

## Review Article

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# The geography of eco-innovations and sustainability transitions: a systematic comparison

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**Abstract:** The need to address environmental challenges through innovation-based transformative change has become more urgent than ever and the spatial dimension of pathways towards sustainability has attracted increasing scholarly interest. Over the last decade, research on environmentally oriented innovation has entered the geographical discourse from different directions. This paper starts with the premise that, among other contributions, two main directions of research can be identified within the current geographical discourse that do not yet interface much – a broad, yet conceptually more traditional debate on eco-innovation and a newer discourse around socio-technical transitions that adds a further perspective. Having justified this assumption by a short literature review, we perform a keyword-based literature search, which confirms that there are indeed two distinct bodies of literature and few studies to date that integrate features from both fields. Following this, an in-depth review of the sources clarifies the differences in perspective and the common object of analysis of the basic systemic elements of actors, institutions and technologies. While this juxtaposition illustrates why the two fields of research have hardly cross-fertilised each other so far, it also shows that they are in substance far from irreconcilable. On the contrary, the nuanced synthesis of research findings reveals numerous complementarities that constitute promising avenues for future geographical

research. These are considered necessary to improve the understanding of the geography of innovation-based transitions towards sustainability.

**Keywords:** geography; eco-innovations; sustainability transitions; institutions; actors; technologies

## 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 has come to increasingly address issues around desirable, i.e. sustainability-focused, innovation (Barbieri et al. 2016; Rennings 2000) and systemic transitions (Köhler et al. 2019; Markard et al. 2012). In the political sphere, this “orientation towards [a] directionality of innovation” (Edler and Boon 2018, p. 433) has led to initial steps towards a paradigm shift, where transformative innovation policies complemented the prevailing focus on economic growth and competitiveness (Schot and Steinmueller 2018; Weber and Rohracher 2012).

During the early years of this normative turn in innovation studies and innovation policy (Sjötun and Njøs 2019; Uyarra et al. 2019), the spatial dimension of innovation-based and transformative change has remained largely unaddressed. Recently, however, a number of 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 this paper, we will suggest that while geographical research on this topic draws on multiple traditions, two of those stand out as particularly important for the development of the current disciplinary discourse. On the one hand, a perspective that emphasises the constructive potential of environmentally oriented innovations, i.e.

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eco-innovations, and their enabling factors, building on research on innovation systems and industrial path development (e.g. Cainelli et al. 2012; Costantini et al. 2013; Peruchas et al. 2020). On the other hand, a perspective that highlights the need for systemic sustainability transitions through a wide diffusion and application of eco-innovative products, processes and practices. This line of research emphasises the resistance and obstacles to change and is also more critical of the positive potential of eco-innovation as such (e.g. Binz et al. 2020; Coenen et al. 2012; Truffer et al. 2015).

Due to this in a way fundamental differences, the two perspectives do not integrate naturally and the productive integration of findings from either side remains below its potential. More recently, however, some research attempts have been undertaken towards that end, such as work on green industrial and technological path development in regions (Grillitsch and Hansen 2019; Trippel et al. 2020), the green economy and green growth (Capasso et al. 2019; Gibbs and O'Neill 2014) or (regional) lead markets (Losacker and Liefner 2020; Quitzow et al. 2014).

Against this background, this paper aims to make a twofold contribution. First, it will seek to empirically corroborate that there are indeed two distinct bodies of literature that, in practice, overlap little. Second, it will attempt to characterise both directions of research in order to better understand why they have had little correspondence with each other, while also exploring what benefits might accrue if such integration efforts were pursued more proactively. Quite evidently, the two mentioned domains of discourse draw on different research traditions and hence come with different methodological and epistemological assumptions.

Although the geographical literature concerned with sustainability transitions does not deny that eco-innovations and their enablers are central part of transition dynamics, it focuses on co-evolving institutional arrangements, which can be both obstacles and facilitators of socio-technical change. With a view to its perspectives on space, research on the geography of transitions follows relational and constructivist approaches of social and economic processes that it conceives as driven by multi-scalar relations of actor dynamics (Binz et al. 2020; Miörner and Binz 2021; Zolfagharian et al. 2019). Moreover, transition studies conceptually construct sectoral change and mainly uses qualitative case studies to uncover relevant factors that enhance or impede transitions towards sustainability (Hansen and Coenen 2015; Mattes et al. 2015; Strambach and Pflitsch 2020). This literature is therefore interested in the processes

after a potentially environmentally friendly solution, stressing its societal importance, is implemented, i.e. it mainly looks at the application and demand side of (non-technological) innovations as well as their diffusion across space (van den Berge et al. 2019).

The geographical discourse on eco-innovations is empirically and conceptually more heterogeneous but united by the fact that it finds its origin in innovation economics (Antonioli et al. 2016; Cooke 2012; Sotarauta and Suvinen 2019). As such, it regularly takes a more resource- and (growth) potential-oriented perspective and conceives institutions as enabling factors rather than as an element of inhibiting regimes. Such research on the geography of eco-innovations usually tends to quantitatively assess spatial determinants of green innovations, considering them a key prerequisite of technological and industrial change towards sustainability. Accordingly, much of the literature focuses on green technologies, while other types of eco-innovation that relate to social or organisational change receive little attention (Cainelli et al. 2015; Cooke 2012; Peruchas et al. 2020). Put differently, much of this literature starts from a territorial supply-side perspective on technological and industrial development and, in doing so, tends to maintain a more traditional concept of space as composed of political reference areas in which relevant institutions are constituted and resources made available. Importantly, this explicitly includes the discourse emerging in continuation of the (regional) innovation systems literature. However, it often lacks explicit conceptual references to broader sectoral changes, whose occurrence it documents (Antonioli et al. 2016; Horbach 2014; Krupoderova and Portnov 2020).

Despite the abovementioned differences in research objects, methods and concepts, research on the geography of eco-innovations and sustainability transitions do not represent opposing poles and are not fundamentally irreconcilable. Rather, both directions of research are two relevant poles in a broader discourse on the geographies of innovation that is far from exclusively limited to them. Moreover, researchers from both fields agree on the systemic character of eco-innovative or transformational processes, which are driven by (networks of) actors, institutions as well as material artefacts (Dawley 2014; Markard et al. 2012; Rohe and Chlebna 2021).

As mentioned above, the geographical debate is far from restricted to these two domains of discussion, nor are these domains mutually exclusive. Nonetheless, they are determinant elements of the current discourse that shape its dynamics and directionality. Against this background, their

apparent lack of integration seems surprising and deserves further investigation. Accordingly, this paper does not aim to provide a comprehensive literature analysis. Instead, it seeks to address the specific question whether two central streams of literature interface properly and, if not, why so. Subsequently, it seems to establish the potential benefit that could result if the situation were improved.

Empirically, we approach the first step of this analysis by classifying current papers on the basis of keywords that are characteristic for either presumed direction of research. Since this approach is based on assumptions, the aim is to test whether a keyword-driven search strategy built on qualitative scoping can demonstrate that there are two directions of research which are relevant in absolute terms and roughly on a par with each other. Furthermore, we determine whether both fields indeed overlap little.

Concluding, the paper will underline the benefit of integrating geographical research perspectives, following the call of Binz et al. (2020, p. 3), who see “the need to combine the topical concerns [...] with a more serious engagement with current theorizing in human geography and related spatial theories in the social sciences”. In line with this, this paper does not solely aim to take stock of specific perspectives within the geography of innovations, but also points to the importance of linking with related discourses.

The structure of the paper is as follows. After characterising conceptual and theoretical features of geographical work on eco-innovations and sustainability transitions, we outline the methodology applied to identify studies based on keywords and subsequently review them in detail. The results sections shed light on similarities, differences and complementarities between the two research streams regarding their conceptual perspectives on institutions, technologies and actors. Finally, we document the necessity to further reconcile innovation- and transformation-oriented perspectives in order to better understand spatial dynamics against the backdrop of grand societal challenges.

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

Not least since a ‘spatial turn’ in eco-innovation oriented and transitions research has emerged, the “inattention to space” (Gibbs and O’Neill 2014, p. 212) is increasingly being challenged, paving the way for necessary geographic debates (Coenen 2015; Rinkinen et al. 2016). Specifically, 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. Surprisingly, however, the existing geographical literature remains quite heterogeneous, although eco-innovations, which include (non-) technological measures that lead to a reduction of environmentally harmful impacts, are considered a necessary condition for systemic transformations (Kemp et al. 2019; Rennings 2000).

Within economic geography, work on sustainability and innovations has come to interface from two different directions in recent years. On the one hand, research on the geography of innovation, which tends to have a positive view on innovation, has increasingly focused on sustainability issues. In doing so, it has translated the concept of innovation systems rather directly to the field of sustainability-oriented innovation. In this perspective, eco-innovation creates positive momentum, with innovators being drivers of change. On the other hand, the geographical literature on sustainability transitions has become more attentive to space and begun to conceive systemic changes as a multi-scalar endeavour. This research field focuses on transformative change more comprehensively, assigning much importance to the diffusion of environmentally friendly innovation. While it does not dispute the transformative power of novelty, it tends to focus more at the detrimental effects of resistance (to adoption), and how those can be overcome.

Naturally, the existing geographical literature on sustainability-oriented innovations is not made up of these strands alone, nor is it apodictically possible to assign a specific paper to either domain. Given how they come together from such characteristically opposite, yet not opposing, dimensions and still not interface broadly, they seem a most obvious candidate for further analysis.

### 2.1 The geography of eco-innovations

The diverse 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 (Horbach 2014; Perruchas et al. 2020). Far from forming a clearly delimited field, related research encompasses spatial perspectives on green technology and industry development (e.g. Barbieri et al. 2020b; Perruchas et al. 2020) as well as the identification of regionally specific determinants for eco-innovations and green entrepreneurship (e.g. DiVito and Ingen-Housz 2019; Horbach and Rammer 2018). In essence,

the research's overarching interest is to examine region- or country-specific conditions that enable a wide variety of innovation activities – mainly related to green technologies and industries – conducive to green development (Antonoli et al. 2016; Cooke 2012; Mazzanti 2018).

Although eco-innovations can be explicitly technological, organisational, social or institutional in nature (Renings 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 with persistent and heritable features (Nelson and Winter 1982). Hence, 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).

Today, much of the established literature around environmentally related innovation and change relies on quantitative research methods. These studies primarily use large samples of patent, publication, firm-level and/or socio-economic data obtained from official administrative databases or surveys to investigate the distribution of eco-innovative activities across regions or countries (Horbach et al. 2014; Santoalha and Boschma 2021). Accordingly, eco-innovation activities and their interrelationships are typically investigated at the level of clearly definable spatial units (Hansen and Coenen 2015), with a predominant focus remaining on resource endowments and socio-institutional framework conditions that characterise specific regions. Against this backdrop, empirical analyses 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).

Conceptually, research on eco-innovations and its spatial characteristics builds on established notions from innovation studies in economic geography that have been widely applied in recent decades. These include, for

example, (regional) innovation systems and evolutionary approaches such as spatial path dependency and regional branching (Dawley 2014; Perruchas et al. 2020). Both emphasise the importance of geographical proximity for knowledge spillovers and interactive learning processes, some of which stem from traditional approaches towards establishing innovation capacities of territories (Boschma 2005; Jaffe et al. 1993). Hence, most of the studies draw on theories that are at least developed from a basis in traditional economics although their approach has been substantially broadened and does not necessarily take a neo-classical stance. Therefore, it should be noted that this line of research does not refer to a clearly definable set of conceptual and analytical frameworks (see Table 1. for summary).

## 2.2 The geography of sustainability transitions

Spatial perspectives have more recently also been given greater attention in transition studies (e.g. Boschma et al. 2017; Truffer et al. 2015) which is also evidenced by the geography's addition to the STRN research agenda (Binz et al. 2020; Köhler et al. 2019). Different from the economically informed eco-innovation studies discussed above, this literature takes a decidedly multidisciplinary perspective. Beyond insights from economics and sociology, it is substantially informed by political science, historical insights, technological perspectives from the domain of engineering and discourse-oriented ones from psychology and the humanities (Zolfagharian et al. 2019).

More precisely, 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, early research on sustainability transitions focused primarily on the role of technologies (Kemp and Soete 1992). Acknowledging the interdependencies of actors, institutions and technologies within sustainability dynamics, however, the notion of socio-technical systems has become increasingly central (Kemp et al. 1998; Markard et al. 2012).

With a view to geographies, the transitions literature emphasised that transitions towards sustainability result

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

Geographical research oriented towards...	Research focus	Origins	Understanding of geography	Methodological approaches	Concepts and frameworks
...eco-innovations	<ul style="list-style-type: none"> <li>— Territory-specific determinants for the emergence of eco-innovations</li> </ul>	<ul style="list-style-type: none"> <li>— Evolutionary economics of technological change</li> <li>— Institutional economics</li> <li>— Ecological modernisation</li> </ul>	<ul style="list-style-type: none"> <li>— Regions and countries as empirical items</li> <li>— Clearly delineated spatial units</li> </ul>	<ul style="list-style-type: none"> <li>— Mostly quantitative research methods</li> <li>— Comparative analyses and generalisable knowledge</li> </ul>	<ul style="list-style-type: none"> <li>— Territorial innovation systems</li> <li>— Regional branching</li> <li>— Regional path development</li> </ul>
...sustainability transitions	<ul style="list-style-type: none"> <li>— Place-specificity and multi-scalarity of sustainability transitions</li> </ul>	<ul style="list-style-type: none"> <li>— Science and technology studies (STS)</li> <li>— Ecological modernisation</li> <li>— Place, space and scale are socially constructed</li> </ul>	<ul style="list-style-type: none"> <li>— Regions and countries as objects of conceptual consideration</li> <li>— Relational approaches</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) technological innovation systems</li> <li>— Local/global niche development and experimentation</li> <li>— Global socio-technical regimes</li> </ul>

from complex, socially constructed processes. Beyond economic activities, the actors’ narratives, stories, perceptions and interpretations are essential for the generation of transformational knowledge (Zolfagharian et al. 2019). In addition to technological innovations, the literature thus also focuses on social innovations or, more generally, changes in social practices (Loorbach et al. 2020; Veldhuizen 2020). By invoking a multi-level perspective, it emphasises that actor coalitions can be agents of change as well as of obstruction and continuity (Sjøtun 2020; Steen 2016). To uncover these conflictual transition dynamics, most empirical studies use case studies that explain their spatial unevenness, systemic interdependencies and spatially distinct patterns (e.g. Martin 2020; Strambach and Pflitsch 2020). However, methodological challenges arise on how to gain generalisable insights on the complex and multi-scalar geography of sustainability transitions (Hansen and Coenen 2015). To address this shortcoming, some recent empirical contributions have, in addition, begun to draw on quantitative comparative analyses (Meelen et al. 2019) or social network analyses (Binz et al. 2014; Fontes et al. 2016).

As the consideration of space remains comparatively new to the STS debate, most studies still seek to develop clearer conceptual notions. In doing so, in their overt majority, from a relational perspective. In order to increase context and space sensitivity, much of the previous research on the geography of sustainability transitions has contributed to adjust or reframe the – initially a-spatial – transition frameworks, especially the multi-level perspective (MLP) and technological innovation system approach (TIS) (Bergek et al. 2015; Coenen 2015; Lawhon and Murphy 2012). Although initially setting system boundaries at the national level (Coenen 2015; Wiczorek et al. 2015), geographical studies increasingly acknowledge that TIS as well as sectoral niche and regime structures emphasised in MLP, are characterised 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 (regionalised) global innovation systems (GIS) framework (Binz et al. 2016; Rohe 2020) or global socio-technical regimes (Fuenfschilling and Binz 2018). Against the background of both global production and multi-scalar actor networks as well as the territorial embeddedness of social and institutional dynamics, work on local/global niche development and the influence of experimentation emerged in the last years (Coenen et al. 2010; Roesler and Hassler 2019; Sengers and Raven 2015) (see Table 1 for summary).

### 3 Identification of literature for in-depth review

The rationale for further reviewing the literature on the geography of eco-innovations and sustainability transitions in-depth, is to provide better and clearer insights into these related strands of research. To this end, we will first examine whether the abovementioned premise of a diverse strand of literature oscillating between two converging yet still clearly distinguishable poles or perspectives can be substantiated in practice.

Although this in-depth review represents a structured, transparent and replicable procedure, we are aware of the limitations of this methodical procedure. In essence, information retrieval is strongly dependent on the search strategy, which is influenced to a certain extent by the researchers' scientific background. The same applies to the assessment of the relevance and analysis of the obtained literature. In addition, differences in language and publication types, for example, can lead to some relevant contributions not being included in the analysis (Snyder 2019; Tranfield et al. 2003). To minimise a biased selection and analysis, the literature review therefore follows in principle the systematic approach illustrated in Figure 1 (see also Petticrew and Roberts 2006).

To test whether relevant, mutually exclusive corpora of literature can be identified, we started by compiling keywords commonly considered as characteristic terminology of either eco-innovation or transitions research. To not entirely rely on intuition, the first draft of this list was corroborated and amended based on a limited literature

review drawing on key contributions such as those cited in the above, introductory section. Technically, both search queries consist of two parts (see Table A1 in the Appendix). In the suggested domain of eco-innovation literature, we expect terms around the central notions of 'innovation' and 'development' that reflect this literature's assumed focus on economic development as a core objective and innovation as its driver. For this purpose, a detailed thesaurus of search terms, including frequent synonyms for eco-innovation, was developed based on Rennings (2000) seminal paper and a review by Barbieri et al. (2016). Additionally, notions like 'branching' or 'entrepreneurship' denote specific, long standing strands of research that we have – by means of assumption – attributed to this broader field.

Conversely, the known core characteristic of the emerging geography of transitions literature is reflected in the core notions of 'transition' and 'socio-technical change' as well as a number of others characteristic for the field, like 'technological innovation system' or 'multi-level perspective'. These keywords were compiled based on reviews by Markard et al. (2012), Kivimaa et al. (2019) and Hansmeier et al. (2021). As outlined above, it is evident that the more clearly delineated sustainability transitions literature would use a more specific set of vocabulary. What is less clear, in contrast, is whether this would prevent it from using the rather generic terminology by us attributed to the 'eco-innovation' domain as well. In that sense, the analysis was consciously designed to test whether both domains are from this terminological perspective truly distinct from each other, or whether the literature on socio-technical transition can already be considered fully integrated into the geographical discourse at large.

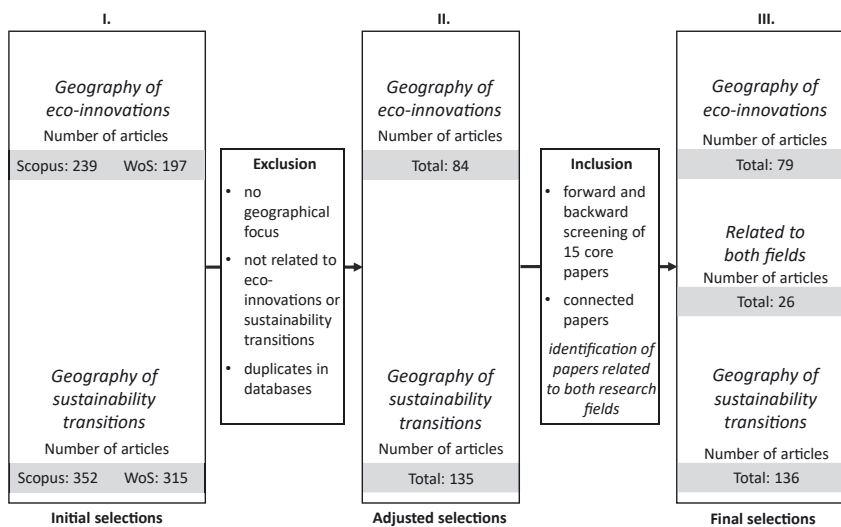
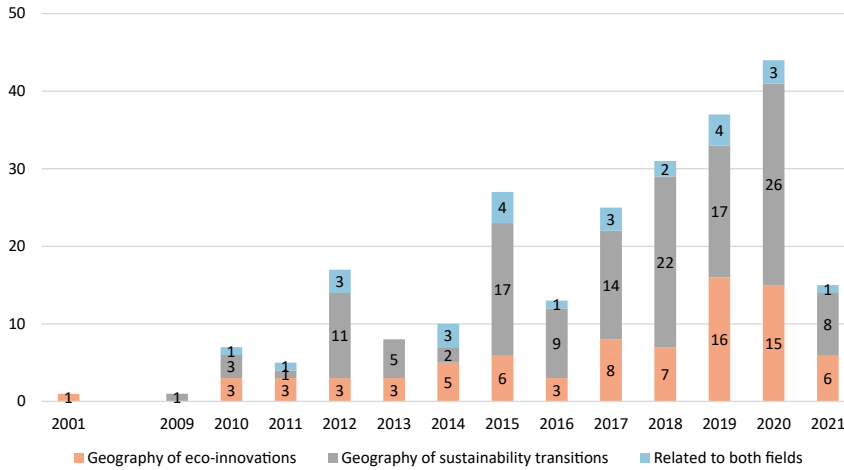


Figure 1: Procedure for identifying the relevant literature (author's own figure based on Kivimaa et al. (2019)).



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

To avoid the inclusion of non-geographical literature, both search strategies are complemented with a concise yet comprehensive list of geography-specific terms such as “spatial”, “local”, “regional” and “international” which serve as a necessary condition for any paper to be included in the corpus of reference for this study (Binz et al. 2020; Boschma et al. 2017; Krupoderova and Portnov 2020).

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 broader directions of research – were performed. 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> The exclusion of duplicates reduced the preliminary number of studies by 84 and 135 respectively (see Figure 1).

Due to the literatures’ heterogeneity, not all relevant studies could be identified with the initial search queries.

<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.

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 79 journal articles, and that for research on the geography of sustainability transitions to 136 journal articles. 26 papers can be assigned to both strands of literature (see also Supplementary Data for overview of the articles).

When looking at the development over time (see Figure 2), it becomes apparent that both lines of research started to emerge in the late 2000s. While the years after 2009 were shaped by a rather moderate development, the annual publication output for the geographical literature on eco-innovation has risen sharply since 2017. A very similar dynamic is also evident in the literature on the geography of sustainability transitions, in line with the overall development of transition studies (Hansmeier et al. 2021; Köhler et al. 2019). More importantly, the analysis confirms our initial hypotheses that much journal articles can only be assigned to one of the two perspectives, despite a rather broad search strategy.

<sup>2</sup> www.connectedpapers.com.

## 4 Geographical perspectives on key elements influencing innovative and transformative change towards sustainability

Considering that spatial conditions have a crucial impact on eco-innovation and the transition to a green economy and sustainability in general (Binz et al. 2020; Boschma et al. 2017; Horbach 2014), some previous work has already reviewed the relevant geographical literature. However, these reviews only address either the geographical literature on eco-innovation (Krupoderova and Portnov 2020), innovation in the context of green growth (Capasso et al. 2019) or sustainability transitions (Hansen and Coenen 2015). Since our text-based analysis has corroborated the existence of two still noticeably distinct directions of geographical literature on eco-innovative and transformative change, the following sections will explore in more detail whether our initial priors on these streams characteristics actually apply, and, if so, to what degree and in what ways.

Unlike Capasso et al. (2019) and Hansen and Coenen (2015), for example, who emphasise similar factors around policies, institutions, technological capabilities, markets or physical resources, we assume differences in perspective with regard to key systemic elements of institutions, actors and technologies. There are two main reasons for this. On the one hand, the aforementioned categories partly overlap, for example, policies may well be considered formal institutions (Capasso et al. 2019). On the other hand, the categories on actors, institutional and technological elements help to explain the spatial development dynamics of systemic change towards sustainability 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).

### 4.1 Actors

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). The diverse research perspectives agree that these actor networks are to a significant extent constituted locally or regionally, as geographical proximity facilitates diffusion processes and relations between actors (Gibbs and O'Neill 2014; Hansen and Coenen 2015).

With its perspective more strongly grounded in regional economies, a large part of the established geographical literature on eco-innovation tends to primarily consider dynamics and enabling conditions within specific regions (Antonioli et al. 2016; Cooke 2011; DiVito and Ingen-Housz 2019). While an acknowledgment of the role of multi-national companies and transnational entrepreneurs is increasingly present (Cainelli et al. 2012; Chiarvesio et al. 2015), it does not commonly occupy centre stage. Research on the geography of sustainability transitions, in contrast, which is based primarily on a relational understanding space (Raven et al. 2012), tends to emphasise that actor networks might quite commonly transcend spatial scales (Coenen 2015; Jiusto and McCauley 2010). Therefore, a multitude of actors – both inside and outside the specific territory under study – is potentially relevant to shape processes of eco-innovative and transformative change (Truffer and Coenen 2012; Wieczorek 2018; see also Table 2).

Based on a perspective drawing on evolutionary and institutional economics, moreover, the geographical literature on eco-innovation, sees actors mostly as drivers and facilitators of (socio-)economic activity. They perform research, invent, innovate, produce, enact legislation or whatever precisely to enable green technological change, create value and advance the development of society both economically and environmentally (e.g. Antonioli et al. 2016; Cooke 2010). So far, a remarkable share of this research strand focuses primarily on actors from academia, politics and business, the so called ‘triple helix’, with particular emphasis on the role of established companies and start-ups (Colombelli and Quattraro 2019; Georgeson et al. 2014; Sunny and Shu 2019). The latter are seen as a vital source of green technology and industry development, not least due to their often greater technological variety (Trippel et al. 2020). Suggesting that new companies often emerge in the environment of existing companies or spin-off directly from them (Chapple et al. 2011; Corradini 2019), many studies on the geography of eco-innovations seek to conceptualise change in a logic of path development and regional branching rather than disruptive changes (Cooke 2012; MacKinnon et al. 2019b).

Although research on the geography of transitions agrees on the importance of scientific, political and economic actors in terms of knowledge and skill creation as well as the implementation of financial and regulatory frameworks, it puts much stronger focus on actors from civil society as well as intermediaries (Klitkou and Coenen 2013; Loorbach et al. 2020; Sjøtun and Njøs 2019). This broader actor perspective is also motivated by transition studies’



Table 2: Main findings on actors, institutions and technological elements by broader direction of research.

Geographical research oriented towards...	Actors	Institutions	Technological elements
...eco-innovations	<ul style="list-style-type: none"> <li>— Role of actors from academia, politics and business (triple helix) typically assessed within specific territories</li> <li>— Predominant focus on established companies and start-ups</li> <li>— Logic of path development is emphasised, as newcomers often emerge in the environment of existing actors</li> <li>— Actors are seen as drivers and facilitators of change</li> </ul>	<ul style="list-style-type: none"> <li>— Both formal and informal institutional structures seen as localised contextual factors that explain spatial variation of eco-innovation activities</li> <li>— Institutions develop in a place-specific manner over long time periods</li> <li>— Policy instruments important to overcome market failures associated with double externalities of eco-innovations</li> <li>— Dominance of supply-push policies to enhance green technology development</li> </ul>	<ul style="list-style-type: none"> <li>— Complex eco-innovations rely on context-specific and temporal conditions that result in path and place dependencies</li> <li>— Regional technological relatedness influences green diversification processes</li> <li>— Spillover and transfer of research-intensive knowledge and technologies within and between regions</li> <li>— Focus on technology development</li> </ul>
...sustainability transitions	<ul style="list-style-type: none"> <li>— Potential relevance of a multitude of actors from all domains</li> <li>— Strong focus on civil society and intermediary actors</li> <li>— Actor networks transcend spatial scales</li> <li>— Similar actors can take on different roles that vary over time and space</li> <li>— Conflicts and tensions between actor groups</li> <li>— Incumbent actors constrain socio-technical change, while niches actors are crucial for changing the status quo</li> </ul>	<ul style="list-style-type: none"> <li>— Institutional embeddedness of technologies and sectors beyond specific territories</li> <li>— Multi-scalar institutional perspectives</li> <li>— Legitimacy of environmentally friendly products and processes is crucial to change sector-specific institutions</li> <li>— Policy interventions – policy mixes – oriented towards transformational failures</li> <li>— Importance of demand-side policies that focus on consumers' perspectives and mitigate industrial barriers</li> </ul>	<ul style="list-style-type: none"> <li>— Multi-scalar perspective on technology emergence and diffusion</li> <li>— Importance of niches (protected spaces) and local experimentation to exchange ideas, imaginaries and practices</li> <li>— Bottom-up and top-down activities between spatial levels to scale transformative practices and technologies</li> </ul>
Similarities	<ul style="list-style-type: none"> <li>— Actors generate knowledge and influence power within networks</li> <li>— Since geographical proximity facilitates diffusion and exchange processes, actor networks are often locally or regionally constituted</li> <li>— Agency affects industrial paths and transformative trajectories towards sustainability</li> </ul>	<ul style="list-style-type: none"> <li>— Formal and informal institutions impede or enhance eco-innovative and transformative change</li> <li>— Policies and regulation vary across space, with (supra)-national priority settings potentially influencing sub-national territories and vice versa</li> </ul>	<ul style="list-style-type: none"> <li>— Both technological and non-technological solutions (including knowledge) influence systemic change</li> <li>— Technological interdependencies beyond the regional level</li> </ul>

emphasis on the complexity of socio-technical systems, non-technological types of innovation and the inclusion of the demand side. In particular, civil society actors such as cooperatives, community initiatives or sharing platforms are found to influence transformative change by creating and translating ideas, mobilising broader engagement, raising awareness and providing an environmentally friendly environment (Fontaine 2020; Hansen et al. 2018; Hawkey 2012; Loorbach et al. 2020; Roesler 2019). Beyond knowledge creation, actors from the societal domain take on softer forms of power by producing alternative rationalities necessary for socio-technical change (Fuenfschilling and Binz 2018). Intermediaries, in turn, produce place-based configurations of systemic elements that support sustainability-related change (Barnes 2019; Hess et al. 2018; Sotarauta and Suvinen 2019). Their core function is to span and interconnect subsystems within and beyond territories by creating shared visions, conducting experiments, building trust, spreading legitimacy, providing resources as well as generating and sharing knowledge (Blum et al. 2015; Essletzbichler 2012; Lukkarinen et al. 2018).

Besides an overall broader understanding of actors, geographical transition studies differ from those with a pure innovation focus in that they emphasise directionality and hence the inevitability of conflicts and tensions between actor groups. Transition studies emphasise that similar types of actors might take several and varying roles in transition processes (Raven et al. 2012), with conflicting interests arise not only from their functional attribution to a specific subgroup like industry or science, but also from their focus on either maintaining or challenging the existing regime (Haarstad and Rusten 2016; Murphy 2015; Strambach 2017). In the perspective of transitions research, powerful regime-level actors, such as incumbent, multinational firms, operate across spatial level and constrain socio-technical change through unilateral decision-making, power asymmetries and vested interests (Fuenfschilling and Binz 2018; Haarstad and Rusten 2016; Tripl et al. 2020). This perspective is hardly ever explicitly stressed in the parallel, innovation-oriented strand of literature.

Following the geographical transitions literature, the status quo will only be changed by actors who are not closely intertwined with the current system (Veldhuizen 2021). And while small, new firms that emerge from (regional) niches may play a central role in this context, their capacity to affect regime change on their own will often remain limited (Coenen et al. 2015a). To overcome technological barriers and accelerate transition processes, studies acknowledge the importance of additional competences of new actors as well as state and private financial support (Andersson et al.

2018; Bento and Fontes 2015; Truffer et al. 2015), the communication of expectations and counter-narratives on future possibilities through engaged actors (Bauer 2018; Raman and Mohr 2014) and the early involvement of different actors in regional networks, including users and incentivised regime actors (Faller 2016; Rohe and Chlebna 2021; Vermunt et al. 2020). Accordingly, most geographical systems transitions literature takes a much broader and at the same time more differentiating perspective on actors than traditional innovation system studies.

Against this background of debates on stability and change, however, research strands on the geography of transitions and green path development, have more recently converged in developing agency perspectives to explain spatial particularities. In this context, agency stresses the role of (individual) actors and how they affect both industrial paths and trajectories towards sustainability. As such, actors purposefully and deliberately influence innovative and transformative change, which are conditioned by past experiences and geography (Boschma et al. 2017; Dawley 2014; Sotarauta et al. 2021; Steen 2016). Tripl et al. (2020) suggest a distinction between firm-level and system-level agency, both of which are considered necessary. Although firm-level agency in particular includes economic actors' activities that trigger green regional development, the geographical literature on eco-innovation and regional innovation systems has only very sporadically taken up agency perspectives (Dawley 2014; Sotarauta et al. 2021). Research on the geography of transitions, in turn, usually refers more distinctly to the importance of system-level actors and their agency in transforming technological, organisational, societal and institutional configurations (Barnes 2019; Sjøtun 2020). The transition research's interest in these change agents is consistent with its focus on processes that lead to the creation of new assets and the overcoming of path-dependent industrial and institutional regime structures that prevent sustainability transitions from happening (Fuenfschilling and Binz 2018; MacKinnon et al. 2019a; Tripl et al. 2020).

## 4.2 Institutions

The behaviour of actors is inevitably linked to the institutional context. This sets the rules of the game, which can be cognitive, regulative and normative in nature (Binz et al. 2016; Coenen et al. 2010; Davies and Mullin 2011). A general distinction is made between informal institutions such as norms, values or cultures, sometime also designated as conventions, and formal institutions such as rules, laws or regulations. Policies are also often be seen as formal institutions (Capasso et al. 2019). Both types of institutions

might impede or enhance eco-innovative and transformative change (Grillitsch and Hansen 2019; Isaksson and Hagbert 2020). From a geographical perspective, institutions have not only a local and regional but also a multi-scalar dimension due to national and supranational technological and industry-wide rules (MacKinnon et al. 2019b).

The diverse geographical literatures on eco-innovations and sustainability transitions agree that informal institutions are central to explaining spatially differentiated development patterns. Where they differ, however, is in their focus on the spatial effectiveness of informal institutions and their manifestation. Research contributions evaluating geographical aspects of eco-innovations usually stress the institutional embeddedness of actors and processes within specific places (e.g. Chapple et al. 2011; DiVito and Ingen-Housz 2019; Grillitsch and Hansen 2019). This builds on the recognition that innovation as a social phenomenon is based on knowledge and interaction, embodied in skills and routines, which in turn are shaped by regional institutional assets (Carvalho et al. 2012). These have developed over long periods of time in a place-specific manner and influence regional eco-innovative performance (Truffer et al. 2015), for example in the context of the emergence of green start-ups (Corradini 2019) or the early adoption of environmentally friendly solutions (Losacker and Liefner 2020). Rigid institutional structures, as often found in old industrial regions, pose barriers to green path development and make unrelated diversification more challenging (Boschma et al. 2017; Tödtling et al. 2020). In essence, studies with a regional science focus engage with regional institutional structures as localised contextual factors to explain spatial variation of eco-innovation activities.

Due to the often global nature of dominant sectors and technologies (socio-technical regimes), transitions research additionally emphasises the role of broader socio-technical contexts independent of space and scale (Boschma et al. 2017; Coenen and Truffer 2012; Grillitsch and Hansen 2019), as these may be just as important for understanding the spatiality of the emergence and stability of industries and technologies as local framework conditions (Dewald and Fromhold-Eisebith 2015; Truffer and Coenen 2012). For example, new and potentially more sustainable products and processes that are not well aligned with the prevailing sector-specific institutions barely diffuse and scale up, irrespective of how conducive the regional context is. This lack of legitimacy is usually accompanied by scepticism and low user acceptance (Binz et al. 2016; Rohe and Chlebna 2021; Späth and Rohrer 2012). Just like with a view to actor networks, geographical research on transitions has a more

pronounced tendency towards multi-scalar institutional perspectives than established research on eco-innovations (e.g. Strambach 2017).

Just as informal institutions shape places and vice versa, so do formal institutions (Trippel et al. 2020). There is widespread consensus in both the innovation- and transition-oriented geographical literature 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). In general, 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. These regions can well be called transition regions and are characterised by certain governance capabilities that can be inspiring for other territorial units (Cooke 2011). Conversely, (supra-)national policies usually set the conditions and incentives that facilitate or impede implementation at the regional level (Carvalho et al. 2012; Haarstad and Rusten 2016; Quitzow 2015). However, differences between the research streams exist in the necessity and justification of policies and regulations.

Research on the geography of eco-innovations often sees policies as formal instruments to address problems associated with double externalities of environmentally friendly products and processes. These illustrate that technological eco-innovations are not only characterised by knowledge spillovers to actors in the innovation phase, but also by bringing about a socially desirable outcome in the diffusion phase, with eco-innovators bearing the total costs (Perruchas et al. 2020; Quatraro and Scandura 2019; Rennings 2000). As this reduces the incentive to invest in innovation, many studies point to the importance of green technology push policies such as public and private R&D, investment subsidies and venture capital funding (D'Agostino and Moreno 2019; Georgeson et al. 2014; Sunny and Shu 2019). This predominantly supply-side perspective has recently been complemented by work on eco-innovations that also considers market or regulatory pull instruments. In particular, work on (regional) lead markets for eco-innovations emphasises that regulations provide advantages if they address place-specific environmental problems. This will both increase demand and diffusion of technologies within and across regions, allowing other territories to follow successful regulatory approaches (Cooke 2011; Losacker and Liefner 2020; MacKinnon et al. 2019b).

Transition studies, on the other hand, point to the importance of policies that are transformational in nature and address various system failures beyond innovation

research's focus on market failures (Magro and Wilson 2019; Weber and Rohracher 2012). Transformative policies aim to overcome failures resulting from, among others, insufficient integration of the user/consumer perspective or policy coordination between sectors. 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). Given the complexity of socio-technical systems and the contested ideas of sustainability, geographical transition studies highlight the importance of demand-oriented (innovation) policies that mitigate rigid market and industry barriers. These need to take into account both local endowments and global forces (Coenen et al. 2015b; Sjøtun and Njøs 2019; Veldhuizen 2020; Wieczorek 2018). In order to increase demand and thus the diffusion of environmentally friendly products and practices, studies suggest fostering networks and learning processes across different spatial and regime scales (Coenen et al. 2015a; Martin 2020; Roesler and Hassler 2019).

### 4.3 Technological elements

Technological elements as central determinants of systemic change include not only technologies as such (material artefacts) but also the knowledge associated with them (Markard et al. 2012). On the one hand, there is widespread agreement among the studies of the various literature streams that the emergence and diffusion of technological eco-innovations, such as renewable energy technologies (RETs) or efficiency techniques in buildings, are necessary to cope with environmental challenges. On the other hand, both innovation and transition studies point to the limitations and difficulties of this technological fix and increasingly refer to the dissemination of non-technological solutions and knowledge (Hansen and Coenen 2015; Peruchas et al. 2020).

Geographical research on eco-innovation and green industrial/technological path development usually refers to the context specificity and temporality of (eco-)innovative change (Gibbs and O'Neill 2017; Kemp et al. 2019). At the same time, eco-innovations are more complex and rely on diverse knowledge inputs from various actors in the innovation system (Barbieri et al. 2020a; De Marchi 2012). This results in a place and path dependencies of sustainability processes, with technological relatedness having a significant influence on the green diversification of regions (Colombelli and Quatraro 2019; Santoalha and Boschma 2021). Against this background, the availability of

related skills and capabilities facilitate regional knowledge spillovers within and across sectors and industries (Antonoli et al. 2016; Losacker 2020).

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. In essence, geographical research on eco-innovations focuses predominantly on interdependencies at the same spatial level (Rohe 2020), with a view e.g. to the question of whether the environmental performance and innovation activities in a given region are influenced by those of adjacent ones (Benedetti et al. 2020; Costantini et al. 2013; Quatraro and Scandura 2019).

Although transition studies do not negate the importance of horizontal interdependencies, the emergence of sustainable solutions is attributed to niches that are not necessarily confined to a specific spatial level (Sjøtun 2020). In line with the multi-level perspective, they form protected spaces that allow the development and experimentation of technologies as well as reconfigurations of unsustainable societal practices detached from institutionalised regime structures (Binz et al. 2016; de Haan et al. 2021; Fusillo et al. 2022; Lukkarinen et al. 2018). While, by definition, these do not need to be local, geographical transitions research emphasises that geographical and social proximity tend to facilitate the building of trust and exchange of ideas. Unlike established innovation studies which primarily emphasise the localisation of research-intensive technology creation and knowledge transfer, much research on the geography of transitions focuses on the localisation of new ideas, imaginaries and alternative practices in localised, socio-cognitive spaces (Longhurst 2015; Meelen et al. 2019; Sengers and Raven 2015).

Transformative change is thus initiated and scaled up, with both bottom-up and top-down activities between spatial levels resulting from a dynamic process of interdependencies (Dewald and Fromhold-Eisebith 2015; Radinger-Peer and Pflitsch 2017; Sengers and Raven 2015). As such, vertical linkages across scales, i.e. multi-scalar interdependencies have a decisive influence on the transformation of sectoral structures. The upscaling and downscaling of transformative practices, both between niches and regimes and between spatial levels, have been widely confirmed in transition studies (e.g. Cooke 2010; Gibbs and O'Neill 2014; Späth and Rohracher 2012). Similar to these ideas, Losacker and Liefner (2020) developed the regional lead market framework and empirically demonstrate that regions can drive national

and international diffusion of transformative innovations when a competitive advantage is achieved through an early market formation and technological capabilities. In this case, regions “act as (...) lighthouses for eco-innovation to other regions and countries” (Cooke 2011, p. 106).

Conversely, the national and international level influence regions, e.g. through 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 change towards sustainability is fostered also depends on the regional absorptive capacity, which is seen as crucial for the identification, assimilation and exploitation of external information and technological developments (Bento and Fontes 2015; Blum et al. 2015).

## 5 Discussion

Covering more than a decade of numerous conceptual and empirical contributions, this paper compared two important directions within the broader literature on sustainability-oriented innovation. By conducting keyword-based searches based on assumptions regarding the terminology either domain would use, the analyses confirm that there are indeed two large bodies of literature which can be identified and also delineated based on a divergent use of terminology – since the number of studies mixing terminology from both domains remains rather limited. Nevertheless, this does not limit comparability; rather, despite heterogeneity, complementarities emerge along the three previously mentioned categories of analysis of actors, institutions and technologies.

A first aspect concerns the question by which actors innovative and transformative processes can – and should primarily – be driven. Here, the two broader literature directions put different emphases on the role of specific actors. Established but rather diverse eco-innovation research tends to at least equally consider opportunities for change within existing path dependencies and actor coalitions (e.g. ‘path renewal’) (Cooke 2012; MacKinnon et al. 2019b), whereas transition research tends to regard the overt majority of incumbents as obstructive (‘regime’) and hence to suggest that radical change be driven by actors outside established regime structures (Fuenfschilling and Binz 2018; Späth and Rohrer 2012). Although eco-innovation research does include inquiry into the conditions under which new paths emerge (e.g. Strambach and Pflitsch 2020; Trippel et al. 2020), there is still a lack of differentiated empirical findings, particularly on the role and relationship of new and established actors.

More recently, the emergence of research on (change) agency demonstrates that there is indeed a possible field of convergence (e.g. Sjøtun 2020; Sotarauta et al. 2021). More and more empirical findings suggest that roles in the development and use of environmentally friendly solutions are less clear-cut than assumed in earlier transition studies (e.g. Santoalha and Boschma 2021; van den Berge et al. 2019) and also conceptual contributions tend to increasingly suggest that change is neither always primarily, nor most successfully driven by complete regime outsiders. Accordingly, we believe that an integration of insights from both research directions could help to develop a more inclusive perspective on the diversity of actor roles and their respective capacity to develop conditions for change agency. It could provide more clarity about the influence of the diverse agents of change we observe in empirical reality.

A second dimension of inquiry for which such an integration could be beneficial concerns the question which role future conceptual frameworks should attribute to institutional barriers of eco-innovation and transitions. In the geographical literature on eco-innovations, optimistic assumptions prevail concerning the potential enabling impact that supportive framework conditions and institutional setting can have on actor behaviour. As common within economics and business administration studies, eco-innovation tends to be framed as the outcome of (more or less) rational, entrepreneurial choices contingent on regulation, policies, markets, and institutions (e.g. Antonioli et al. 2016; Horbach and Rammer 2018). This, however, falls short of acknowledging the complexity of an empirical reality in which technological and psychological path dependencies often at least superimpose any rational consideration. Future research in that area will therefore have to better consider the effects of sector or technology-specific institutions as well as to incorporate the social and organisational dimensions of innovation which are often better acknowledged in transition studies. In this endeavour, it could benefit from relevant insights concerning institutional arrangements that drive or prevent sustainable change, not least with a view to the role of the demand side, the essential role of societal actors and the socio-psychological fabric into which all meaningful transformation will have to be embedded. Eventually, this would also require a shift in analytical perspective as institutions cannot simply be understood as pure spatially-bound contextual factor but require a multi-level, relational perspective on geography. However, it would not necessarily require an outright turn towards purely qualitative approaches. Instead, it could help nurture an effort to develop a more informed and conceptually better justifiable strand of quantitative analysis.

A third dimension of inquiry concerns the role of regions' structural characteristics with regard to technologies and knowledge. Having added space to sustainability, the geographical transitions literature focuses quite prevalently on the role of actors in specific niches. More traditional aspects of the regional environment in which these actors perform their processes of experimentation, like factor endowment, physical and institutional infrastructure or (relative) location tend to be considered less systematically. Although, for example, Grillitsch and Hansen (2019) have looked at different types of regions, the question which particular opportunities or challenges, for example, regions with an mature technological and industrial base face during transitions remains unconsidered.

Arguably the existing literature on the geography of eco-innovation provide many relevant insights which could inform future inquiries in transition studies. While the methodological and epistemological may vary, general insights into the relevance or irrelevance of certain aspects for specific processes may still be valuable. Many basic relationships have been empirically proven with sufficient certainty that their basic message can be adopted rather than risking relearning what is already known.

In summary, our analysis suggests that the sustainability transitions literature could profit from the established eco-innovation discourse about as much as the other way round. In recent years, some cross-over studies on regions' role of driving green innovation and restructuring have begun to pursue the avenue of inquiry, but much further ground remains to be covered, in particular with a view to the core field of inquiry that puts sustainability-oriented innovations centre stage.

## 6 Conclusions

As complex and multi-scalar processes, eco-innovative and transformational change require additional and multidisciplinary research efforts to develop a better understanding of and more precise insights into territorial and sectoral interdependencies. Against this background, this paper has demonstrated how future efforts could profit from a better integration of insights from two main strands of literature that shape a substantial share of the disciplinary discourse today. While acknowledging a lack of connectivity as well as differences in substance, we demonstrate that those key lines of research are neither conceptually nor epistemologically irreconcilable at a fundamental level.

Despite the diverse and increasingly converging work, further research is also needed to promote the integration of an in part still rather fragmented discourse. While the benefit of integration is already obvious for the existing

discourses around agency, institutions and technologies, we expect that it will gain additional relevance in those on individual and psychological characteristics that are only just emerging (e.g. Huggins and Thompson 2021). These are also increasingly coming into focus due to the growing need for non-technical innovations and social adaptation processes. Against the background of the importance of actors' converging interests and values, newer methodological approaches such as the socio-technical configuration analysis seem helpful to transcend and unduly simplistic divide between quantitative and qualitative research (Heiberg et al. 2022).

Beyond arriving at a better conceptual understanding of ongoing spatial transition processes, our findings also suggest that a denser mutual recognition of both directions of research could enable better and more robust policy advice, e.g. with a view to how regions can steer and enable change towards sustainability (see also Bugge et al. 2022; Tödting et al. 2020).

With a view to limitations, one important aspect is that this study's design and stated ambition prevented it from covering the current discourse in economic geography comprehensively. While this has not been the ambition, (economic) geography remains to explore whether the green transition exacerbates or mitigates spatial inequalities, i.e. whether it improves lagging regions potential to catch up or the opposite. On this – and other – more comprehensive challenges, our study may provide limited insight. Very likely, future research will have to acknowledge and elaborate deeper on further strands of the literature, beyond the scope of this paper, before robust conclusions can be drawn.

A first example of those are environmentally oriented debates in (economic) geography, which focus on important human-environment interactions without an explicit focus on innovation. A second example are studies on processes of social adaptation and the social and organisational innovations developing in their course. Given the complexity of systemic change, research is also needed on how the multi-scalarity of transitions goes hand in hand with political realities, according to which regional decision-making processes are, if at all, confined to one's own territory. Moreover, insights on the practicability and suitability of policies aiming at environmentally friendly products and practices at the regional level are still limited. Therefore, it might also help contextualise the spatial implications of various increasingly transformative (innovation) policies that seek – in a pragmatic, sometimes a-theoretical manner – to accelerate change in a variety of ways.

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## Appendix A

This appendix contains details on the conducted search strategy.

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

	Scopus	Web of science
Geography of eco-innovations	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)
Geography of sustainability transitions	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)

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