Green industrial path development in different types of regions

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Keywords: Green growth; regional development; cleantech; industrial path development; place-based policy; regional policy

JEL: R10; R58; O30; O38; P48; Q50; Q58

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1 Introduction

The fields of innovation studies and economic geography have for long enjoyed fruitful cross-fertilization. Geographical perspectives have increased the knowledge about the spatial embeddedness of innovation processes, and the innovation systems approach has led to improved understanding of the possibilities for regional policies to facilitate industry development. This is evident in the seminal contribution of Tödtling and Trippl (2005, p. 1203) on "a differentiated regional innovation policy approach", but also in more recent work on possibilities and conditions for industrial path development in different types of regions (Trippl and Isaksen 2016; Grillitsch and Asheim 2018). In short, work on the functioning and challenges of innovation systems (Klein Woolthuis, Lankhuizen, and Gilsing 2005) has been central to providing a nuanced understanding of regional policies for (new) industry development.

While the innovation system approach has taken a central position in the field of innovation studies during the last decades, an emerging perspective in innovation studies focused on transformative change is gaining increasing importance (Schot and Steinmueller 2016). Closely connected to the field of sustainability transitions (Markard, Raven, and Truffer 2012), the focus is on radical changes in the socio-technical systems that provide core services such as mobility and housing. Consequently, the object of study changes from single innovations to transitions in socio-technical systems, and innovations are not assumed to necessarily have a positive impact on societal welfare (Soete 2013). In turn, this has led to increasing attention towards policies for transformative change (Weber and Rohracher 2012; Kivimaa and Kern 2016; Grillitsch, Hansen, Coenen, Miörner, and Moodysson 2018).

We argue that this most recent generation of innovation studies offers new opportunities for cross-fertilization between the fields of innovation studies and economic geography (see also Strambach 2017; Tödtling and Trippl 2018), in particular since the imperative of sustainable development has been taken up across multiple levels of government, including regional authorities (Cagnin, Amanatidou, and Keenan 2012; Coenen, Hansen, and Rekers 2015). One manifestation of this is the increasing emphasis on developing green industrial paths, which is found in regions with highly varying characteristics. However, so far, we have limited knowledge about the prospects for the development of green industrial paths in various types of regions and the accompanying differences in the required policies. Consequently, in the current paper we conceptually address the following two research questions:

- *How do regions differ in their opportunities for green industry path development?*
- *What are the implications for policies in different types of regions?*

We take pre-existing regional industrial specialization patterns as a starting point for developing a typology of regions (section 2). Drawing on the path development literature, we then suggest the likely green path development opportunities in different types of regions (section 3). Subsequently, we consider the relevance of insights from the literature on transformative system challenges for green path development (section 4), before outlining policy mixes for different types of regions (section 5). Finally, we conclude by emphasizing that green industrial path development requires contextualized policies, which give attention to both structural innovation system challenges and transformative system challenges (section 6).

2 Clean and dirty industries in regional contexts

In this section, we propose a typology of regions that is useful for developing place-based policies for green industrial path development. The regional typology rests on regional industrial specialization patterns in clean or dirty industries. Furthermore, we relate the regional industrial specializations to the regional context in terms of the regional support system for green innovation and entrepreneurship.

Defining clean and dirty industries is not a straightforward task. Clean industries may be thought of as industries that develop and sell products, solutions or technologies that improve the environment, either directly or through a more efficient utilization or resources (FORA 2009), and dirty industries can conversely be conceived as industries where production and consumption of the industry's goods deplete the natural resources of our planet. We make this conceptually neat distinction in order to develop ideal types of regions, appreciating, however, that in reality industries are placed on a continuum from clean to dirty, depending on their overall environmental performance. In this, we recognize the need for considering industries' impact according to multiple dimensions of environmental sustainability, from climate change to biodiversity, ocean acidification etc., which increases complexity. For instance, the wind power industry is a relatively clean industry as the production of electricity is carbon free. However, the production and installation of wind power stations is not fossil-free. The automotive industry is dirty but becomes cleaner through the introduction of new technologies such as electric or hydrogen-powered engines.

The typology differentiates regions based on specializations in clean or dirty industries. Since Marshall's (Marshall 1997:1920) work on industrial districts, specialization has been a key concept in economic geography as well as regional economics. It features in various streams of literature, including industrial districts (Pyke, Becattini, and Sengenberger 1990; Asheim 2000), clusters (Porter 2000; Malmberg and Maskell 2002; St. John and Pouder 2006), new economic geography (Krugman 1991; Martin and I.P. Ottaviano 1999), and recently smart specialization (Foray, David, and Hall 2009). Regional industrial specializations are driven by traded and untraded interdependencies (Storper 1995). Economies of scale, low transportation costs and a high importance of intra-industry trade promote industrial colocation (Krugman 1991). Regional specialization gives raise to external economies such as pooled labor markets, the growth of supporting industries, and knowledge spillovers (Porter 2000). Regional industrial specialization facilitates knowledge exchange due to the embeddedness of knowledge in a socio-institutional context (Gertler 1995), thereby promoting what has been framed as localized learning (Maskell and Malmberg 1999) and learning regions (Morgan 1997).

Regional industrial specialization contains a quantitative and qualitative dimension. On the one hand, it has to do with scale whereas the relative importance of an industry is misleading (Kemeny and Storper 2015). This is because the above-mentioned external economies are linked to scale and not relative size. A high share of an industry in a small regional economy may not trigger the external economies while a small share in a large region may suffice to result in these economies. Furthermore, there is a qualitative dimension to specialization. Within the same industry, some regions focus on the high-end, knowledge-intensive activities related to for instance product development, management, marketing, finance, etc. whereas other regions focus on the low-end, low-skill activities such as scale manufacturing. The proposed typology thus differentiates regions based on clean and dirty industries that have achieved a

critical mass in the leading-edge activities of an industry. Accordingly four types of regions can be identified, which are in the interest of easy reference labeled with colors: 1) regions with no industrial specialization (white regions), 2) regions with a specialization in a dirty industry (brown regions), 3) regions with a specialization in a clean industry (green regions), and 4) regions with a mix of specializations in dirty and clean industries (multi-colored regions).

Industries do not exist in a vacuum, but are embedded in a regional context. As regards developing industrial specializations, the regional system for innovation and entrepreneurship plays an important role. The notion of a regional support system for innovation and entrepreneurship relates to the extensive literature on innovation systems and entrepreneurial eco-systems (Grillitsch and Asheim 2018). This literature suggests that innovation and entrepreneurship activities are shaped by regional factors that go beyond industrial specializations. According to the regional innovation system approach, the exploitation of knowledge in industrial contexts is fueled by knowledge generation from for example universities and research institutes and supported by intermediaries such as technology parks, technology transfer centers, or incubators (Autio 1998; Tödtling and Trippl 2005). While the innovation system and entrepreneurial eco-system concepts overlap in some aspects (e.g. importance of human capital, networks, knowledge intermediaries), the latter puts more emphasis on what can be broadly defined as entrepreneurial capital (e.g. competence about business models, access to risk capital and smart money, role of successful entrepreneurs to further promote entrepreneurship, etc.) (Isenberg 2011; Mason and Brown 2014). Moreover, the innovation system literature views innovation and entrepreneurial activities as embedded in a social-institutional context, which shapes the outcome of these activities (Cooke 1992; Asheim and Gertler 2005).

Considering these concepts the four regional types can be further characterized. Regions that exhibit a mix of specializations – multi-colored regions – are typically located in core regions with a strong and comprehensive support system for innovation and entrepreneurship. The reason is that scale is a defining feature of industrial specialization according to the definition used in this paper. Achieving scale in several industries thus implies a substantial accumulation of knowledge embodied in individuals, routines embodied in organizations, as well as resources linked to individuals, firms, and non-firm actors. This typically coincides with the location of major universities, research institutes, as well as training and education facilities. Furthermore, the presence of several industries implies that knowledge and resources are relatively heterogeneous and create demand for a variety of general purpose type knowledge-intensive business services such as ICT, legal, financial and marketing advisory services. This is a conducive environment where entrepreneurial capital can accumulate and be recycled (Isenberg 2011). For example, we follow the argument of Storper et al.'s (2015) that the metropolitan San Francisco Bay area is specialized. Yet, it is specialized in more than one industry comprising among others IT and software, life science and biotech, as well as environmental and clean-tech. Furthermore, it is a center for professional services that typically locate in such regions.

Regions with a specialization in a clean or a dirty industry typically have similar profiles in terms of regional context conditions and the regional support system for innovation and entrepreneurship, but differ in the main challenges for green path development. Specialized industries are typically located in regions where the support system for innovation and entrepreneurship is adequate for fostering

innovation in the sector of specialization. Specialization in "one" industry implies that the accumulation of knowledge and resources has advanced in relation to one field of economic activity. This creates a strong local demand for higher education and research institutes to adapt their activities to the needs of the industry, thereby supporting incremental innovations and strengthening the existing industrial paths. However, the region has not achieved a critical mass in other fields. This in turn entails that, compared to multi-colored regions, the support system is weaker as regards the more generic resources for innovation and entrepreneurship such as variety in knowledge and resources, knowledge intensive business services, or access to risk capital and smart money, which constrains the generation of path-breaking innovations.

Regions without critical mass in any industry – white regions – typically offer a weak and limited regional support system for innovation and entrepreneurship. This is implicit in our definition of industrial specialization, which focuses both on the scale and quality of industrial specializations. It implies that such regions have not accumulated high-value added, knowledge-intensive activities in any industry. As regards the regional support system for innovation and entrepreneurship, it may well be that some elements are present. For instance, Morgan (2016) shows that even though Wales/UK has good universities, the region has had limited success in utilizing the higher education system for developing industrial specializations and remained on a low growth trajectory (Morgan 2016). Also, there may be innovative firms in the periphery but they rely to a large extent on extra-regional linkages to access knowledge and resources (Grillitsch and Nilsson 2015). Overall, therefore, the regional support system for innovation and entrepreneurship is limited and weak.

3 Green industrial path development in different types of regions

"Evolutionary theory deals with path dependent processes, in which previous events affect the probability of future events to occur" (Boschma and Frenken 2006, p. 280f). From an evolutionary perspective, path-dependence does not stand for deterministic developments. "[P]ath-dependent systems also need mechanisms that generate novelty, and hence new pathways of development." (Martin and Sunley 2006, p. 407). This has been studied in the literature on new industrial path development and path creation (Garud, Kumaraswamy, and Karnøe 2010; Simmie 2012; Dawley 2014; Grillitsch and Trippl 2016). Industrial path development can come in many shapes (Martin and Sunley 2006), is driven by a variety of mechanisms, and fueled by sources at the regional and extra-regional scale (Grillitsch, Asheim, and Trippl 2018). Following the evolutionary idea that previous events affect the probability of future events, the regional preconditions will also shape the likelihood with which certain types of green path development will occur.

Several proposals have been advanced how to frame the different types of path development (Martin and Sunley 2006; Grillitsch, Asheim, and Trippl 2018). We focus on four major forms: First, path development may simply represent growing existing green paths. Second, path upgrading consists of a major qualitative change of existing industries, which can rest on several mechanisms such as the introduction of new technologies, organizational innovations, or business models. As regards greening, the introduction of clean technologies to a dirty industry would stand for green path upgrading. Third, path diversification implies that existing industries move into other industries. Two main mechanisms for

path diversification have been identified in the literature: path branching based on related variety (Frenken and Boschma 2007) as well as diversification based on unrelated knowledge combinations (Grillitsch, Asheim, and Trippl 2018). Forth, the emergence of new clean industries, which are unrelated to the knowledge bases of the existing regional industries, is another form of green path development.

3.1 White regions

We argue here that the likelihood of certain types of green industrial path development is contingent on regional characteristics. In white regions without critical mass in any specialization, we can exclude diversification as a relevant form of new path development because diversification rests on exploiting accumulated knowledge and resources from one industrial specialization in another industry, either based on related or unrelated knowledge combinations. This leaves upgrading and path emergence as possible options. The empirical examples from the literature often refer to the creation of new sustainable paths in renewable energy (Essletzbichler 2012; Dawley 2014; Simmie, Sternberg, and Carpenter 2014). It is hardly technological breakthroughs that drive the rise of renewable energy in such contexts. The rise of such new paths is, however, to a high degree place-specific due to regional actor constellations, natural resources that can be exploited for renewable energy, and existing infrastructure. Therefore, the main challenge often does not lie in importing the technology but in shaping the conditions for their implementation, which requires the coordination and mobilization of distributed actors (Späth and Rohracher 2010). These processes are, however, not exclusively local, but embedded in multi-scalar institutional contexts and networks through which knowledge and resources can be mobilized (Grillitsch 2015; Binz, Truffer, and Coenen 2016; Chlebna and Simmie 2018; Trippl, Grillitsch, and Isaksen forthcoming).

Path upgrading is the other likely form of path development in white regions. The idea of path upgrading acknowledges that even though white regions lack a critical mass in any industry, some firms or entrepreneurs may have a high level of capabilities. Indeed, there are innovative firms in the periphery, which tend to compensate for a lack of local knowledge spillovers with national or international networks (Grillitsch and Nilsson 2015). Pivoting around such core agents, the region may attempt to establish a strong position in a green niche, or enhance their position in global value chains. Furthermore, it is thinkable that regions have developed a certain scale in a clean industry (e.g. production of solar cells), but focus on low-skill manufacturing while the high-value and knowledge intensive activities are located elsewhere. For such regions, path upgrading in the sense of increasing knowledge-intensity in the industry and attracting higher-value added activities to the region (such as research and development) could potentially play an important role.

3.2 Green regions

Green regions have achieved a critical mass of high-value, knowledge intensive activities in a clean industry. Considering that there is still a long way to achieve a global “green” economy, the possible future market is large. Following a pure economic logic, early concentration has a big impact in the long term as industries scale up due to increasing returns (Krugman 1991). Firms that achieve scale economies early will be hard to catch-up later. The growth of a strong regional specialization, however, is not only a process of individual firm growth but concerns also the creation of interdependencies between regional actors in terms of knowledge flows embedded in a shared socio-institutional context,

which underpins learning and innovation activities (Gertler 1995; Storper 1995). As a regional specialization gains momentum, self-reinforcing mechanisms promote growth even further. This relates among others to the attraction of new firms and skilled labor, the formation of new firms through university or corporate spin-offs, the development of a specialized supplier base, as well as dynamic competition between firms.

Another important source of path development in green regions is to diversify into other industries based on the existing competencies in a clean industry. In this regard, we refer to the path branching argument advanced in evolutionary economic geography, which stipulates that "firms typically diversify into products that are technologically related to its current products" (Frenken and Boschma 2007, p. 637). It is further argued that firm diversification leads to regional diversification and in consequence to firm and regional growth. This will further contribute to the self-reinforcing mechanisms mentioned above. An example would be the reuse of competences from the manufacturing of wind turbines for the manufacturing of hydropower turbines. Finally, it may be added that we do not see regional emergence of a new clean industry unrelated to existing industries in the region as a very likely form of new path development in green regions. The reason is that most actors will have vested interests in the existing specialization and occupy knowledge and resources, which would have to be redirected to new paths. Hence, it is more likely that these actors can be mobilized to further grow an existing specialization or to diversify based on the existing competencies, than develop new paths where the accumulated knowledge and resources are of little value.

3.3 Brown regions

Brown regions are similar to green regions as regards their industrial and economic dynamics, but have completely different challenges in terms of clean industry development. Brown regions are similar as they face strong lock-ins due to the existing specialization. This implies that it will be difficult to mobilize actors for strategies that devaluate past investments and thus are against vested interests. Hence, it may be the most promising pathway to "green" the dirty industry by introducing new technologies that reduce the environmental impact. One typical example is the introduction of electric or hydrogen powered cars, which would make the dirty automotive industry cleaner. While the greenness of the automotive industry still depends on other aspects such as the environmental impact of producing electricity or hydrogen, it is a step towards a greening. Another possibility is the use of existing competencies for new green purposes. The mechanism behind is diversification, for instance of the oil and gas industry in Norway to offshore wind that reuses competences from the maritime environment (Steen 2016; Asheim, Grillitsch, and Trippl 2017b).

3.4 Multi-colored regions

Green industrial path development in multi-colored regions can take many shapes. As multi-colored regions are defined by specializations in several more or less green industries, all forms of green path development are in principle relevant. The difference is, however, that such regions facilitate the introduction of new technologies, diversification, or the growth of clean industries. One reason is that the complexity for knowledge transfer and learning increases with cognitive distance (Nooteboom 2000). Introducing technologies that are new to an industry or diversification (especially based on unrelated variety) implies that cognitive distance needs to be overcome, which is facilitated if actors are embedded

in a similar socio-institutional context or located in close geographic proximity (Boschma 2005; Hansen 2015). In fact, Agrawal, Cockburn, and McHale (2006) show that co-location is especially important for co-patenting involving different technological fields. As regards growing industries, the availability of resources, in particular human capital, and of knowledge-intensive business services such as legal, financial and marketing advisory services play an important role. Furthermore, the closeness to decision makers as regards shaping regulations and markets has been mentioned as an important factor for the growth of clean industries (Coenen, Moodysson, and Martin 2015).

In addition to the aforementioned forms of path-development, there are additional opportunities in multi-colored regions. Strong capacities in research and development are a major source for the development of new technologies for clean industries. In collaboration with industry, efforts appear useful that target the implementation of such new technologies in a variety of industries. An example would be the use of material- and nanotechnology to increase energy efficiency. Furthermore, as multi-colored regions are home to several specializations, an additional opportunity may be what Grillitsch, Asheim and Trippl (2018) called a shift between industries. This occurs if certain competencies and resources currently occupied in dirty industries are reused in clean industries. For instance, an engineer may have relevant competencies for both dirty and clean industries. A growing clean industry could then absorb relevant labor from shrinking dirty industries, thereby facilitating a transition towards a greener regional economy without negative consequences such as structural unemployment.

Table 1: Regional typology for green industrial path development

	White	**Green**	**Brown**	**Multi-colored**
Regional industrial specialization	No specialization	Specialization in a clean industry	Specialization in a dirty industry	Mix of industrial specializations
Support system for innovation and entrepreneurship	Weak and limited	Strong in supporting sector-specific innovation, but weak in provision of generic resources	Strong in supporting sector-specific innovation, but weak in provision of generic resources	Strong and comprehensive
Forms of green path development	• Regional emergence of green industrial paths • Upgrading of existing embryonic green industrial paths	• Growing existing clean industrial specializations • Diversification into other clean industries based on accumulated knowledge and resources	• Introduce new technologies to green the dirty industry • Diversification into clean industries based on existing competencies	• Forms of path development for clean and dirty industries apply also in this context • Developing new technologies for clean industries • Shift resources from dirty to clean industries

4 Policy rationales for green path development

A natural starting point for considering possible policy implications for green industrial path development in different types of regions is the literature on structural innovation system failures (Klein Woolthuis, Lankhuizen, and Gilsing 2005; Laranja, Uyarra, and Flanagan 2008). Building on the innovation systems literature, this perspective highlights how policy intervention is justified in order to make innovation systems function effectively. In a regional setting, this implies understanding the regional innovation system and addressing eventual deficiencies regarding the *capabilities* of regional actors, *network* failures in the form of too weak or too myopic network relations internally or externally in the region, and *institutional* shortcomings such as inadequate formal (e.g. rules, regulation and laws) and informal (e.g. norms and values) institutions that hamper regional innovativeness.

However, as the focus of the current paper is not on increasing innovativeness and development of new industrial paths *in general*, but specifically for *clean* industries, important complementing insights can be gained from the literature on transformational system challenges (Weber and Rohracher 2012; Grillitsch, Hansen, Coenen, Miörner, and Moodysson 2018). From this perspective, the rationale for policy intervention is to facilitate transitions in socio-technical systems[1] and the emphasis is consequently on factors inhibiting this, in particular focusing on issues in relation to directionality, experimentation, demand articulation, and policy learning and coordination. However, while transitions in socio-technical systems are different from industry development, the specificities associated with new *green* industrial path development imply that certain aspects from the transformational challenge framework are of importance in this context as well. Below, we briefly elaborate on the four challenges and consider 1) their specific relevance for green path development and 2) if we would expect variation in the importance of addressing the challenges for different types of regions.

4.1 Directionality challenge

Directionality "points to the necessity not just to generate innovations as effectively and efficiently as possible, but also to contribute to a particular direction of transformative change" (Weber and Rohracher 2012, p. 1042). In this case, orientation for industry development is needed. Firstly, this requires establishing a shared vision for regional industry development. In addition to a prioritization of clean over dirty industries, it may also include specification of a focus on particular clean industries. Secondly, policies concretizing the vision need to provide designated support for clean industry development. Furthermore, directionality is particularly important for clean industries as policies should also create room for clean industries by destabilizing competing dirty industries, e.g. by initiating control policies or withdrawing support (Kivimaa and Kern 2016). Arguably, the challenge of achieving directionality towards clean industry development will be less important in green regions, where this focus may follow almost inevitably from the character of the existing industry structure.

[1] Socio-technical systems deliver services such as energy, housing or transportation to society, and can be understood as consisting of "(networks of) actors (individuals, firms, and other organizations, collective actors) and institutions (societal and technical norms, regulations, standards of good practice), as well as material artefacts and knowledge" (Markard, Raven, and Truffer 2012, p. 956). A transition in a socio-technical system implies a fundamental restructuring of the manner in which a service is delivered.

4.2 Experimentation challenge

Experimentation refers to the importance of activities aimed at, firstly, testing new technologies and social practices and, secondly, learning about the structures inhibiting their diffusion and how to overcome these structures (Sengers, Wieczorek, and Raven 2016). Consequently, experimentation is particularly important to clean industry development as clean industries are based on technologies that challenge existing structures (Geels 2002). The challenge of achieving a sufficient level of experimentation is predominantly important to address in black and multi-colored regions, where structures around incumbent industries are more strongly established than in white and green regions.

4.3 Demand articulation challenge

Demand articulation highlights the need of considering market uptake of products and services. In the context of clean industries, market uptake is particularly challenging, as green technologies often do not result in specific user-benefits, but rather produce benefits for non-payers in the application phase (Rennings 2000). Further, insufficient knowledge about user practices and needs are evident in the case of many green technologies (see e.g. Nyborg and Røpke 2013) and may further inhibit the diffusion of green technologies. These challenges are particularly important to target for clean industries producing products with a high degree of technological complexity, since localized demand is central to these types of industries. Conversely, demand articulation is likely to be less important for clean industries producing low-complexity products for mass markets (Huenteler, Schmidt, Ossenbrink, and Hoffmann 2016; Binz, Gosens, Hansen, and Hansen 2017; Hansen, Klitkou, Borup, Scordato, and Wessberg 2017). Consequently, challenges related to demand articulation may be particularly important to tackle in multi-colored regions, which have favorable preconditions for achieving specialization in clean industries with high technological complexity.

4.4 Policy learning and coordination challenge

Policy learning and coordination direct attention to the need for coherence and consistency between policy levels and fields, while at the same time allowing for modification and transformation of policy approaches based on learning and previous experiences (Weber and Rohracher 2012; Rogge and Reichardt 2016; Grillitsch, Hansen, Coenen, Miörner, and Moodysson 2018). Addressing the policy learning and coordination challenge is central for complex, uncertain and long-term processes. As development processes for new clean industries are not *per se* more complex, uncertain and lengthier than development process for new industries in general, we would not expect that addressing this challenge is of greater importance for development of clean industries compared to dirty industries. Still, addressing this challenge is arguably always a priority for industry development, even if the specific focus may differ between the regions. As new clean industry development processes are likely to be particularly lengthy and uncertain in white regions, which are characterized by a lack of existing specializations to build on and a weak support system for innovation, policy learning is of key importance here. Conversely, policy coordination may be of greater significance in the other types of region: in green regions that are likely characterized by the existence of multiple “green policies” in need of coordination; in brown regions where policies should transition from supporting one type of industry to another; and not least in multi-colored regions where policies supporting a variety of green and brown industries will coexist.

5 Green path development policies in different types of regions

The current section brings together the likely types of green path development for the different types of regions (section 3) with the key transformational challenges (section 4) in order to emphasize the geographical variation in key policy priorities. Consequently, we outline policy mixes for green path development for our four ideal type regions, drawing on previous work on policy initiatives for addressing structural innovation system failures (Tödtling and Trippl 2005; Hassink 2010; Isaksen and Trippl 2017; Grillitsch and Asheim 2018) and transformational system challenges (Grillitsch, Hansen, Coenen, Miörner, and Moodysson 2018) as well as empirical illustrations from the literature. Table 2 summarizes the overall policy objectives and the specific focus of policy instruments at the level of actors, networks and institutions.

Table 2: Place-based green path development policies

	White	**Green**	**Brown**	**Multi-colored**
Policy objective	Develop specialization in a clean industry through path upgrading and path emergence	Grow existing specializations and develop new ones through path diversification	Transform dirty into clean through path upgrading and path diversification	Develop and grow clean industries and transform dirty into clean through path emergence, diversification and upgrading
Targeting actors	• *Attract external actors in a clean industry* • *Strengthen capabilities of existing actors in a green niche* • Develop governance learning capabilities	• *Build a critical mass, accumulate experience and resources, and develop economies of scales* • *Build competencies in developing business models and growing businesses* • *Stimulate intrapreneurship in green incumbents*	• *Build competencies in technologies/solutions needed for greening the industry addressing both firms, but also higher educational institutes and government* • *Attract actors from outside the region with such competencies* • *Stimulate clean intrapreneurship in dirty incumbents* • Promote green institutional entrepreneurs	• *Build a critical mass, accumulate experience and resources, and develop economies of scales* • *Build competencies in developing business models and growing businesses* • *Stimulate green entrepreneurship* • Support identification of lead users for new green technologies • Develop capabilities on green public procurement for innovation • Promote capabilities for experimentation among non-firm actors

Targeting networks	• *Strengthen extra-regional networks to key players related to the niche* • *Strengthen extra-regional networks to universities* • *Coordinate between actors involved in technology diffusion* • Establish networks to learn from extra-regional policymakers • Connect to and build on green directionality exercised by global level actors	• *Strengthen networks to providers of entrepreneurial resources* • *Strengthen networks to unrelated industries* • *Foster coalition between the private and public sector around the green path*	• *Strengthen networks to unrelated knowledge sources that may contribute to greening* • *Break-up alliances that hinder green restructuring* • Encourage collaboration between incumbents, start-ups and civil society • Challenge established regional hierarchies in policymaking	• *Strengthen networks between dirty and clean industries regionally* • *Strengthen university industry links* • Stimulate interaction between producers and lead user • Encourage collaboration between heterogeneous actors
Targeting institutions	• *Provide institutionalized access to resources available in core regions* • *Promote open, outward looking mindedness* • *Develop a shared green vision among multiple actor groups* • Establish and promote green policy rationales • Set green objectives that provide direction in an actionable way • Promote clean industry development across policy domains	• *Promote a global market perspective* • Coordinate green diversification policies across multiple policy fields • Establish systematic evaluation and learning mechanisms for diversification policies	• *Provide incentives for adopting clean technologies* • *Provide incentives for diversification experiments* • *Provide assistance in accessing funding devoted to greening* • *Develop a "becoming green" vision and align policies accordingly* • Support green test and demonstration projects • Promote risk-taking behavior and acceptance of failure	• *Decrease institutional boundaries between industries* • *Increase incentives for mobility between industries as well as sectors* • *Support the development of new green paths by creating local demand* • Promote social acceptance for green emerging technologies • Gradually increase exposure of experiments to selection pressures • Align policies targeting multiple industries

Italics: policy initiatives addressing structural innovation system failures; underlined: policy initiatives addressing transformational system challenges

5.1 White regions

With the lack of specializations in white regions, clean industry path development policies should stimulate path upgrading and path emergence. Path upgrading requires attention to improving the capabilities of green niche actors through specialized training programs and support for attracting highly skilled labor in clearly defined competence fields. It also involves connecting green niche actors to industry leaders and universities outside of the region. Regional policymakers may facilitate this by supporting the creation of formalized partnerships to extra-regional actors in the form of e.g. innovation projects. Policymakers may also encourage an international outlook among regional firms in a green niche by creating awareness of developments in technologies and markets through e.g. organizing seminars and workshops with invited international experts.

Path emergence in the case of white regions involves deployment of clean technologies developed elsewhere. Policymakers may facilitate this by establishing connections to extra-regional technology providers and project developers, and by supporting competence development in relation to servicing of the infrastructures. However, as illustrated in Murphy and Smith's (2013) analysis of wind energy development in the Scottish periphery, of perhaps even greater importance is to coordinate between the multiple local actors with a stake in the deployment, and facilitate a visioning process that encourages an embedded and contextualized implementation of the technologies in the region. In this case, the degree of stakeholder involvement in the development process and anchoring in the community are key explanatory factors behind the varying success of wind development projects (Murphy and Smith 2013).

The absence of existing specializations also implies that white regions are characterized by, firstly, a need for setting a green direction for development, and, secondly, particularly lengthy and uncertain clean industry development processes, hence, emphasizing the need for focusing on policy learning. The case of Murau, Austria nicely illustrates the importance of these policy priorities for economic development in white regions, in this case centered on bioenergy. Most importantly, a very broad coalition of actors established a green energy vision, which led to private sector alignment with the vision and facilitated private investments in the bioenergy field. The establishment of this vision also resulted from drawing on and linking up to agents exercising directionality at the national and international scale, including a federal ministry and the international network of energy agencies, which promoted transitions in energy systems (Späth and Rohracher 2010; 2012). Drawing on Grillitsch, Hansen, Coenen, Miörner, and Moodysson (2018), we would argue that policies in white regions should also focus on strengthening so-called governance learning capacities (Borrás 2011) understood as the abilities to reflexively consider the wider implications of policies, in order to learn about (un)successful policy instruments and practices in a given context. Such abilities follow not only from policy evaluations and benchmarks, but also from efforts targeting building wider organizational capacity and intelligence among public and non-public policymakers.

5.2 Green regions

The strong presence of a clean industry in green regions implies that policies should focus on growing existing specializations and stimulate path diversification based on existing knowledge and resources. In terms of growing existing specializations, one of the most well-described empirical cases (e.g. Simmie 2012) is the development of the Danish wind turbine industry, centered in Jutland. This case highlights

several key policy priorities, in particular the importance of continuous enrolment by policymakers of multiple types of actors in shaping the further-development of the path. Policy also played a key role in supporting internationalization of the industry and in facilitating the accumulation of knowledge and experience by establishing organizations such as the Danish Wind Turbine Test Station (Garud and Karnøe 2003; Meyer 2004; Buen 2006).

To our knowledge, there is little empirical work on regional path diversification from one clean specialization to another (cf. Cooke 2010). However, arguably, policy priorities are to stimulate intrapreneurship in green champions and strengthen networks to unrelated industries (Grillitsch, Asheim, and Trippl 2018). Reflecting this, previous research highlights how partnerships between cleantech firms specialized in clean technologies, and producers of traditional, non-environmentally conscious products are important for firm-level diversification into new cleantech products (Hansen 2014).

Considering green regions' specialization in a clean industry, it is likely that the regional policy mix consists of multiple green policies in need of coordination. We expect this to be particularly important in terms of supporting diversification into new green industries. Work on policy mixes for green industry development highlights the importance of alignment between policies targeting diverse aspects, from knowledge development to market access and availability of finance (Rogge and Reichardt 2016; Binz, Gosens, Hansen, and Hansen 2017), but also the role of coordination in terms of the policy strategy, which may vary significantly (see Imbert, Ladu, Morone, and Quitzow 2017).

5.3 Brown regions

Policies in brown regions should contribute to the greening of dirty industries through path upgrading and stimulate path diversification where existing competencies are utilized for new green purposes. Some contributions in the literature highlight how policies may facilitate greening through path upgrading. González-Eguino, Galarraga, and Ansuategi (2011) underline the need for regionally-based, industrial policies that give polluting industries in old industrial regions incentives to adopt new green technologies. Focusing specifically on the Ruhr Valley, Hospers (2010) describes the role played by public policies in the form of designated technology transfer offices, strict environmental rules incentivizing firms to minimize environmental impacts, and support for demonstration projects. In the Ruhr, this greening eventually led to path diversification into the environmental technology industry, which today employs 100,000 people in the region. Other contributions focusing specifically on path diversification into clean industries include Steen (2016) and Steen and Hansen (2014), which analyze diversification of oil and gas regions into offshore wind turbines. They show that start-ups by entrepreneurs with a background in oil and gas are of some importance, but this process is in particular driven by diversification of oil and gas firms into the new market, thus, emphasizing the need for policies supporting intrapreneurship and diversification experiments. The latter entails support for establishing relations to firms with complementary assets and market knowledge (see also Hansen and Coenen 2017). Finally, Dawley's (2014) analysis of offshore wind in the UK also highlights the importance of policy efforts supporting diversification of the oil and gas industry, in this case in the form of individual consultations where policymakers raised awareness among oil and gas suppliers of market opportunities in the emerging industry.

The strong presence of incumbents in brown regions implies that it is central to address challenges related to directionality and experimentation. In this respect, Steen (2016) underlines the importance of agency for green path diversification and how this agency is informed by expectations about future developments in technologies, markets and value chains. This highlights the role of policy in supporting green institutional entrepreneurs that may influence the formal and informal institutions that shape the future orientations of actors. Furthermore, Hospers (2010) points to the significance of challenging established hierarchies, including the importance of *"a modernization of institutions and procedures of regional policy"* (p. 50) in order to provide fertile ground for the experimentation needed for clean industry development in the region. To this, we would add the importance of introducing policies that promote risk-taking behavior and acceptance of failure (Grillitsch, Hansen, Coenen, Miörner, and Moodysson 2018). Finally, Hospers (2010) also shows how a multi-faceted and aligned policy approach was instrumental in developing the environmental technology industry in the Ruhr Valley, thus, highlighting the role of policy coordination in diversifying brown regions into clean industries.

5.4 Multi-colored regions

Green path development in multi-colored regions may happen through path emergence, diversification and upgrading. Thus, an additional priority of policies is to develop new clean industries endogenously. This is exemplified by Gibbs and O'Neill's (2014) account of green economy policies in Boston, which stresses the importance of facilitating university-industry relations for the development of new clean industries, and establishing test environments for experimenting with prototypes for new green technologies. Furthermore, the Boston case also points to the role played by designated organizations gathering actors from multiple industries and sectors with a focus on green entrepreneurship, support for developing business models, and workforce mobility.

Considering the favorable preconditions for achieving specialization in technologically complex clean industries, challenges related to demand articulation are important to tackle in multi-colored regions. Analyzing fuel cell technology, Tanner (2014) highlights how some multi-colored regions develop specialization in the industry based on the existence of sophisticated users with core competences in integrating the fuel cells into new applications. This draws attention to the need for demand-side policies aimed at identifying lead users for new green technologies and stimulating interaction between producers and lead users. In line with this, Gibbs and O'Neill (2014) note the importance of incorporating instruments aimed at creating local demand in green economic development policies in Boston, and Carvalho, Mingardo, and Van Haaren (2012) point to role played by public procurement policies for greening of the heavy vehicle industries in cities such as Hamburg and Gothenburg. In addition, we would emphasize the relevance of policies promoting social acceptance for green emerging technologies as an additional aspect of a demand-sensitive policy portfolio in multi-colored regions (Grillitsch, Hansen, Coenen, Miörner, and Moodysson 2018). Finally, Carvalho, Mingardo, and Van Haaren (2012) also showcase the importance of coordination between policies targeting multiple industries, from transportation and vehicle manufacturing, to fuel cells and biogas.

6 Conclusions

The paper contributes with a regional typology and policy framework aimed at facilitating the identification of policy challenges and opportunities for green industrial path development as well as appropriate policy interventions. In a nutshell, the proposed framework rests on differentiated types of regional industrial specializations. In the context of green industrial path development, we suggest to distinguish industrial specializations in clean and dirty industries. This leads to a typology where regions can be specialized in a clean industry (green regions), a dirty industry (brown regions) or a mix of clean and brown industries (multi-colored regions). In addition, there are regions without a pronounced industrial specialization (white regions). We elaborate why and how these regional types are related to specific innovation system and transformative challenges, opportunities for green industrial path development, and suitable policy interventions.

The proposed framework brings together two literatures related to new industrial path development in regions and policy for transformative change. The former has provided insights about new industrial path development in different regional contexts, but is in principle agnostic about the cleanliness of the developed industries. The latter has increased our understanding about the challenges for switching from unsustainable to sustainable patterns of consumption and production, but is not concerned with industrial path development in particular regional contexts. We consider it to be a relevant and timely conceptual contribution to synthesize these insights and elaborate on the implications for green industry development in specific regional contexts.

We would argue that this also is an important contribution for policy in practice. After all, policymakers have the most direct influence, power and responsibility for their constituencies. Moreover, if policies are conducive not only for the environment, but also for the creation of jobs and income, then it will be comparably easy to mobilize the required support. However, we do acknowledge that this paper focuses on clean production and gives less attention to the role of clean consumption patterns. Also, the paper does not focus on national/global institutional constraints for the development of clean industries (which have previously been studied in greater detail, see Capasso, Hansen, Heiberg, Klitkou, and Steen 2018), but concentrates on the opportunities for green path development in specific regional contexts. Thereby, it zooms in on what regional policy makers can feasibly and realistically achieve to contribute to a green economy.

The primary value of the proposed regional typology and policy framework lies in their application. This calls for empirical research to validate the conceptual arguments as well as to further our theoretical understanding of green industrial path development in different types of regions. We have provided empirical illustrations based on existing research for the four regional types. However, we would suggest a dedicated research design, which theoretically selects cases to investigate the differences and similarities as regards innovation system and transformation challenges, opportunities, and policy interventions by regional type. We can already foresee that it will sometimes be difficult to identify the regional type of “real cases”. This is because clean and dirty industries cannot be identified as two exclusive categories. Rather industries’ cleanliness or dirtiness measures on a continuous scale. Also, empirically degrees of industrial specialization will be observed. This implies that our framework discusses the “neat” end points of continuous scales while it is impossible to conceptually account for all

shades of grey. Consequently, the observed challenges, opportunities and adequate policy interventions in specific regions may deviate from the "ideal" regional types. However, this does not invalidate the causal relationships on which the regional typology and policy framework rests. Applying the respective reasoning should thus yield valid inferences also for regions that do not fit the ideal types.

Besides the empirical application and validation of the framework, we would also like to point out several blind spots in the literature. It is necessary to reflect on what can be done at the regional level: what is outside the power of regional governments? Do regional governments e.g. have the power to address the challenges identified in the policy framework and stimulate green industrial path development accordingly? Also, we consciously decided to build the framework on the notion of industrial specializations. Other relevant dimensions for green industrial path development can be linked to this notion. For instance, a strong industrial specialization implies the presence of strong and powerful actors being at the top of hierarchies in global production and innovation networks. However, we do not discuss the role of power explicitly (e.g. Sotarauta 2015; Hansen and Mattes 2018). Furthermore, we do not dig into qualitative differences in industrial specializations. For instance, the knowledge base approach suggests that knowledge, learning, and innovation differs between industries and regions (Asheim, Grillitsch, and Trippl 2017a). However, we do not address such differences in our framework. Therefore, we would consider it valuable to intersect our typology with other dimensions that zoom in on systematic differences between regions, for instance as regards power of regional actors, or type of knowledge bases developed in regions.

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