 2015; Horbach, 2008). The geography of eco-innovations literature stresses in particular that the current and future market demand is expected to create both economic benefits as well as environmental benefits in the region (e.g. Caprotti, 2012; Colombelli and Quattraro, 2019; DiVito and Ingen-Housz, 2019; Horbach and Rammer, 2018). Accordingly, markets can be seen as “*stimulators of change*” (Cooke, 2015, p. 4) on which regions can exert a formative influence. This process of market formation, a core function in the TIS framework (Bergek et al., 2015), is decisive to understand the spatiality of sustainability transitions. Dewald and Truffer (2012) assume in their foundational work on local sources of market formation that it consists of three sub-processes ranging from the formation of market segments to sell product variants, the formation of market transactions between supply and demand to the development of user profiles. Regions play a particularly important role in the early phases of the formation of markets, as the processes presuppose a certain spatial proximity of actors with specific perceptions and capabilities (Chiarvesio et al., 2015; Losacker and Liefner, 2020). Following the understanding of transition research, these (niche) markets can provide protected spaces for the development and experimentation of technologies (Binz et al., 2016; Lukkarinen et al., 2018). Once the demand grows, new market opportunities arise for producers and end-users become attracted beyond the regional borders that help to accelerate the diffusion of eco-innovations (Binz et al., 2017; de Haan et al., 2021; Fusillo et al., 2020).

Addressing grand challenges requires policy interventions that go beyond structural failures in innovation systems and focus on transformational failures (Coenen et al., 2015a; Magro and Wilson, 2019). Indeed, there is widespread consensus that policies and environmental regulation are another key driver to achieve green restructuring and systemic changes towards sustainability (De Laurentis, 2013; Hess et al., 2018; Martin, 2020; Park and Lee, 2017). Far from being one-dimensional, transformative innovation policies can take various forms and combinations of instruments, i.e. policy mixes (Kern et al., 2019), which have to be adapted to regional circumstances in order to ensure their adequate design, implementation and functionality (Magro and Wilson, 2019; Tödtling et al., 2020). Scholarly work finds that policies and priority settings vary substantially across space (Steen et al., 2019; Wesseling, 2016), with regional (innovation) policies able to influence higher level policy frameworks and, conversely,

national policies setting the conditions and incentives that facilitate or impede implementation at the regional level (Carvalho et al., 2012; Haarstad and Rusten, 2016; Quitzow, 2015). Against this backdrop, Essletzbichler (2012) argues that policies at the regional level are particularly suited to driving sustainable change, as they are able to benefit from knowledge spillovers and incorporate the diversity of technologies, actors, visions and regime structures. However, the lower level design and implementation of policies seems to require a certain degree of regional autonomy (Cooke, 2011). Remarkably, the eco-innovation literature mainly looks at supply side factors, i.e. the emergence of technologies and industries (e.g. Cainelli et al., 2015; Dawley, 2014; Ghisetti and Quatraro, 2017), while the transition literature elucidates the importance of demand-side approaches, i.e. the acceleration of transition processes (e.g. Coenen et al., 2015a; Quitzow, 2015).

## **5. Actors in eco-innovation and transition processes**

Usually understood and conceptualised as organisations (Rohe and Chlebna, 2021), actors are crucial in generating knowledge and shaping power within networks that drive eco-innovations, green technologies and sustainability transitions (Tödtling et al., 2020; Wieczorek, 2018). Both lines of research agree that these actor networks are mostly constituted locally or regionally, as geographical proximity facilitates diffusion processes and relations between actors (Gibbs and O'Neill, 2014; Hansen and Coenen, 2015). However, given the relational understanding of geography in transition studies (Raven et al., 2012), actor networks might simultaneously transcend spatial scales (Coenen, 2015; Justo and McCauley, 2010). Therefore, together with the systemic perspective characteristic of both lines of research, a multitude of actors is potentially relevant to shape processes of eco-innovative and transformative change (Truffer and Coenen, 2012; Wieczorek, 2018).

### **5.1 Types and functions**

A systematic review of the academic literature reveals that, in addition to the triple helix of science, industry and government as central elements in innovation systems (Veldhuizen, 2020), actors from civil society as well as mediators or intermediaries are increasingly of research interest. Therefore, five types of actors were identified:

- 1) *Scientific actors* include universities, higher education institutions, research centres and facilities as well as laboratories, which are considered crucial in both the eco-innovation and transitions literature. In addition to their core function as institutions for generating knowledge and human capital as well as conducting R&D, research institutions in general and universities in particular play a leading role in the development of eco-innovations and the dissemination of transformative knowledge (Calignano et al., 2019; Giudici et al., 2019; Horbach, 2014; Klitkou and Coenen, 2013; Quatraro and Scandura, 2019). Against this backdrop, Pflitsch and Radinger-Peer (2018) refer to the boundary-spanning capacity of universities in regional settings that

helps to catalyse transitions by transcending disciplinary and sectoral boundaries. This also includes the potentials of stimulating cluster initiatives (McCauley and Stephens, 2012), establishing the participation in policy initiatives (Calignano et al., 2019) or creating niches to incubate more sustainable modes of production and consumption (MacKinnon et al., 2019a). At the same time, higher education institutions might partly create or change paradigms through educating, teaching, research and outreach (De Giorgi et al., 2015; Radinger-Peer and Pflitsch, 2017). Especially due to the often limited resources of smaller businesses in terms of knowledge diffusion, the direction of research and lobbying in the context of sustainable development, scientific institutions play a key role in innovation and socio-technical systems. Accordingly, their absence is seen to have negative impacts on the scope and pace of eco-innovative and transformative change (Chapple et al., 2011; Sawulski et al., 2019).

- 2) A second important group of actors includes those from the *political or public sector*. At the national level, the government is seen to play various decisive roles, for example as a decision maker in the development of environmentally friendly technologies or industries (Bichai et al., 2018; Munro, 2019), in the initiation of large-scale projects (Haarstad and Rusten, 2016; Murphy and Smith, 2013), in the provision of financial resources (MacKinnon et al., 2019b; Nilsson and Nykvist, 2016) or in setting regulatory and political frameworks (Cooke, 2011; Dawley, 2014). Interestingly, policymakers tend to pursue supply-side policies when the industry is important to the country, while demand-side incentives are more conducive to green technology diffusion from abroad (Fabrizio et al., 2017; Wesseling, 2016). At the regional level, studies find that policymakers have a rather enabling and supportive role in the wider eco-innovative or transformative change (Frank et al., 2018; Hoppe and Miedema, 2020; MacKinnon et al., 2019a; Raman and Mohr, 2014; Roesler and Hassler, 2019). Although regional governments can also exert steering effects through innovation policies (Ghisetti and Quatraro, 2017; Grillitsch and Hansen, 2019), they are primarily able to foster cooperation processes, knowledge exchange and experiments, due to their experience about actor constellations and capabilities (Isaksson and Hagbert, 2020; Martin and Coenen, 2015; Rohe and Chlebna, 2021; Wieczorek et al., 2015b). Political actors are hence challenged in that they have to recognize opportunities for sustainable change and deliberately shape new actor networks beyond established industries (Martin, 2020; Santoalha and Boschma, 2021). Differences in the response to societal challenges also result from the structure of the nation's market economy, for example a liberal market model in North America versus a more co-ordinated market model in Sweden, which allows regional and national policymakers to play either a passive or proactive role (Cooke, 2011).
- 3) Actors from the *business sector* are at the centre of the literature on the geography of eco-innovations. Accordingly, (networks of) incumbent companies of all sizes (Cainelli et al., 2011;

Georgeson et al., 2014) on the one hand and green start-ups (Colombelli and Quatraro, 2019; Cooke, 2010a; Corradini, 2019) on the other, are seen as crucial for eco-innovation activities. Studies indicate that companies tend to eco-innovate and strive for sustainability when environmental policies create incentives, when they have an increased environmental responsibility or when future expectations regarding economic development are positive (Essletzbichler, 2012; Ghisetti and Quatraro, 2013; Steen, 2016). While innovation activities of economic actors are determined by interactions within close geographic boundaries (Antonioli et al., 2016; Cooke, 2011; DiVito and Ingen-Housz, 2019), recent studies note the importance of multi-national companies and transnational entrepreneurs in diffusing knowledge and leveraging unrecognized potentials, especially in sectors characterized by global value chains (Binz et al., 2017, 2016; Chiarvesio et al., 2015; Sjøtun, 2020). Few transition studies reflect on the importance of entrepreneurs, generally conceptualising them as innovators or system builders who drive new practices and systemic arrangements (Cooke, 2010b; Hojckova et al., 2020). In contrast, geographical work on eco-innovations regards new green innovators, i.e. start-ups, as a vital source of green technology and industry development, not least due to their often greater technological variety (Colombelli and Quatraro, 2019; Tripl et al., 2020). Since new companies often emerge in the environment of existing companies or directly from them (spin-offs) (Chapple et al., 2011; Corradini, 2019), research on the geography of eco-innovations follows implicitly the logic of path development and path creation rather than disruptive changes (MacKinnon et al., 2019b).

- 4) Resonating with the broad actor perspective in transition studies (Köhler et al., 2019), various studies on the geography of sustainability transitions explicitly examines actors and stakeholder groups from *civil society* beyond the business, science and public sector (Loorbach et al., 2020; Sjøtun and Njøs, 2019). In scholarly work on eco-innovations, on the other hand, the role of societal actors is of minor importance, which can also be attributed to the focus on endogenous or path-dependent branching processes of business actors described above (Binz et al., 2016). Although a few studies indicate the positive influence of users or non-governmental organisations (NGOs) on green technology development, this influence tends to be rather incremental (Cooke, 2012; Panapanaan et al., 2014). These findings are partly in line with those obtained by Faller (2016), who points to the passive role of citizens in the context of energy transitions. In general, therefore, it seems that cooperatives, community initiatives, sharing platforms, interest groups, etc., primarily influence transformative change by creating and translating ideas, mobilising broader engagement, raising awareness and providing an environmentally friendly environment through long-term relationships (Fontaine, 2020; Hansen et al., 2018; Hawkey, 2012; Loorbach et al., 2020; Roesler, 2019). In this way, actors from the

societal domain take on softer forms of power by producing alternative rationalities necessary for socio-technical change (Fuenfschilling and Binz, 2018).

- 5) Actors who perform overarching functions in innovation or socio-technical systems, such as aligning activities between actor groups or strengthening learning processes, are referred to as *intermediaries* (Kivimaa et al., 2019; Lukkarinen et al., 2018; Van Boxstael et al., 2020). However, a clear conceptual delineation of intermediaries is difficult, as they are mostly operating across sectoral and geographic boundaries, which potentially also applies to the types of actors described above (Sengers and Raven, 2015). Intermediaries are particularly influential in that they produce place-based configurations of systemic elements that support sustainability-related change (Barnes, 2019; Hess and Sudibjo, 2018; Sotarauta and Suvinen, 2019; Trippl et al., 2020). Since the broader strategic position requires a continuous adjustment in shifting ecologies (Van Boxstael et al., 2020), mediating actors especially are examined by the literature on the geography of transitions. Several studies show that regional development agencies, intermediary networks, regional assemblies or entrepreneurs in clusters and firms essentially contribute to the success of transitions. They do so by creating shared visions, conducting experiments, building trust, spreading legitimacy, providing resources as well as generating and sharing knowledge (Blum et al., 2015; Cooke, 2010b; Essletzbichler, 2012; Lukkarinen et al., 2018; Sengers and Raven, 2015). Given the complexity and multi-scalarity of transitions, studies find that (trans-)local intermediaries span and interconnect subsystems, thus triggering regional sustainable change and, conversely, influencing global developments (de Haan et al., 2021; Gustafsson and Mignon, 2020; Mattes et al., 2015; Rohe and Chlebna, 2021).

## 5.2 Changing roles and conflicts of interest

Far from being an uncontested concept, sustainability is accompanied by divergent interests and disagreements among a wide range of actors. Hence, the direction and scope of pathways towards sustainability are constantly being negotiated, making the diffusion of innovation and transitions aimed at sustainability long-term and open-ended processes (Fontaine, 2020; Köhler et al., 2019). The spatial and temporal dynamics of sustainability processes thus largely result from the prevailing groups of actors (Raven et al., 2012). Against this backdrop, Sotarauta et al. (2021) show, however, that similar actors can not only take on several roles, but these also vary between regions, making generalizable statements about driving or restraining forces difficult. For example, in one region public authorities lead the change, while in another they are an impeding factor.

Following the conceptualisation of transition processes, it is assumed that actors at the regime level such as incumbent firms constrain and prevent socio-technical change through unilateral decision-making, power asymmetries and vested interests (Fuenfschilling and Binz, 2018; Haarstad and Rusten, 2016; Trippl et al., 2020). The status quo would therefore only be changed by actors who are not closely

intertwined with the current system (Veldhuizen, 2021). Their actions in turn lead to reservations and persistence of established actors if they fear displacement (Santos and Lane, 2017). In this context, Späth and Rohracher (2012) and Mura et al. (2021) point to the importance of actors on the local level, who not only mobilise and align the necessary resources for socio-technical change, but also demonstrate its feasibility.

Conflicts of interest regarding sustainability-oriented innovation and transition activities exist both between and within the different groups of actors. For example, Magro and Wilson (2019) report that actors can not only be involved in governance setting processes but also in their evaluation, while Hermans et al. (2016) emphasize the continuous renegotiation of upscaling and outscaling processes of grassroots movements. Intergroup conflicts mainly arise due to the diversity of institutional frameworks and political arenas associated with the complexity of transitions, leading to tensions between the private and public sector (Haarstad and Rusten, 2016; Hansen and Coenen, 2015; Murphy, 2015; Strambach, 2017).

Disagreements can also be caused by actors at different spatial levels. In the case of the solar industry in Germany, Quitzow (2015) shows that regional and national governments disagreed on renewable energy legislation. This also accords with earlier observations, which showed that entrepreneurial experiments on the regional level were hampered by national governments (Lovio and Kivimaa, 2012). The lack of support from stakeholders, including those outside the political sphere, hinders the development of eco-innovations and transition processes and their transferability to other territorial units (Galliano et al., 2019; Hansen and Nygaard, 2013). At the same time, Coenen et al. (2015b) point out that the adoption of new products is sometimes beyond the influence of regional actors and tends to be sector-specific due to national or international regulations.

Actors not only perform multiple roles, their importance also changes during green technology development stages and transition processes. Scholarly work affirms the importance of cognitively distant knowledge and capacity building at early stages by committed actors at the regional level such as individual firms, engineers, business development professionals, politicians or sustainability initiatives (Andersson et al., 2018; Barbieri et al., 2020a; Faller, 2016; Loorbach et al., 2020). In later phases, state support, private financial support and additional competences of new actors seem to become more important (Andersson et al., 2018; Bento and Fontes, 2015). This is crucial in order to overcome technological barriers and develop markets that can ultimately induce sustainability processes at the national and international scale (MacKinnon et al., 2019b; Truffer et al., 2015). However, scepticism and frustration seem to increase among the actors involved, if processes of sustainable technology development are delayed by unclear responsibilities and lengthy approval procedures (Hoppe and Miedema, 2020; Rohe and Chlebna, 2021).

In order to overcome barriers and tensions between actors and to accelerate the diffusion of eco-innovations and sustainability transitions, the reviewed studies suggest several starting points. Besides

the communication of expectations and counter-narratives on future possibilities through engaged actors (Bauer, 2018; Raman and Mohr, 2014), the early involvement of different actors in regional networks, including users, is a key success factor (Faller, 2016; Rohe and Chlebna, 2021). This also includes the creation of incentive structures to involve regime actors (Vermunt et al., 2020). Geographical and social proximity tend to facilitate the building of trust between actors and the initiation of experimental spaces that serve the alignment between heterogeneous actor backgrounds to achieve institutional change (Boschma et al., 2017; Coenen et al., 2010; Rohe, 2020).

**Table 2**

Main findings on regions and actors by research stream

	<b>Regions</b>			<b>Actors</b>	
	Embeddedness	Trans-regional linkages	Regional determinants	Types and functions	Changing roles and conflicts of interest
<i>Geography of eco-innovations</i>	<ul style="list-style-type: none"> <li>• Socio-institutional embeddedness of eco-innovation activities within specific places</li> <li>• Degree of territorial embeddedness depends on the form of knowledge creation, actor networks and institutions</li> </ul>	<ul style="list-style-type: none"> <li>• Intra- and interregional relations, i.e. horizontal linkages</li> <li>• Knowledge and technology spillovers</li> <li>• Focus on (non-)spatial forms of proximity</li> </ul>	<ul style="list-style-type: none"> <li>• Technological capabilities and specialisation lead to place and path dependency (Regional branching)</li> <li>• Expected market demand</li> <li>• Supply-side policies to overcome market failures</li> </ul>	<ul style="list-style-type: none"> <li>• Economic actors (firms &amp; start-ups) contribute significantly to the creation and diffusion of eco-innovations within and across territorial boundaries</li> </ul>	<ul style="list-style-type: none"> <li>• Dynamic changes and conflicts of interest hardly in focus, if at all during green technology life cycles</li> </ul>
<i>Geography of sustainability transitions</i>	<ul style="list-style-type: none"> <li>• Socio-technical systems are embedded in broader geographical and institutional settings</li> <li>• Embedding of new technologies at the regional level requires alignment of socio-technical system structures</li> </ul>	<ul style="list-style-type: none"> <li>• Multi-scalar relationships, i.e. vertical linkages</li> <li>• Higher spatial scales influence transformative dynamics at lower levels and vice versa</li> </ul>	<ul style="list-style-type: none"> <li>• Processes of market formation influence spatiality of sustainability transitions</li> <li>• Policy interventions oriented towards transformation failures and demand-side</li> </ul>	<ul style="list-style-type: none"> <li>• Intermediaries align activities and strengthen learning processes; connect multi-scalar (sub-)systems</li> <li>• Societal actors exert incremental influences on transitions, (mobilisation of engagement, idea creation, awareness raising etc.)</li> </ul>	<ul style="list-style-type: none"> <li>• Incumbent actors constrain socio-technical change</li> <li>• Importance of (local) actors not intertwined with the system to induce transitions</li> <li>• Disagreement within and between group of actors as well as at different spatial scales</li> </ul>
<i>Similarities</i>	<ul style="list-style-type: none"> <li>• Changes towards sustainability are embedded in socio-institutional structures that are spatially constituted</li> </ul>	<ul style="list-style-type: none"> <li>• Interdependencies beyond the region level</li> <li>• Access to global networks crucial for regional eco-innovation and transformative capacity</li> <li>• Dynamics depend on type of region, technological and industrial characteristics</li> </ul>	<ul style="list-style-type: none"> <li>• Policies are a key driver to achieve green restructuring and systemic changes towards sustainability</li> <li>• Policies have to be adapted to regional circumstances</li> </ul>	<ul style="list-style-type: none"> <li>• Scientific actors generate and disseminate knowledge on eco-innovations and transitions</li> <li>• Political actors decide on resources and conditions for sustainability; supportive and enabling role at the regional level</li> </ul>	<ul style="list-style-type: none"> <li>• Sustainability is accompanied by divergent interests and disagreements</li> <li>• Similar actors can take on different roles that vary over time and space</li> <li>• Proximity facilitates trust building</li> </ul>

## 6. Discussion and Conclusion

Recent years have seen increasing research interest in the geography of eco-innovations and sustainability transitions. Therefore, it seemed timely to take stock of, review and contrast the literature of both lines of research. Although their main objects of analysis are closely related – eco-innovation is an essential prerequisite for transformations on the systems' level – different conceptual, methodological and epistemological traditions underlying the two research strands have so far prevented closer convergence.

By drawing on the specific research foundations and logics, the purpose of the current study was to highlight the most notable differences and commonalities of the two literatures with a specific focus on their conceptualisation and understanding of regions as well as actor groups that stand in the focus of their analytical interest. At the same time, the systematic analysis of more than two hundred papers provides several indications of complementarities, showing that both research streams cast light on two sides of the same coin in substance. Thus, this analysis underlines and elucidates that both fields harbour numerous, obvious potentials for conceptual cross-fertilisation and theoretical bridging (Binz et al., 2020; Hansmeier et al., 2021).

On the one hand, research on the geography of eco-innovations agrees on the socio-institutional embeddedness of innovation dynamics within specific places. In line with this conceptualisation of place-specific social and institutional dependencies, the eco-innovation literature mainly analyses horizontal linkages within and between regions, taking into account different (non-)geographical aspects of proximity (Coenen and Truffer, 2012). The spatiality of eco-innovations is again essentially attributed to technological specialisation and capabilities, market demand and supply-side policies, all of which can have a pronounced small-scale, i.e. regional, dimension. Since eco-innovation research mainly relies on quantitative research methods, the more administrative delineation of regions could thus also be a result of practical considerations regarding the availability of statistical data. At the same time, the literature focuses on economic actors, such as companies and start-ups, while conflicts of interest and changing roles of actors are hardly examined.

On the other hand, geographical work on sustainability transitions is characterised by a relational understanding of places and spaces, which explains both the focus on the territorial embeddedness of socio-technical structures and their multi-scalar interrelationships. Given the more fluid notion of regions and constructivist assumptions, regional determinants are less the focus of research. The role of regions is rather seen in the formation of markets and the creation of protected spaces for niche experimentation, pointing to the importance of demand-side policies. Moreover, the sustainability transitions literature aims at providing a broader understanding of actors beyond industry, science and business. As studies show, civil society groups can have significant (positive and negative) impacts on socio-technical change by creating spatially constituted institutional frameworks so that

relevant analyses hardly focus on the level of firms alone. This also includes forces of inertia and conflicts of interest, which are taken into account by applying a more dynamic perspective.

Taken together, the systematic review of both research traditions reveals overlaps and research gaps that are worth addressing in future scientific work. With regard to embeddedness discussions, ambiguities persist about the extent to which institutional, social and technological structures are spatially effective and influence eco-innovation and transition processes. Here, the systematic analyses of sustainability transitions research prove promising for investigating the socio-institutional constitution of places beyond regional conditions. Studies on both horizontal and vertical relations would additionally help to trace eco-innovation activities across spatial scales and at the same time to investigate interregional relationships and the importance of spill-overs in transition processes that more realistically reflect socio-technical change. The literature on eco-innovations might again profit from a deeper engagement with constraining factors, since innovation emergence and diffusion, especially with regard to normative eco-innovations, are significantly shaped by rigid forces (Boschma et al., 2017). Stronger interdisciplinary research approaches are also needed with regard to (changing) roles of actors. Given the scope of sustainability processes, the focus on economic actors in the eco-innovations literature certainly falls short and intermediary and societal actors have been underexposed so far. Conversely, the sustainability transitions literature's neglect of established economic actors is surprising, especially as they can also promote change towards sustainability. As questions remain to be answered concerning the changing roles of actors over time, studies should be conducted on whether and when actors change from drivers to preventers of eco-innovative and transformative change and vice versa. A more dynamic understanding of actors and their actions is needed to explain spatial variations in sustainability dynamics.

In addition to the recommendations for further research that leverages the potential of both research fields, the findings of this review have a number of important implications for (transformative) innovation policies. Due to the need to trigger changes on both the production and consumption side and to accelerate the diffusion of eco-innovations, relevant policy measures, also at the regional level, should increasingly address the demand side (e.g. Edler and Boon, 2018; Tödtling et al., 2020). Although administrative areas continue to be the reference of policy instruments, policymakers should be aware of the socio-institutional constitution and relationality of places and spaces as drivers of transformations. This also includes political attention to the importance of interregional and scalar relations. At the same time, the involvement of different groups of actors in innovation and transformative policies is essential to reduce inhibiting conflicts. Especially intermediary and societal actors, who often drive eco-innovations, need to be more in the focus of policymakers. Yet, tackling environmental challenges and accelerating transitions towards sustainability will only succeed together with established actors from science, business and politics.

## Appendix A

This appendix contains details on the conducted search strategy as well as more in-depth evaluations of the identified studies.

### Search strings

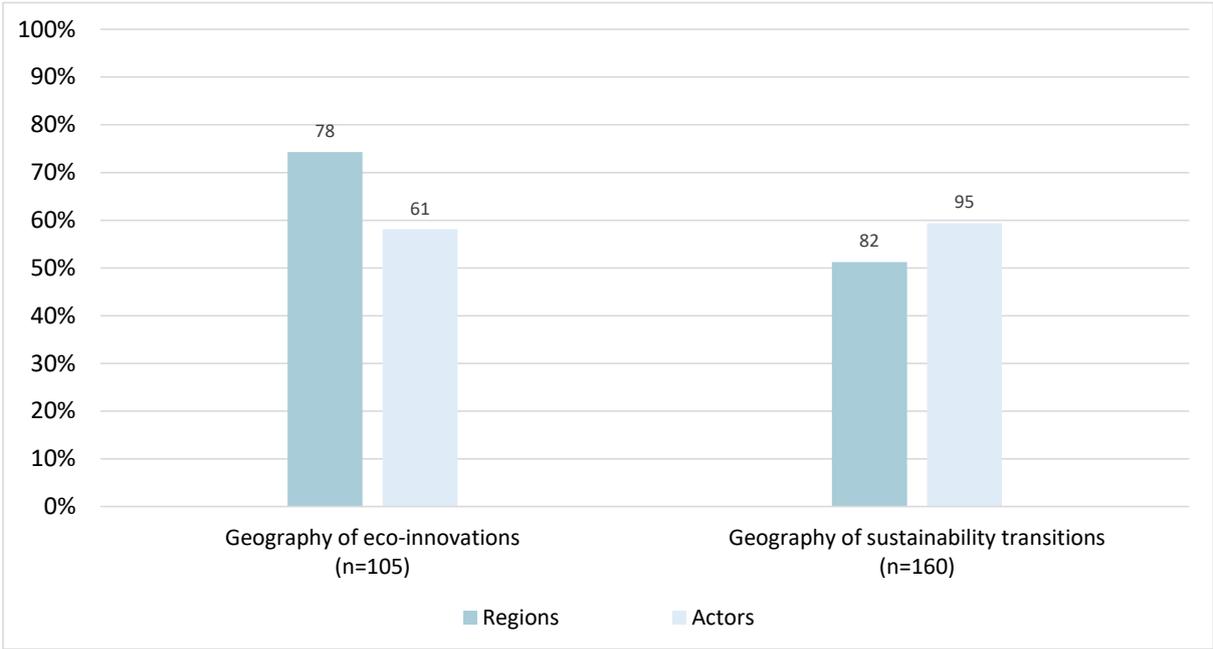
**Table A1:** Search terms used by research stream and database

	Scopus	Web of Science
<i>Geography of eco-innovations</i>	TITLE-ABS-KEY ( ("eco-innovation" OR "environmental innovation" OR "sustainab* innovation" OR ( ( clean-tech OR cleantech ) PRE/0 ( innovation OR industr* OR sector OR "start-up" OR startup ) ) OR ( green PRE/0 ( innovation OR "tech* development" OR "industr* development" OR "tech* innovation" OR growth OR diversification OR entrepreneur* OR "start-up" OR startup ) ) ) AND ( geograph* OR ( spatial PRE/0 ( scale OR dimension OR context ) ) OR ( local PRE/0 ( scale OR context OR development OR knowledge OR network ) ) OR ( regional PRE/0 ( scale OR level OR development OR econom* OR diversification OR branching OR analys* ) ) OR ( ( transnational OR international ) PRE/0 ( linkages OR level ) ) ) ) AND ( LIMIT-TO ( SRCTYPE , "j" ) )	TS=( ("eco-innovation*" OR "environmental innovation*" OR "sustainab* innovation*" OR ( ( clean-tech OR cleantech ) NEAR/0 ( innovation* OR industr* OR sector* OR "start-up*" OR startup* ) ) OR ( green NEAR/0 ( innovation* OR "tech* development" OR "industr* development" OR "tech* innovation*" OR growth OR diversification OR entrepreneur* OR "start-up*" OR startup* ) ) ) AND ( geograph* OR ( spatial NEAR/0 ( scale* OR dimension* OR context* ) ) OR ( local NEAR/0 ( scale* OR context* OR development OR knowledge OR network* ) ) OR ( regional NEAR/0 ( scale* OR level* OR development OR econom* OR diversification OR branching OR analys* ) ) ) OR ( ( transnational OR international ) NEAR/0 ( linkages OR level ) ) ) ) and Articles (Document Types)
<i>Geography of sustainability transitions</i>	TITLE-ABS-KEY ( ("sustainab* transition" OR "transition studies" OR "*technical transition" OR "socio-technical change" OR "multi-level perspective" OR "technological innovation system" OR "strategic niche management" OR "transition management" OR ( "global innovation system" W/255 transition ) ) AND ( geograph* OR ( spatial PRE/0 ( scale OR dimension OR context ) ) OR ( regional PRE/0 ( scale OR development OR innovation OR governance OR level ) ) OR ( local PRE/0 ( scale OR context OR development ) ) OR ( ( transnational OR international ) PRE/0 ( linkages OR level ) ) ) ) AND ( LIMIT-TO ( SRCTYPE , "j" ) )	TS=( ("sustainab* transition*" OR "transition studies" OR "*technical transition*" OR "socio-technical change" OR "multi-level perspective" OR "technological innovation system" OR "strategic niche management" OR "transition management" OR ( "global innovation system" NEAR/255 transition* ) ) AND ( geograph* OR ( spatial NEAR/0 ( scale* OR dimension* OR context* ) ) OR ( regional NEAR/0 ( scale* OR development OR innovation* OR governance OR level* ) ) OR ( local NEAR/0 ( scale* OR context* OR development ) ) OR ( ( transnational OR international ) NEAR/0 ( linkages OR level* ) ) ) ) and Articles (Document Types)

### Descriptive statistics and text mining:

Descriptive statistics (see Fig. A1) show that about 60 percent (61 or 95) of the papers in both fields have an actor focus, whereas the proportion of papers that apply a regional perspective, i.e. that look conceptually or empirically at the role of individual regions or make interregional comparisons, diverges. Articles related to both research strands are part of both literature corpora, thus retrieving information on the geography of eco-innovation from 106 and on the geography of sustainability

transitions from 160 journal publications. Around three-quarters (78) of studies on the geography of eco-innovations explicitly focus on regions, while this applies to almost 50 percent (82) of the research on the geography of sustainability transitions. The characteristics described above are also evident in more in-depth textual analyses. Using text mining methods, typical key terms and themes of each literature corpus were identified. Fig. A2 illustrates the most frequently used keywords as word clouds. To ensure meaningful frequency counts, words were reduced to the root word in a first step. This process is called text stemming and results, for example, in the words ‘innovation’, ‘innovations’ or ‘innovative’ being reduced to ‘innov’. Where appropriate, word stems were then completed manually, turning ‘innov’ into ‘innovation’ or ‘technolog’ into ‘technology’. It is striking that a variety of terms such as ‘innovation’, ‘region’, ‘technology’, ‘policy’, ‘environment’, ‘industry’ or ‘energy’ are of equal relevance in geographical studies on eco-innovation and sustainability transitions. These terms are used on average at least 30 times per publication. Interestingly, the term ‘actor’ is clearly used more frequently in research on the geography of sustainability transitions (nearly 29 times per document) than in the eco-innovation research context (approx. 12 times per document), but this can partly be explained by the fact that the latter focuses less on actors in a more general sense than on firms in particular (on average about 45 times vs. an average of 9 times in transition studies).



**Fig. A1:** Number and share of articles by research stream that have a focus on actors and/or regions



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