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A critical review and agenda for future research

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The geography of environmental innovation: A critical review and agenda for future research

Sebastian Losacker ¹, Hendrik Hansmeier ², Jens Horbach ³, Ingo Liefner ⁴

Abstract

Environmental innovations make an important contribution to solving ecological and climate crises. Although these crises are global phenomena, the regional dimension plays a crucial role, as regions both provide the conditions for the development of environmental innovations and promote widespread use and diffusion. Against this background, this article has two objectives. Firstly, we critically review the state of research on regional determinants of environmental innovation. Secondly, based on these results, we develop an agenda for further research in regional studies that will help to better understand the geography of environmental innovation and to come up with useful region-specific policy recommendations.

Keywords: environmental innovation, geography of innovation, sustainability transitions, regional development, geography of transitions

JEL codes: O31, O33, Q55, R11

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1 Introduction

The emergence and diffusion of environmental innovations is of utmost importance to combat and mitigate negative environmental impacts brought about by human-environment interactions. Environmental innovations can contribute to solving global challenges at the regional level, with regions being key arenas for developing environmental innovation, for pioneering their application and for promoting widespread use and diffusion. Environmental innovation is indeed an inherently geographic phenomenon, as the underlying innovation processes involve region-specific bundles of factors that determine the particularities of the innovations developed and adopted.

In recent years, the analysis of environmentally related innovations has become an increasingly popular research topic in regional studies, which is evident, for example, from multiple dedicated sessions at the ‘Geography of Innovation’ conferences and growing numbers of research articles. While much of this literature refers to the early innovation process, such as technology development (Barbieri, Perruchas, et al. 2020; Li et al. 2021; Montresor and Quatraro 2020; Santoalha and Boschma 2021), some deals with the production of environmental innovations and their markets, namely green industries and green regional development (Gibbs and O’Neill 2017; Grillitsch and Hansen 2019; Tripl et al. 2020). Moreover, researchers working in the field of sustainability transitions are investigating which spatial factors contribute to the diffusion and legitimacy of environmental innovations, enabling transformations of socio-technical systems beyond the regional level (Binz et al. 2014, 2020; Rohe and Chlebna 2021). In addition to this trend of geographers addressing the various facets of environmental innovation, researchers from the broader fields of innovation studies or environmental economics are increasingly focusing on spatial issues in their research as well (Antonioli et al. 2016; Cainelli et al. 2012; Horbach 2014; Horbach and Rammer 2018). Consequently, a large body of literature has emerged in recent years that, to put it concisely, addresses *the geography of environmental innovation*.

Research on the geography of environmental innovation has been unbalanced, however. Analyses of the regional conditions affecting the generation of environmental innovations tend to dominate, while the equally important aspects of scaling-up and diffusion as well as the role of basic regional characteristics that affect environmental innovations have so far been under-researched. Moreover, the state of research is fragmented across several disciplines, and geographical literature lacks a critical overview of the importance of regions in the development and diffusion of environmental innovations. At the same time, a research agenda at the intersection of regional studies and environmental innovation is still missing. In order to fill these gaps, this article has two main objectives. Firstly, the article aims to review the current state of research on regional determinants of environmental innovation, including both innovation emergence and diffusion. We thus seek to identify factors that can explain why some regions show better conditions for environmental innovation than others. Secondly, drawing on our critical review, the article aims to develop an agenda for further research on the geography of environmental innovation. The agenda is designed for researchers from core geographic fields such as human or

economic geography, regional studies and regional science, but it will also be helpful for geographically interested researchers from environmental economics, innovation studies or sustainability transitions, among other fields.

The remainder of this article is structured as follows. In Section 2, we discuss the conceptual background and the characteristics of environmental innovation and how they are relevant from a regional perspective. Section 3 encompasses the literature review, summarizing regional supply-side and demand-side determinants as well as regional institutional and political determinants of environmental innovation that have been identified in previous research. In Section 4, we provide suggestions for future research based on the review. In this context, we point to important regional factors that have been neglected so far and, on a more general level, we call for a demand-side turn in research on the geography of environmental innovation. Our concluding remarks are presented in Section 5.

2 Environmental innovation: what is it and why should we care about its geography?

An environmental innovation is a ‘[...] *new or improved product or practice of a unit that generates lower environmental impacts, compared to the unit’s previous products or practices, and that has been made available to potential users or brought into use by the unit*’ (Kemp et al. 2019, p. 35). This definition builds on earlier approaches (Arundel and Kemp 2009; Rennings 2000) and summarizes the core meaning in a relatively straightforward way: an environmental innovation is new and is introduced to the market (innovation part, see also OECD Oslo Manual), and it reduces environmental harm (environmental part). The environmental effect of eco-innovations can stem from lower resource use (e.g. energy efficiency), lower levels of pollution (e.g. filtering technologies) or any other form of reduced negative environmental impacts. Other definitions might further discern whether the beneficial effects on the environment are intended or not, they might distinguish between innovations according to the degree of environmental impact or they might explicitly include social or organizational innovations as well. That said, the use of the term environmental innovation in this article is largely limited to green technologies, goods and processes, and disregards other forms of innovation (e.g. business models).

From a social science perspective, green technologies and environmental innovations feature some interesting peculiarities and they therefore differ from regular technologies and innovations. Arguably the most important peculiarity of environmental innovations is the so-called double-externality problem. That is to say, they generate positive spillovers in two phases: innovation development and innovation diffusion. The former is a general problem of innovations. Organizations that invest in R&D produce knowledge that can be used by other organizations which, however, do not bear any of the costs. This chronic problem of free-riding is prevented mainly through governmental R&D subsidies, first-mover advantages and an elaborate intellectual property rights system. However, environmental innovations also produce positive spillovers in the diffusion phase, as adopters contribute to reducing negative

environmental impacts. While this has a non-excludable positive effect on other organizations and on society as a whole, adopters alone bear the costs. Accordingly, this double-externality problem might cause firms and other organizations to underinvest in environmental innovations (Beise and Rennings 2005; Jaffe et al. 2005; Rennings 2000).

The second distinctive feature of environmental innovation is a natural consequence of the double-externality problem. Environmental innovations require regulatory support to be successfully developed and compete in the market. From an innovation economics perspective, technology push and demand pull mechanisms provide an explanation for the emergence and diffusion of ordinary innovations, but an additional triggering force, the regulatory push/pull, is required to stimulate environmental innovations (Rennings 2000). Environmental regulations tend not only to encourage innovation, but can even help offset the costs of innovation development and lead to increased profits for the innovator. Environmental regulation can thus deliver a win-win situation for competitiveness and for the environment through its knock-on effect on environmental innovation. This phenomenon is commonly referred to as the porter hypothesis and is yet another feature of environmental innovation (Porter and van der Linde 1995; Rexhäuser and Rammer 2014). Based on these theoretical approaches, numerous empirical studies have examined the determinants of environmental innovation (Hojnik and Ruzzier 2016; Horbach 2008, 2016, 2019; Horbach et al. 2013). Essentially, three different groups of determinants can be distinguished, most of which take effect on the level of the innovator and/or innovation adopter:

- Supply-side determinants (e.g. technological capabilities, market characteristics)
- Demand-side determinants (e.g. expected market demand, environmental awareness)
- Institutional and political determinants (e.g. environmental policies and regulations, innovation networks)

Apart from the institutional and political determinants, which have an implicit geographical nature due to being linked to jurisdictions, the importance of geography and regional factors has received relatively little attention in empirical research on environmental innovation (Horbach 2014). This is surprising, given that the potential of environmental innovation and green industries for regional development has been discussed intensely for many years. In this context, it is generally assumed that green industries can have positive effects on regional economies and regional development (Capasso et al. 2019; Gibbs and O'Neill 2017). Countries and regions with strong green industries, exporting complex green goods, are, in fact, found to have increased capabilities to further innovate in green technologies while having lower CO₂ emissions (Mealy and Teytelboym 2020). Moreover, employment in green industries has a multiplying effect and can be linked to the creation of additional jobs in a region. Regions in which green industries thrive are also less affected by external economic shocks, meaning that green industries improve regional economic resilience (Vona et al. 2019). However, because green industries typically involve specialized jobs and rely on high levels of human capital, they present uneven growth

opportunities for regions with varying factor endowments (Consoli et al. 2016; Sofroniou and Anderson 2021). Given these impacts on regions, their economies and their environments, it is of significant value to better understand the *regional* determinants of environmental innovation, complementing existing knowledge on the general determinants listed above.

3 The geography of environmental innovation: regional determinants

In this section, we review the literature that deals with supply-side, demand-side and institutional conditions affecting environmental innovation that are determined or co-determined on the regional scale. In Section 4, we will outline under-researched issues in these three spheres and additionally discuss the need to extend the research focus towards the influence of basic regional characteristics. While there are already useful systematic literature reviews that deal with the determinants of environmental innovations (Barbieri et al. 2016; Hojnik and Ruzzier 2016; Horbach 2019), we limit our review to those studies that have an explicit implication for regional studies. As mentioned before, three different groups of factors have been examined in detail in the related literature: supply-side determinants, demand-side determinants, and institutional and policy determinants (Horbach 2008). While most of these determinants, particularly the pull factors that relate to expected market demand, take effect on the firm or innovator level (Horbach 2019), many determinants such as environmental regulations or technological capabilities and R&D activities on the supply side bear an explicit geographic dimension. In Figure 1, we present the three groups of determinants usually discussed in the literature, adding the regional dimension to each of these factors. Figure 1, in that sense, visualizes the underlying conceptual framework of this article and the structure of Sections 3 and 4. Table 1 provides an overview of the most important insights on the determinants of the geography of environmental innovation that have received much attention in the literature so far.

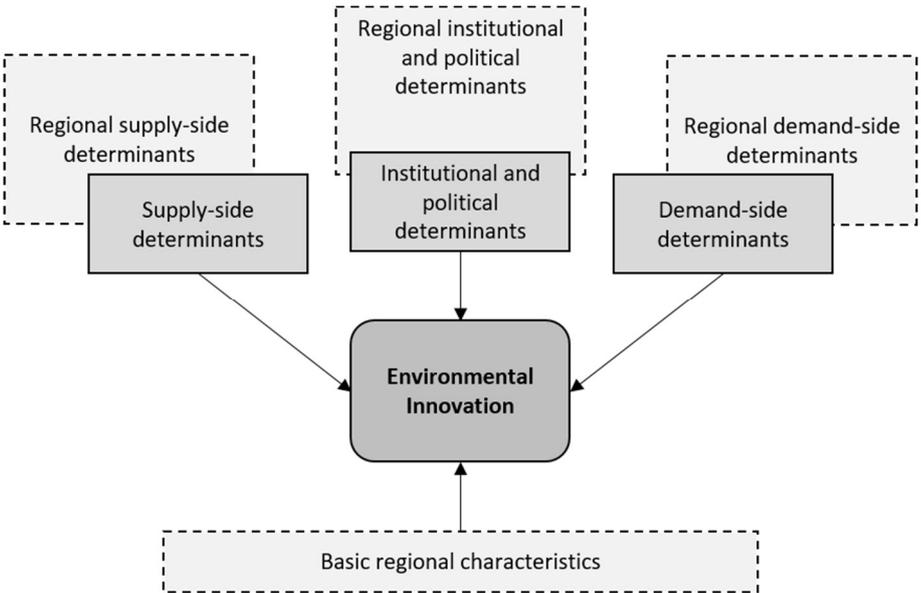


Figure 1: Determinants of environmental innovation (own figure, based on Rennings 2000; Horbach 2008, 2019)

Table 1: Regional determinants of environmental innovation

| <i>Regional supply-side determinants</i> |
|--|
| <ul style="list-style-type: none"> • Green technologies are more complex than non-green technologies and therefore require additional (local) knowledge and research inputs • Universities and other research facilities play a particularly important role for green technology development due to local knowledge spillovers, local human capital supply and university researchers involved in collaborative R&D processes • Green technologies generally benefit from additional external knowledge and open innovation modes, which emphasizes the relevance of efficient green regional innovation systems • Regions and countries are more likely to diversify into green technologies if local technological capabilities are related, even if a region is specialized in related dirty technologies • Relatedness to the local technological capabilities will also increase the probability that a region specializes in green technologies • A local knowledge base that is diversified over unrelated technologies (unrelated variety), will be more important for the development of green technologies that are in the early stage of the life cycle, while mature green technologies benefit from related variety |
| <i>Regional demand-side determinants</i> |
| <ul style="list-style-type: none"> • The demand for environmental innovation triggers the emergence of green industries in a given region (local demand-pull) • The agglomeration of pioneering firms that use environmental innovations will increase the likelihood that other firms in the region will also adopt green technologies • Similar demonstration effects occur on the level of individuals and households, with geographic proximity to early adopters increasing diffusion rates • The diffusion of environmental innovations strongly depends on technology legitimization, which can differ profoundly between regions • Regional environmental awareness and green political orientation induce the development and diffusion of green technologies • Lead market regions can demonstrate the positive effects of an environmental innovation and pioneer its applicability. Other regions and nations anticipate the benefits and follow the lead market's example |
| <i>Regional institutional and political determinants</i> |
| <ul style="list-style-type: none"> • Environmental regulations and policies trigger market demand for green technologies that local firms and other innovators are likely to respond to, increasing regional green technology development • Environmental regulations and policies in a given region or country force the adoption of cleaner technologies, counteracting the double-externality problem associated with the diffusion of environmental innovations • Based on innovative and stringent environmental policies, regions and countries might become lead markets that demonstrate the benefits of an environmental innovation • Regulations and policies in other regions might trigger green technology development in the focal region • Place-based innovation policies that combine supply-side and demand-side rationales can trigger regional environmental innovation |

3.1 Regional supply-side determinants

On the supply side, determinants of environmental innovation mainly involve the technological capabilities of the innovator, including input factors such as R&D and (external) knowledge (Hojnik and Ruzzier 2016; Horbach 2008, 2019). These input factors for (environmental) innovations, however, depend not only on the innovating organization itself, but particularly on external knowledge, research collaborations and local knowledge spillovers, which the literature on the geography of innovations and regional innovation systems has been demonstrating for more than two decades (Asheim et al. 2016). However, given their higher complexity (Barbieri, Marzucchi, et al. 2020), green technologies will need additional (local) knowledge and research inputs when compared to regular innovations. A number of studies have analyzed these additional efforts needed for the development of environmental innovations, many of which include explicitly geographical features. For instance, Horbach (2014) finds that environmental innovations benefit more from spatial proximity to universities and research institutions than regular innovations. In addition, green technologies are more likely to emerge when academic inventors are involved in their development (Quatraro and Scandura 2019) while they also require higher human capital inputs (Horbach 2014). These empirical findings emphasize the importance of universities in ‘green regional innovation systems’ (Cooke 2010), marking them as crucial actors in analyses of (the geography of) environmental innovations. Other supply-side regional determinants of green technology development include, inter alia, local knowledge stocks, agglomeration economies, and public research subsidies (Arranz et al. 2019; Corradini 2019; Corsatea 2016; Giudici et al. 2017). Moreover, green technologies often stem from teams of inventors who are able to creatively recombine existing knowledge (Orsatti, Quatraro, et al. 2020). They also generally require a higher degree of R&D cooperation and external knowledge in the developmental phase (Cainelli, De Marchi, et al. 2015; De Marchi 2012; Ghisetti et al. 2015; Horbach et al. 2013). In that regard, collaborative R&D processes will be particularly beneficial to environmental innovation emergence if partners are located in close geographic proximity (Ardito et al. 2019; Cainelli et al. 2012; Chiarvesio et al. 2015). These findings carry important implications. That is to say, efficient innovation systems and open innovation modes will be crucial for successful eco-innovation efforts, with regions being a promising scale for innovation emergence.

Additional insights can be gained from an evolutionary perspective on green technology development in regions. In that regard, it is noteworthy that green technologies are more likely to be invented in regions that are generally characterized by high technological capacity (Corradini 2019). Diversifying into green technologies will also depend on the local existing competencies, with relatedness playing a major role (Perruchas et al. 2020). Against this background, relatedness is relevant for green diversification processes irrespective of the technological domain, with some green technologies emerging in regions specialized in fossil fuel technologies (Santoalha and Boschma 2021; van den Berge et al. 2020). In other words, regions have many opportunities to diversify into the development of green

technologies drawing on their existing competencies. However, Barbieri et al. (2020) find that the role of related knowledge bases for developing green technologies will also depend on the technology life cycle. They show that unrelated variety, i.e. a local knowledge base that is diversified over unrelated technologies, will be more important for the development of green technologies that are in the early stage of the life cycle. For inventing mature green technologies, on the other hand, related variety will be more important. Technological relatedness also affects regional specialization processes, with relatedness increasing the likelihood of a region specializing in green technologies (Montresor and Quatraro 2020).

Similar mechanisms also apply at the industry level. From an evolutionary perspective, regional preconditions will strongly affect the way diversification in green industries might take place. Based on these considerations, Grillitsch and Hansen (2019) introduce a typology for green industry development in different types of regions, distinguishing between peripheral regions and metropolitan regions as well as between regions already specialized in green industries and regions specialized in dirty industries. Peripheral regions, for instance, will need to focus their developmental strategies on path emergence and path upgrading processes, supporting the growth of new green industries. Regions that specialize in dirty industries, on the other hand, might focus on new technologies that clean the existing industry or they might focus on diversifying into green activities that build on existing competencies, following a related diversification rationale (Grillitsch and Hansen 2019). While these conceptualizations help to uncover the importance of regional heterogeneity, single firms as well as broader system-level actors do play a crucial role in green regional path development (Sotarauta et al. 2021; Tripl et al. 2020). That is to say, pioneering firms might contribute to the formation of local green industries, affecting regional development through agentic processes of asset modification, as do other (non-local) actors such as national policymakers or NGOs (Holmen and Fosse 2017; H. Martin and Coenen 2014; Tripl et al. 2020). In that regard, green path development will, in many cases, not only depend on regional factors, but also on the interconnection of regional factors and (global) industry or technology dynamics (Nilsen and Njøs 2021; Njøs et al. 2020).

3.2 Regional demand-side determinants

While demand-side determinants of environmental innovations have traditionally been associated with characteristics of the innovator or adopter, i.e. anticipating future market demand, high levels of environmental consciousness and environmental awareness (Horbach 2008), demand-side factors can also take effect on the regional level. The demand for environmental innovation can, in fact, trigger the emergence of green industries in a given region, highlighting the importance of local demand-pull mechanisms (Bednarz and Broekel 2020). Moreover, it is found that environmental awareness differs between regions or countries and positively affects the development of environmental innovations and the creation of green start-ups (Corsatea 2016; Giudici et al. 2017; Horbach 2016). Regional demand can thus induce the development of environmental innovations. However, regional demand-side

determinants might play a more important role in the diffusion phase. Many environmental innovations are very specifically tied to local environmental conditions and/or environmental problems and therefore tend to have strong regionalized demand and market formation processes (Binz and Truffer 2017). This does not apply to products in mass markets such as electric vehicles, but ranges from renewable energies (e.g. dependence on wind, sun, water) to climate change adaptation technologies (e.g. flood protection or water scarcity technologies). Moreover, the diffusion of environmental innovations depends very much on legitimization or, in other words, on the willingness of consumers to adopt an environmentally benign technology (Bergek and Mignon 2017; Hekkert et al. 2007). As technology legitimization results particularly from place-specific factors such as localized institutions, legitimacy will differ between regions, leading to differences in diffusion rates across space (Heiberg et al. 2020; Rohe and Chlebna 2021).

In addition, innovation diffusion is a social process in which early adopters can influence further potential adopters to use an innovation (Rogers 1962). This process unfolds through various channels of information exchange, being both simpler and more likely in geographical proximity (Hägerstrand 1968). While these diffusion mechanisms apply to all types of innovations, it is very likely that they are more important for environmental ones. Given the assumption that many potential adopters, particularly firms, often fail to anticipate the benefits of environmental innovations due to incomplete information as well as organizational and coordination problems, it is reasonable to conclude that demonstration effects from peers are particularly important for the diffusion of environmental innovations (Montalvo and Kemp 2008; Porter and van der Linde 1995). In fact, several lines of evidence suggest that the agglomeration of pioneering firms that use environmental innovations will increase the likelihood that other firms in the region will adopt environmentally benign technologies as well (Antonioli et al. 2016; Cainelli et al. 2012; Horbach and Rammer 2018), emphasizing the importance of local demonstration effects for environmental innovations. Of course, demonstration effects are not limited to innovation diffusion in firms, they also occur on the level of individuals or households, for instance in the case of PV installations (Graziano and Gillingham 2015; Wolske et al. 2020).

These diffusion mechanisms stemming from the demand for environmental innovations not only take effect between adopters in a given region, but also between different regions, following the notion of (regional) lead markets. Lead market regions demonstrate the positive effects of innovations and can drive their international diffusion (Beise and Rennings 2005; Quitzow et al. 2014). Other regions and nations anticipate the benefits of an innovation that the lead market has already implemented and follow its example. The result is a simple spatial pattern of innovation diffusion with one pioneering region and many laggards. The concept of lead markets has proven particularly useful explaining the diffusion of environmental innovations, as they depend strongly on regulations and local demand conditions (Horbach et al. 2014; Rennings 2014; Walz and Köhler 2014). Although lead markets are mostly studied at the national level, recent case studies also show that lead markets can emerge at the regional level,

steering interregional as well as international environmental innovation diffusion (Cooke 2011; Losacker and Liefner 2020).

3.3 Regional institutional and political determinants

It has long been recognized that regulations and policies are key to environmental innovation (Jaffe et al. 2005; Rennings 2000). Internalizing external costs associated with the adoption of environmental innovations by means of adequate policies and regulations implies that administrative areas such as cities, provinces or nations with stringent environmental policies have higher diffusion rates of environmental innovations than areas with rather lax policies (Cainelli, D'Amato, et al. 2015; Frey 2012; Popp 2010; Woerter et al. 2017). Essentially, the same inducement effect applies to the diffusion of environmental innovations as to their development. While from a theoretical viewpoint, regulations ought to counteract the double externality problem in the diffusion phase (Jaffe et al. 2005; Rennings 2000), they also induce the invention of green technologies, and not merely their use. More stringent environmental policies will lead to an increase in green technology development in a given region or country, with different types of policy instruments being effective for different green technology domains (Dechezleprêtre and Sato 2017; Johnstone et al. 2010, 2012). The immediate consequence of this causal relationship is an uneven distribution of green innovation output (and use) across space. Stringent policies that promote innovation development and diffusion in a region or country can, moreover, result in a so-called regulatory advantage that favors the creation of a lead market for environmental innovation (Beise and Rennings 2005). However, from a geographical perspective, the role of regulation and policies is much more complex. It is possible, for instance, that foreign environmental policies induce domestic green technology development and vice versa (Dechezleprêtre and Glachant 2013; Herman and Xiang 2019; Popp 2006). In particular, policies on the national or supra-national level can foster the diffusion of environmentally benign technologies, for instance via carbon pricing (Baranzini et al. 2017). In fact, most studies on the effect of environmental regulation and policy on the development and diffusion of environmental innovations are at the level of nation states. The importance of regulation at the subnational level is less frequently studied, but might show similar inducement effects (Cao et al. 2019; Corsatea 2016; Losacker and Liefner 2020).

On the regional level, place-based innovation policies are important to support green industries and to leverage the application of sustainable technologies. In that sense, it is important to support both green technology development, i.e. the supply side, and diffusion processes, i.e. the demand side, depending on the regional context and place specificities (Hansmeier and Losacker 2021; Tödtling et al. 2021). In fact, regional administrative bodies exhibit great potential to support diffusion processes using green public procurements, also nurturing early market formation and early adoptions (Ghisetti 2017; Lauer and Liefner 2019; Nesterova et al. 2020). Green public procurement, however, also exhibits positive effects on future green technology development within a region (Orsatti, Perruchas, et al. 2020).

4 Suggestions for future research

As outlined in Section 3, several traditional determinants of environmental innovation bear an explicit regional imprint. In this section, we propose avenues for further research on the regional dimension linked to the supply side, the demand side, and to institutional and political factors. We will argue that research on the geography of environmental innovation will need to focus on the use of technologies and on demand-side issues. In addition, we point to a set of further regional factors that have largely been ignored in the literature on environmental innovation. Table 2 presents research questions that we consider to be important.

4.1 Regional supply-side determinants: towards the interplay of green and digital technologies

Regarding the inputs for the development of environmental innovations, much research has already been conducted on supply-side factors (see Section 3.1), including the role of other (related) technologies and regional innovation capacities. Often overlooked, however, are enabling technologies, which do not necessarily have to be related to green technologies per se or lie in the same technological domain. In this context, digital technologies could play a major role for the development and application of environmental innovations, for example in the areas of energy or resource efficiency. Particularly at the regional level, the question arises as to the extent to which digital technologies can increase the capabilities to innovate in green domains. Digital technologies might also help to establish regional circular economies and to clean production processes. While some studies already explore this nexus to some extent (Montresor and Quatraro 2020; Santoalha et al. 2021), more research in regional studies will be needed, especially against the background of the new funding period (2021-2027) of the EU regional policy that focuses on so-called ‘twin transitions’, that is, both green and digital transformations in regions.

4.2 Regional demand-side determinants: towards a demand-side turn

One of the most important differences between the *geography of innovation* and the *geography of environmental innovation*, in our view, relates to technology adoption and diffusion. Traditional research on the geography of innovation has for many years focused on the regional hotspots of innovation development. As a result, researchers were able to gain a broad understanding of the regional (supply-side) factors that contribute to the emergence of innovations (Asheim et al. 2016). However, this perspective is not sufficient for the analysis of environmental innovations, since environmental innovations only unleash their positive effects when they are widely diffused. This implies that we not only need to understand which regional factors contribute to the emergence of innovations, but we need to comprehend, in particular, which regional factors on the demand side facilitate the market success and adoption of environmental innovations. Research on the geography of environmental innovation should thus refrain from focusing too much on the supply-side factors for the development of green

technologies. In contrast, more attention should be paid to regional factors relating to the diffusion of green technologies. This demand-side turn in geographical research on innovation will have far-reaching consequences for the way research is designed. First and foremost, the research focus will shift to regions that are typically ignored in the literature, such as rural areas that do not contribute to the development of innovations. However, these regions are in a significant position to use environmental innovations, e.g. in energy, agro-food or transportation sectors, and to provide feedback effects on the further development of green technologies. We will discuss a number of regional factors that matter in this regard in Section 4.4. Secondly, researchers will need to develop methodological approaches that capture the use of green technologies rather than their development in order to successfully unveil the regional dimension of innovation diffusion (Losacker 2021).

4.3 Regional institutional and political determinants: towards regional regulations and multi-level policy effects

It is evident that regulations and environmental policy play a decisive role in the development and diffusion of environmental innovations. However, most empirical studies examine this relationship at the (inter)national level rather than at the (inter)regional level. Since regions face different environmental pressures and demands, regional differences in regulation and environmental policy do exist in some cases, e.g. in waste management or air pollution. We feel that there is much room for further research on regional regulations, particularly for countries with strong regional governments (China, Germany, USA, etc.) where differences in environmental policy stringency between regions are pronounced. The question is: to what extent do regional environmental policies have the same positive effects on environmental innovation as policies at the national or international level? This also raises the need for research approaches employing multi-level designs that take into account both regional and national regulations and policy factors. In this context, there is also a need for further research on the synergies or conflicts between environmental policy and innovation policy (van den Bergh et al. 2011), and the multi-level governance thereof.

4.4 The role of basic regional characteristics: towards a focus on demographics, infrastructures and industries

In addition to the spatial dimension of the traditional determinants of environmental innovation discussed so far (supply-side, demand-side, institutional and political factors), a number of further regional factors affect development and diffusion processes. These factors, however, have largely been neglected in the geography of environmental innovation literature.

Firstly, regional demographic and socio-economic factors are likely to affect how regions develop and use environmental innovation. While some studies have begun to explore the effects of regional environmental awareness or green attitudes on environmental innovation (see Section 3.2), there is much

room for further research. In fact, the effects of environmental awareness and green attitudes are complemented by additional demographic factors such as age, education, employment and income. These (basic) individual factors have received much attention in the literature on green consumer behavior, but it has not yet been fully explained how they translate to the regional level. It will be necessary to examine the links between these regional characteristics and the capacity of regions to create environmental innovations. At the same time, the question arises as to how the demand for, and thus the use of, environmental innovations differs between regions characterized by different demographic and socio-economic structures, e.g. regions with rapidly aging populations versus regions with young populations.

Secondly, many green technologies, in particular in the energy or transportation sectors, face additional diffusion barriers due to sunk costs of existing physical infrastructure and local assets that strengthen unsustainable regimes (Negro et al. 2012; Unruh 2000). In that sense, the physical infrastructure in a region works like a built regime and leads to tangible lock-ins of unsustainable technologies. For example, transportation, supply infrastructures and waste infrastructures correspond to and perpetuate existing patterns of urban land use and the use of established types of buildings, and are thus extremely difficult to change. These barriers directly translate into regional path-dependencies, making it more difficult for some regions to transition into more sustainable modes of production and consumption (R. Martin and Sunley 2006; Truffer et al. 2015). Moreover, in the energy sector, markets are often shaped by natural monopolies, i.e. access to infrastructure. These monopolistic bottlenecks hinder the market entry of new innovating firms, limiting sustainable action to dominant incumbents (Walz 2007). From a geographical perspective, however, we can observe several examples of new decentralized infrastructure systems that allow environmental innovations to be used at the local level without being dependent on incumbent firms or rigid structures at the national level. These examples include, for instance, community energy initiatives for renewable energy (Bauwens et al. 2016; Roesler and Hassler 2019). Given that many (rural) areas will witness a rise in their urbanization rates in the coming decades, particularly in the global south, it will be necessary to design environmentally friendly infrastructures and built environments, avoiding further lock-ins into unsustainable pathways. Against this background, we feel that the impact of local infrastructures receives insufficient attention in research on the geography of environmental innovation. At this point, it is once again necessary to focus on the demand side and the use of technologies. How should green technologies in the fields of transport or energy be deployed if the infrastructure in many regions is not designed adequately?

Thirdly, the regional industry structure poses significant opportunities and challenges for different types of regions. While the role of the industry mix is usually discussed in the literature on green path development, analyzing how regions can diversify into green industries (Grillitsch and Hansen 2019), little research has been conducted on how the regional industry structure relates to the use and diffusion of green technologies. Research should not only focus on how regions can build green industries to drive

employment and regional development. Instead, future research should focus on how the existing (or new) local industries can use green technologies to establish more environmentally friendly production processes. Both researchers and policymakers need to understand that not every region can be an innovation cluster, for example for wind energy technologies - many regions will need to continue to produce steel needed for wind turbines, and it is important to understand how to make the production processes in these regions more sustainable.

Table 2: Directions for future research on regional determinants of environmental innovation

Regional supply-side determinants: towards the interplay of green and digital technologies

- To what extent can digital technologies and skills increase the capabilities to innovate in green domains? How does this relationship translate to the regional level?
 - How can regions successfully accomplish a ‘twin transition’, i.e. green and digital transformations?
 - What types of digital technologies (artificial intelligence, digital twins, internet of things, etc.) are useful for innovating in what types of green domains (climate change mitigation, waste management, environmental monitoring, etc.)? What roles do regions and geography play in this regards?
-

Regional demand-side determinants: towards a demand side turn

- What are the regional determinants that contribute to regions’ success in using environmental innovation? Which regions will be in the spotlight in this regard – particularly when disregarding the highly innovative regions that usually receive much attention in the geography of innovation literature?
 - What roles do regions that increasingly use green technologies but are not directly involved in R&D activities (e.g. rural regions) have in the spatial organization of innovation processes? How important are feedback effects and DUI-modes of learning stemming from those regions for innovation and diffusion processes?
 - From a researcher’s perspective, what kind of methodological approaches can fit or will need to be developed for studying the use of green technologies in regions as well as the spatiality of eco-innovation processes?
-

Regional institutional and political determinants: towards regional regulations and multi-level policy effects

- Can regional environmental policies have the same positive effects on environmental innovation as policies at the national or international level?
 - How do regional and national-level environmental policies interact in a multi-level governance system? How can regional policies improve the effects of higher-level policies?
 - How do place-based innovation policies (e.g. RIS3) interact with national and particularly regional environmental policies? What role can (place-based) mission-oriented innovation policies play in this context?
-

Basic regional characteristics: towards a focus on demographics, infrastructures and industries

- What demographic and socio-economic factors are important for the development and use of environmental innovation on the regional level? How do these factors relate to regional environmental awareness?
 - What is the role of (physical) infrastructure in regional environmental innovation and how do new and old infrastructures align with the use of green technologies?
 - How does the regional industry structure determine the development and particularly the use of environmental innovation? Which factors are important for the diffusion of green technologies in regions specialized in industries that are difficult to transform (e.g. agriculture, mining, manufacturing)?
-

Similar arguments hold true for rural and agricultural regions. Rural regions will not contribute directly to inventing green technologies when compared to highly innovative regions, but it will be those rural regions that have great potentials to use greener technologies. We therefore, again, call for a demand-side turn in research on the geography of environmental innovations, helping to understand how regions can become more sustainable without completely substituting traditionally dirty industries with green ones, but rather greening the existing industries.

5 Conclusion

In this article, we set two research objectives. The first involved a critical literature review of the regional determinants of environmental innovations. For this purpose, we have analyzed research findings from the pertinent literature on supply-side factors, demand-side factors, and institutional or political factors, which take effect on the regional level or have explicit spatial implications. We conclude that regional determinants on the supply side play an important role for green technology development due to the positive effects of, for instance, regional R&D collaborations and regional university-industry collaborations in green domains. In addition, regional technological relatedness favors the development of environmental innovations. On the demand side, we find that regional environmental awareness and regional demonstration effects are pivotal to the emergence and diffusion of environmental innovations. Finally, (regional) environmental regulations induce both the development and the diffusion of green technologies. However, environmental policy effects have mostly been studied on the national level so far with limited evidence for the regional level. The findings of our literature review were used to address the second research objective in this article: developing an agenda for future research in regional studies on the geography of environmental innovations. We suggest that future research on supply-side determinants should pay increased attention to the interplay of green and digital technologies in regions. Moreover, we point towards the need to study regional environmental policy effects in greater detail, also looking at multi-level policy effects and combined environment-innovation policies. In addition to the set of regional factors that have been studied so far and fit into the traditional groups of determinants, we call for more research on other regional determinants. These include demographic and socio-economic factors on the regional level, regional infrastructures, and the regional industry structure. Most importantly, however, we call for a demand-side turn in research on the geography of environmental innovation. We claim that it is of utmost importance to understand how green technologies diffuse across space, given that their positive environmental effects only unfold when they are widely used. We should therefore shift the research focus from highly innovative regions that develop green technologies to those regions that are usually ignored in the geography of innovation literature, namely less innovative regions that could make great use of environmental innovations.

Last but not least, there are two issues that we need to mention in this article. Firstly, while many of our reflections have focused on geography in terms of regional factors, we would like to emphasize the value

of a global and multi-scalar perspective, as global processes, both in innovation development and in market formations, are essential for many environmental innovations (Binz et al. 2014). The extent to which regional or global facets are important, however, depends very much on the technology or innovation being studied (Binz and Truffer 2017; Rohe 2020). Secondly, in the past decade, much has been written about the importance of regions for the transition of socio-technical systems (Hansen and Coenen 2015; Truffer et al. 2015; Truffer and Coenen 2012). While these authors describe particularly long-term and complex *transformation processes* and regional transition paths towards sustainability, our article has focused on the regional factors shaping the *innovation process* of green technologies that eventually enable deeper system changes. We therefore consider our article complementary to the previously mentioned contributions from the field of sustainability transitions.

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