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Abstract

Regional innovation policy must not only strive for economic competitiveness, but also push novel and more sustainable technological solutions. The complex and multi-scalar process of developing and diffusing new technologies is captured by the Technological Innovation Systems (TIS) framework. However, the approach neglects regional variety and lacks a nuanced and systematic understanding of how technological change plays out differently across places. We thus complement TIS with insights from the literature on Regional Innovation Systems (RIS), which offers manifold comparisons and typologies of institutional contexts for regional innovation. We argue that three ideal-typical configurations – localist-grassroots, interactive-networked, and globalist-dirigiste – exist at the intersection between a technological and specific regional innovation system. We discuss how these regional configurations contribute differently to the development and functioning of the overall TIS and point to the innovation-related challenges they are confronted with. We illustrate our conceptual arguments with a brief comparative case study on three regions in the TIS for onshore wind energy. Overall, this paper contributes to the literature on the geographies of innovation and sustainability transitions, introduces a framework for analyzing regional variety in TIS, and enables more fine-grained and place-specific policy interventions directed at fostering specific technologies at the regional level.

Keywords

Technological Innovation System; Regional Innovation System; Innovation Policy; Geography of Sustainability Transitions; Onshore Wind Energy

Introduction

The climate crisis requires socio-technical systems, such as energy or transportation, to undergo sustainability transitions. Innovation studies contribute to explaining how and why novel practices and technologies for production and consumption emerge (Jacobsson and Bergek, 2011; Smith et al., 2010). The potential of innovations as drivers for transformative change is increasingly recognized in academia and policy (Schot and Steinmueller, 2018). Particularly the Technological Innovation Systems (TIS) approach became a state of the art framework in transitions studies (Köhler et al., 2019), as it enables researchers to investigate the dynamic processes that facilitate or block the development, diffusion, and use of technologies (Bergek et al., 2008).

Recently, TIS scholars pay increasing attention to how geography influences technological development and diffusion within the TIS (Binz et al., 2020). Most contributions in this 'spatial turn' focus on national subsystems and how they influence each other (Bento and Fontes, 2015; van der Loos et al., 2020b; Wieczorek et al., 2015). Regions are either treated as a uniform and homogenous 'regional level' within a multi-scalar system (Binz and Truffer, 2017; Dewald and Fromhold-Eisebith, 2015) or highlighted by single case studies of pioneering or well-developed TIS locations (Martin and Coenen, 2015; Miörner and Trippl, 2019; Rohe, 2020). The debate lacks a differentiated view on regional diversity and how the TIS shapes and is shaped by the various localities in which it materializes (Andersson et al., 2018). As sustainability transitions are often highly place-specific and rely on decentralized technologies such as renewable energy, this lacuna is particularly striking (Hansen and Coenen, 2015).

The uneven geographical distribution of innovative activity has been addressed by the (largely separate) debate on Regional Innovation Systems (RIS) (Asheim et al., 2016; Heidenreich and Mattes, 2019). RIS are "places where close inter-firm communication, socio-cultural structures and institutional environment may stimulate socially and territorially embedded […] innovation" (Asheim and Isaksen, 2002, p. 83). Accordingly, complex innovation processes are contingent upon formal and informal regional institutions and the cooperation among actors from various subsystems (Cooke et al., 2004; Heidenreich et al., 2012). Diverse typologies within RIS literature distinguish regions and regional innovation processes by multiple characteristics (Cooke, 1998; Zukauskaite, 2018). In line with the overall aim of RIS research, these typologies are designed to identify place-specific suggestions on how the economic competitiveness of regions could be enhanced (Toedtling and Trippl, 2005). While some recent research draws theoretically from both TIS and RIS, insights from RIS typologies have not yet been systematically integrated into the TIS framework.

Through this paper's analysis, we further combine the complementary perspectives from the established innovation system frameworks TIS and RIS. We are particularly interested in what we call 'regional configurations', i.e. arrangements in which TIS structures overlap with regional innovation systems and thus create place-specific dynamics. We ask what types of regional configurations exist at the intersection between a technological and specific regional innovation system, how the spatiality of knowledge and market formation varies between them, and which place-specific innovation challenges they might be facing. To answer the first question, we apply RIS typologies to describe the intersection of distinct regional TIS/RIS configurations, distinguishing between localist-grassroots, interactive-networked, and globalist-dirigiste configurations (Cooke, 1998; 2004). We argue that these configurations complement each other within mature technological innovation systems. Second, and in line with the functional and dynamic focus of TIS, we show how regional patterns of knowledge and market formation vary between these configurations and relate to the global TIS (Binz et al., 2016). For this purpose, we integrate insights from debates on knowledge bases and proximity and on the geography of market formation (Asheim and Coenen, 2005; Losacker and Liefner, 2020; Mattes, 2012). Third, we draw on literature around innovation system barriers and problems (Toedtling and Trippl, 2005; Wieczorek and Hekkert, 2012) and discuss the challenges these regional configurations face. This may inform regional policy makers aiming to foster not only the economic performance of their constituent territory, but also to promote the development and diffusion of specific technologies and thus impact the direction of innovative change (Coenen and Morgan, 2019).

We illustrate our theoretical arguments with empirical insights from German regions representing the three ideal type configurations in the TIS for onshore wind energy. From the viewpoint of the global TIS, all configurations play an important, albeit different, role: Some locations act as specialists for technology production (Magdeburg, the globalized-dirigiste configuration), some as hubs for pushing innovation further and linking it to other sectors (Oldenburg, the interactive-networked configuration), and some as rather independent niche hotbeds (North Frisia, the localist-grassroots configuration). Overall, our paper contributes to the literature on the geographies of innovation and sustainability transitions, introduces a framework for analyzing regional variety in mature technological innovation systems, and thus informs fine-grained and place-specific policy interventions at the regional level.

Technological and Regional Innovation Systems

In this chapter, we recognize earlier contributions combining elements from TIS and RIS. As these do not focus on regional variety, we examine these distinct approaches more closely: We discuss what TIS has established regarding the role of regions and the regional level and what RIS typologies exist in the literature.

Previous connections between TIS and RIS research

With their systemic approach to innovation and theoretical roots in evolutionary economy, TIS and RIS follow an Innovation System thinking developed since the 1980s (Edquist, 1997). The innovation process is regarded as non-linear and cumulative, as socially embedded, and as influenced by interactions among public and private actors, as well as by institutions like laws, norms, routines, or expectations (Heidenreich and Mattes, 2019). Apart from RIS and TIS, the family of innovation systems includes national (Lundvall, 1992), sectoral (Malerba, 2002), and multi-scalar frameworks (Binz and Truffer, 2017; Oinas and Malecki, 2002). All aim to inform policy by identifying systemic problems that block the innovation systems' success and efficiency (Wieczorek and Hekkert, 2012).

While TIS are delineated along technological 'boundaries' (including all system elements actively contributing to the development and diffusion of a technology), RIS are delineated along regional ones. Beyond this obvious distinction, further theoretical differences exist between the basic frameworks (Autio, 1998; Bergek et al., 2008; Braczyk et al., 1998; Hekkert et al., 2007): RIS emphasizes supply and technological development, whereas TIS also considers demand and technological diffusion. RIS scholars focus on the capability of regions to learn, viewing the resulting knowledge as the most fundamental system resource, while TIS scholars recognize additional system functions and resources. Thus, TIS aims at analyzing processes that contribute to or block system development, while RIS is rather suited for a comprehensive analysis of the status quo. TIS, however, tends to neglect geography and the impact of context-specific informal institutions, while RIS might turn a blind eye to developments outside the focal region and the relation between technology and innovation (Martin, 2016; Weber and Truffer, 2017).

Recent contributions combine some of these complementary elements from TIS and RIS more or less explicitly as to analyze regional dynamics in technological development and diffusion, using empirical examples from biomass-based industries (Martin, 2016; Martin and Coenen, 2015), renewable energy (Lutz et al., 2017; Mattes et al., 2015), and self-driving cars (Miörner and Trippl, 2019). Most studies agree on the RIS perspective's value in accounting comprehensively for system elements at the regional level. For instance, Mattes et al. (2015) consider actors and institutions from the subsystems of industry, science, finance, intermediaries, civil society, policy, and public administration. Miörner and Trippl (2019) combine these (static) RIS subsystems with (dynamic) TIS functions to analyze the transforming car industry in West Sweden.

There are few comparisons of regional cases in this literature, but they do not link results and their implications back to the TIS and RIS frameworks: For instance, Lutz et al. (2017) identify nine 'energy context types', based on natural and socio-economic conditions for renewables in all German districts.

For these types, they derive generic policy strategies, without accounting for actors, institutions, and past experiences with the technology in the region. Whether TIS dynamics unfold differently across regions and whether generalizable ‘regional configurations’ exist within a TIS remains, therefore, unanswered. We proceed by examining what the stand-alone research on TIS and RIS might contribute to tackling these questions.

The regional level in TIS

A TIS consists of structural elements – actors, networks, institutions – that jointly “contribute to the generation, diffusion and utilization of variants of new technology and/or a new product” (Markard and Truffer, 2008, p. 611)[1]. Instead of merely accounting for the structural composition of the system, TIS emphasizes the dynamic process of forming resources (or system functions) to support technological innovation. Knowledge development and diffusion, market formation, investment mobilization, and legitimation are commonly studied processes (Binz et al., 2016).

A sub-debate on the geography of sustainability transitions led to insights on the importance of place-specific context (Binz et al., 2020), especially for the development of a TIS (van der Loos et al., 2020a; Wesche et al., 2019). Hansen and Coenen (2015) summarize five relevant context factors: Regional visions and policies, informal localized institutions, natural resource endowments, technological and industrial specialization, and local market formation. On-the-ground efforts by local pioneers and social dynamics within regional networks might be added (Chlebna and Mattes, 2019; Jedelhauser and Streit, 2018; Späth and Rohracher, 2012). To capture spatial dynamics within the TIS, some contributions highlight how resources are formed within a region and how they are linked to or transplanted from other localities (Miörner and Trippl, 2019; Rohe, 2020). This emphasizes that resource formation in one place might lead to structural developments elsewhere, which increases uncertainty for policy makers on how to best support innovation systems in their region (Andersson et al., 2018).

So while it has been recognized that a “TIS is a global system with strong regional variations in terms of structure and functioning” (Wieczorek and Hekkert, 2012, p. 76), there is no systematic comparison of the relevance of and difference between local, regional, or subnational territories for technological innovation. Even fine-grained contributions on multi-level dynamics in technology centered innovation systems do not elucidate regional variety and diversity (Binz and Truffer, 2017; Dewald and Fromhold-Eisebith, 2015). The most common argument assumes that innovation systems emerge in local niches and – if successful – diffuse into global regimes (Miörner and Binz, 2020). Accordingly, global dynamics

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[1] Following this broad definition, it is no surprise that *industry* or *sector* are often used synonymously with *technology*. The framework can be used to analyze for instance both the conditions for the development and diffusion of a specific turbine technology, but also (as we do here) for the broader onshore wind energy industry/sector.

are often in the focus of scholars studying a mature TIS, while functional differentiations at the regional level are mostly neglected.

Typologies of regions in RIS

Why economic, industrial and technological development differs across regions has for long been a central question for economic geography. While this debate has been conducted under various labels (Bianchi, 1998; Florida, 2005; Porter, 2000; Saxenian, 1996), many insights have been synthesized into Regional Innovation Systems (Asheim et al., 2016; Braczyk et al., 1998; Coenen and Morgan, 2019); a framework designed to yield policy advice on how to foster innovative regional activity (Heidenreich, 2004; Isaksen et al., 2018; Toedtling and Trippl, 2005). RIS outline how innovation is socially embedded in regional institutional orders (Heidenreich and Mattes, 2019), which explains that not just the industrial and economic context, but also education systems and vocational training, political aspects, and network associations influence the innovativeness of a region (Asheim and Isaksen, 2002).

Even though RIS studies explicitly focus on technological innovation, the debate often lacks nuance or interest when it comes to accounting for how the specific technological bases shape regional innovation patterns (Doloreux and Porto Gomez, 2017)[2]. In empirical accounts, the dominant industry of a region is regularly featured, thus adding an implicit technology-filter (Heidenreich, 2009). Theoretically, however, this plays no role for explaining regional particularities (Braczyk et al., 1998). RIS is usually applied to established sectors like automotive and pharmaceutics, and changes in the framework are needed to accommodate for clean energy technologies (Mattes et al., 2015). Such a systematic classification of how RIS are shaped by technological differences does not yet exist.

RIS offers, however, manifold approaches and typologies for grasping variety in regional innovation systems and regionally embedded innovation processes (Zukauskaite, 2018). Some point out differences regarding innovation barriers (Isaksen, 2001; Toedtling and Trippl, 2005) or the modus operandi of shareholders and investors (Cooke, 2004). Most frequently, scholars distinguish between regions with rather self-centered and autonomously governed innovation system structures and regions that are strongly connected to global activities. The latter are dominated or even controlled by outsiders like multinational companies or national bureaucracies. A third, networked type represents a hybrid

[2] RIS has also been criticized for being too descriptive and static, and it has been noted that insights from empirical observations in one place are difficult to translate to others (Doloreux and Porto Gomez (2017); Weber and Truffer (2017)). Related to RIS, the more recent discussions on (industrial) path creation and development provide a more evolutionary and dynamic perspective (Grillitsch and Hansen (2018); Steen and Hansen (2018)). These path-debates have also been linked to the TIS framework (Binz et al. (2016); Frangenheim et al. (2020); Njøs et al. (2020)). In this paper, we seek specifically for the value added in classical RIS typologies.

case between the former two and is sometimes regarded as an 'ideal' RIS (Asheim and Coenen, 2005; Stuck et al., 2016).

In this vein and providing the perhaps most established typology, Cooke (1998, 2004) refers to localist-grassroots, interactive-networked, and globalized-dirigiste RIS. Other authors use somewhat different nomenclature and emphasize learning processes and how knowledge is created and distributed within and out of the region (Asheim and Coenen, 2005; Asheim and Isaksen, 2002), or the structure of regional networks (Stuck et al., 2016). At their conceptual core, all contributions regard the scale from more local/bottom-up to more global/top-down configurations as the central dimension for distinguishing RIS. Along this scale, Cooke further differentiates regions on a 'business innovation' and a 'governance' dimension: The former captures key characteristics of innovating regional organizations, their interrelations, and the spatial reach of their activities; the latter captures how innovation activities are managed, facilitated, and supported within the region. We claim that this typology can serve as a fruitful complementation to the TIS concept.

Scope of analysis

Research questions

The review above introduced the innovation system frameworks TIS and RIS: TIS offers a dynamic and potentially multi-scalar perspective on the conditions for novel technologies to develop and diffuse. While some TIS studies recognize the role of regional activities in the innovation system, the framework does not have nuanced grasp on regional variety. RIS offers a more fundamental, though somewhat static understanding of regional innovation processes, how they differ between locations, and how they can be shaped by place-specific policy. However, it neglects the demand side and specific requirements for sustainable technologies to thrive. Our effort to combine these complementary insights from the TIS and RIS approach is structured by the three guiding questions below:

What types of regional configurations exist at the TIS/RIS intersection?

How does the spatiality of resource formation differ between these regional configurations?

What are the systemic challenges of these regional configurations?

Regarding the first question, we follow the classic RIS-typology from Cooke and argue that localist-grassroots, interactive-networked, and globalist-dirigiste settings also exist at the intersection between a specific TIS and various RIS. To answer the second question, we focus on 'knowledge' and 'markets'. The spatiality of knowledge and the varying importance of geographical co-location for different knowledge bases have been emphasized by innovation scholars (Asheim and Coenen, 2005; Mattes, 2012) and we integrate these insights into our analysis. On the contrary, while TIS scholars emphasize niche markets, the regional facet and spatial dynamics of mature TIS markets are rarely focused on (Dewald and Truffer, 2012; Losacker and Liefner, 2020; Markard, 2020). We discuss the relevance of (inter-)national and regional market factors for each configuration. For reasons of space, we only touch on spatial variations of other resource formation processes in the discussion. Finally, and to answer the third question, we draw on the literature on innovation system problems and barriers. These challenges might relate to all structural elements of the regional TIS configuration: A thin actor base, fragmented networks, or institutional lock-ins (Toedtling and Trippl, 2005; Wieczorek and Hekkert, 2012).

Theory building with empirical illustrations

In the following, we aim to enhance the understanding of the dynamics and challenges of regional configurations by drawing directly upon the RIS and TIS literature. While building on theoretically informed ideal types, we empirically illustrate them with case studies on onshore wind in three German regions – North Frisia (Schleswig-Holstein), Oldenburg (Lower-Saxony), and Magdeburg (Saxony-Anhalt). These cases resemble the ideal type configurations in many aspects and help to demonstrate them, which is why we focus less on the deviations that we also find in the empirical reality. We hence understand ideal types in a Weberian sense as theoretically constructed "one-sided exaggerations of certain aspects of reality" (Weber, 1973, p. 191) which are useful for comparative and analytical purposes (Kuckartz, 1991).

In our conception, regions can be rural or urban, and the regional level is situated between the local and the national level. We view regional borders as contingent on iterative and relational place-making, meaning that their historical, social and administrative boundaries are subject to change and different perceptions (Hansen and Coenen, 2015). Accordingly, we started our empirical analysis of regional cases at select NUTS-3 units (the rural district of North Frisia and the two district-free cities of Oldenburg and Magdeburg) and iteratively included more districts as to account for the aforementioned criteria. The empirical studies have been conducted within the research project "Regional energy transitions" (REENEA) and are informed by a total of 80 qualitative, semi-structured expert interviews (refer to Rohe and Löhr (2020) and Löhr et al. (2020) for more details on our case selection and methodology). A list of all interviewed stakeholders can be found in the annex.

Case background

To understand the case illustrations, we briefly outline why we regard onshore wind as a suitable context for showing regional configurations: First, the innovation system dynamics of this relatively mature technology have been studied by TIS scholars – but almost always at the national level (Bento and Fontes, 2015; Binz et al., 2017a; Edsand, 2017; McDowall et al., 2013). From a RIS perspective, accounts on renewable energy centered innovation systems – that depend more on political regulation and demand-side influences than other sectors (Binz et al., 2017b) – are rare, thus adding a novel and refined application to that debate. Second, innovation patterns for onshore wind are more configurational and influenced by local contexts than sometimes assumed in the literature (Wesche et al., 2019). This 'spatial stickiness' is prevalent at the core of the value chain (Karnøe and Garud, 2012), but also in downstream segments, which rely on application-oriented and customized knowledge, market access, and legitimation (Rohe, 2020). Therefore, accounting for diversity in regional configurations is promising for this TIS. At the same time, the findings can be transferred to other technologies with complex requirements for installation, use, and market formation, such as offshore wind, bioenergy, or residential heating solutions.

The case study regions are relatively sparsely populated and perform mediocre on socio-economic indicators, while wind speeds are beneficial, and the diffusion of turbines is clearly surpassing the German average (cf. annex). Several organizations active in the wind sector exist in these places. Hence, all regions host considerable structures and processes of the onshore wind TIS. Yet, despite their similar natural and socio-economic context, they represent substantially different regional configurations as they vary in their institutional set-ups and functional contributions to the multi-scalar innovation system. We elaborate these spatial variations in the following sections.

Regional configurations within Technological Innovation Systems

Types of regional configurations

As a first step, we draw upon the typology by Cooke (1998, 2004), outlining ideal-typical differences between localist-grassroots, interactive-networked, and globalized-dirigiste RIS. While these types originally refer to entire RIS, we apply them to regional configurations around the development and diffusion of a distinct technology, i.e. at the intersection between RIS and TIS. The investigation of business innovation and governance sheds light on the specific characteristics of each regional configuration. Moreover, we consider the role of different innovation subsystems. RIS comprise a comprehensive view on the regionally embedded interplay among innovating actors that encompass not only firms ('knowledge exploiting subsystems'), but also public and private research institutions and education facilities ('knowledge generating subsystems') (Autio, 1998). To display the variety of involved fields, we follow later contributions and distinguish between the subsystems of science and education, industry, finance, politics and administration, civil society, and intermediaries (Heidenreich, 2012; Mattes et al., 2015). In TIS, these subsystems are not automatically included and it depends on the research question which structural elements are part of the system (Bergek et al., 2008). Regional configurations at the TIS/RIS intersection can hence be characterized by complementing Cooke's ideal types with an assessment on the subsystem constellation (cf. figure 1). While the subsystems constitute the RIS, they might also be more or less functionally integrated in the TIS. In the localist-grassroots configuration, overlaps between RIS and TIS structures are particularly strong, while this configuration possesses comparably weak connections between regional and global TIS elements. The opposite applies to the globalist-dirigiste configuration. Finally, in the interactive-networked configuration RIS subsystems are well aligned with the TIS and contribute to its global development. The empirical illustration mirrors this.

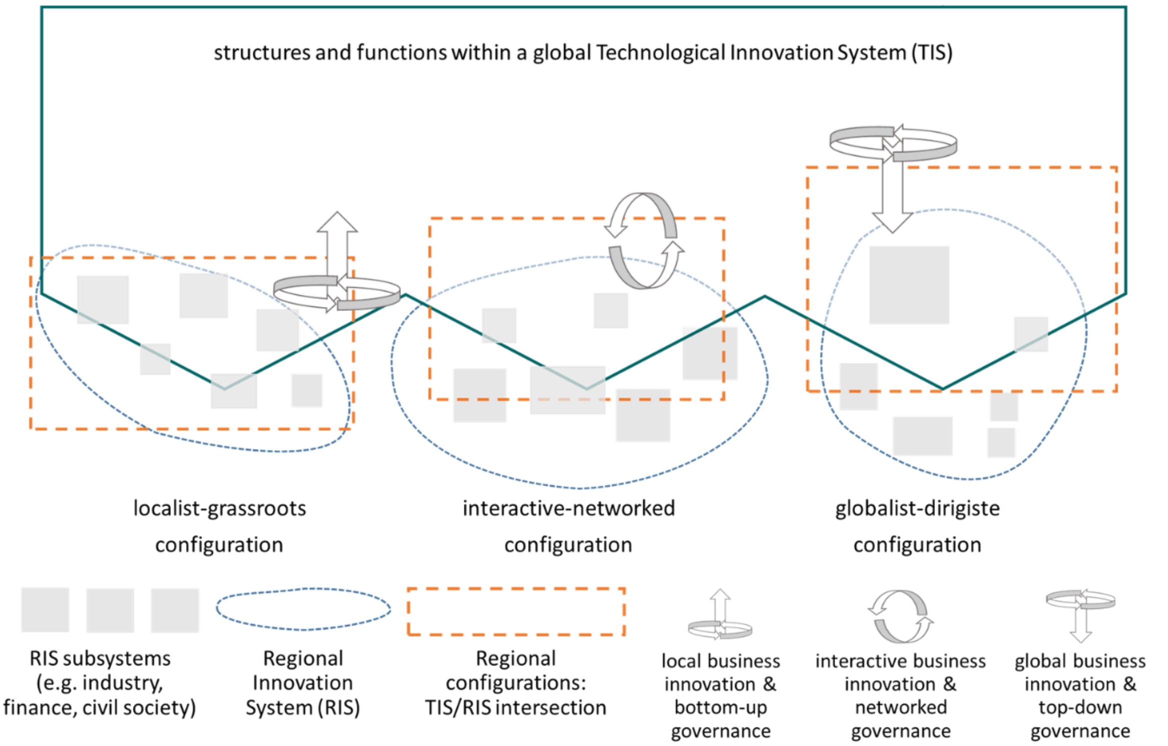

Figure 1: Regional configurations (own figure)

North Frisia exemplifies central traits of the localist-grassroots configuration: Business innovation is locally rooted, and the governance of innovative activity is mostly organized autonomously. The pioneering role of the region is well-known in Germany and proudly mythologized by local actors (Löhr et al., 2020). The onshore sector began developing in the 1980s. It profited from competences in related industries like ship building (Fornahl et al., 2012) and from political support, as the northern Federal States quickly identified the industry's economic potential (Chlebna and Simmie, 2018). Citizen wind parks make up the bulk of installed capacity and farmers and private cooperatives are the most active wind developers (Chezel and Nadaï, 2019; Süsser and Kannen, 2017). There are several intermediaries that pool the political interests of hundreds of small organizations or individual citizens involved with renewable energy and facilitate exchange among them. This underlines the importance of the civil society, supported by local banks that have developed expertise in wind energy and fund many activities (Rave and Richter, 2008). More than would be expected for this ideal type, several service firms and project developers operate beyond North Frisia. While Schleswig-Holstein hosts a distributed network of university energy research and several applied research & development (R&D), the region lacks specialized, high-profile, and globally visible wind research institutes. A subsidiary of a global turbine manufacturer and the biennial Husum wind fair constitute extra-regional structural linkages. Overall, regional subsystems are deeply interwoven with a specific TIS. At the same time, the central regional strengths of this configuration are relatively autonomous from the TIS beyond the region.

The Oldenburg region closely resembles the interactive-networked configuration. On the business innovation dimension, there is a balanced mix of firms from all sizes and both public and private backgrounds: Project developers, survey companies, and a large energy utility are based in the region, as well as universities, research institutes, and service providers. Especially the ventures of the latter firms have a global reach. At the same time, the organizations are strongly interconnected with each other regionally, due to a shared history of cooperation and an intermediary organization facilitating exchange. In Oldenburg, the political subsystem played a crucial part in setting up this configuration in an early phase, but it receded as the system matured. Instead, the networked governance of this regional configuration is coordinated by both formal intermediaries and informal relationships between actors (Chlebna and Mattes, 2020). Diverse organizations jointly undertake regional R&D. This regularly involves funding and project partners from the federal, national, or European level. While all subsystems reached a certain maturity and interact regularly, the intermediating subsystem plays a crucial role in coordinating activities locally and across scales. Overall, the onshore wind TIS is a relatively important part of the regional innovation system, although not a dominant one.

The wind energy TIS in Magdeburg is dominated by Enercon. The turbine manufacturer is the largest private employer in the region. Core components are produced and partly assembled in Magdeburg and then shipped to locations within Germany and Europe. The company chose the production site after reunification in 1990, because of its mechanical engineering assets (abandoned production facilities and a skilled labor force), availability of national subsidies, and logistical infrastructure. R&D, however, takes place at the company's headquarters in Lower-Saxony. Enercon does not cooperate with regional research institutes, although these possess knowledge in engineering and the management of electricity systems. Only few additional project developers and utilities represent the TIS in the region, and some of them are in dispute with Enercon. Most wind farms are owned by external investors, typically from Western Germany. Enercon funds and controls cluster organizations and renewable advocacy associations to a great extent. Magdeburg therefore resembles a globalist-dirigiste configuration, where business innovation is dominated by a large organization. Opposite to Cooke's (2004) original examples (usually regions from France and Italy), however, it is not a powerful national government organizing innovation support top-down and installing research institutes in peripheral regions.

Instead, in Magdeburg an exogenous private firm governs much of the regional innovation processes and sets up supportive infrastructure according to its needs. As with globalist-dirigiste arrangements in general, the activities of few central actors (representing the regional TIS structure) are relatively isolated from an otherwise weakly developed regional innovation system (Stuck et al., 2016).

	Business innovation	**Governance**	**Subsystems**
Localist-grassroots (NF)	• few public actors; possibly large branches of outside firms • medium/high degree of association among actors • limited spatial reach	• locally organized technology-transfer and co-ordination • funding from multiple (local) sources • applied research • generic, problem-oriented specialization	• science subsystem rather weak • financial subsystem important • civil society involved in innovation process
Interactive-networked (OL)	• mix of firms of all sizes and public/private background • high degree of association among actors • widespread reach of firm's activities	• technology-transfer initiated and coordinated in multi-level networks • coordinated funding • mixed research competences • high system coordination • flexible specialization	• all subsystems somewhat developed and interact regularly • intermediating subsystem very important • close relation between industrial and science subsystems
Globalized-dirigiste (MD)	• domination of large, private/public firm(s) and dependent SMEs • large organization(s) control networks and associations • reach of activities rather global	• technology transfer directed from outside • central funding • basic (or no) research • initiation and coordination driven by external intervention • high specialization	• science subsystem isolated or weak • industrial or political subsystem dominant • civil society excluded from innovation process

Table 1: Regional configurations in TIS (own table)

The characteristics of the ideal-typical configurations are summarized in table 1. As the examination of structural components is a basic step in any TIS analysis, this typology is a useful starting point for place-specific analyses.

Resource formation within regional configurations

To grasp the spatial particularities and regional embeddedness of these TIS/RIS configurations better, it is helpful to look at processes of resource formation. We focus on two central resources, knowledge and markets. Knowledge creation is the fundamental process shaping the development of new technological applications and varieties, while market formation captures the distinct problem of diffusing these novelties.

The spatial heterogeneity of knowledge can be understood by drawing on the concept of 'knowledge bases' (Asheim and Coenen, 2005) that vary across technologies and regions (Plum and Hassink, 2011).

Different knowledge bases require varying degrees of co-location, and localized learning is structured accordingly. Synthetic knowledge bases rely on practical experiences and exchange of know-how; they thus link knowledge to localities and favor incremental innovation. In contrary, analytical knowledge bases work in a more planned and structured fashion. The relevant expertise is more codified and hence easier transferrable across locations. Finally, symbolic knowledge refers to aesthetic characteristics and cultural perceptions of products and thereby relies upon geographical and social proximity (Asheim, 2007; Mattes, 2012). Industries themselves (such as the wind industry, cf. table 2) are heterogeneous and may rely on different knowledge bases in parallel (Moodysson et al., 2008). Regional configurations hence build upon various combinations of knowledge bases, as the empirical illustration shows.

Knowledge Base	Geographical proximity	Activity in the onshore wind TIS
Symbolic	Critical	Know-who of local customs and people and skillful communication required to secure sites for socially accepted *wind farm development* or inclusive *business model innovations*
Synthetic	Helpful (auxiliary)	Practical know-how and face-to-face exchange required to innovate turbine components and production processes (*manufacturing*) or manage *applied R&D* on turbine management and grid integration
Analytical	Negligible	*Basic R&D* for turbine development and technical *surveys* and *services* for *turbine operation* driven by structured inputs from physics and computer science and codified knowledge

Table 2: Knowledge bases in the onshore wind TIS (own table, based on Mattes (2012) and Rohe (2020))

The formation of markets is also central for understanding regionally heterogeneous resource formation. TIS scholars usually differentiate between niche and mature markets. Market formation cannot only be driven by engaged entrepreneurs, but also by public demand and regulation on various governance levels (Planko et al., 2017). TIS acknowledges the importance of the demand side but offers few insights on the regional facet of market formation. Niche markets in early TIS development are characterized by co-location of market segments, supplier-customer networks, and user preferences. This makes them dependent on spatially confined structures (Dewald and Truffer, 2012). Contrary, mature markets tend to become multi-scalar and develop multifaceted diffusion patterns. They do not necessarily grow and expand in the same places that have developed TIS elements, which might ultimately erode these regional structures (Andersson et al., 2018; Dewald and Fromhold-Eisebith, 2015). At the same time, the diffusion of environmental technology can be successfully and continuously driven by regional markets. This potential is influenced in part by national factors (price, transfer, and export advantages), but also by regional ones (regulatory, demand, and technological advantages) (Losacker and Liefner, 2020). With these factors in mind, we describe the spatiality of market formation for each configuration in the following.

In North Frisia, the prevailing business model of citizen wind farms requires developers to know how and whom exactly to communicate to, as to receive necessary sites, political support, and public interest in financial participation (Alle et al., 2017; EE.SH, 2019). This symbolic knowledge easily diffuses within interlinked industrial, financial, and civil society subsystems. This network also provides beneficial conditions and unbureaucratic funding for decentralized and applied R&D (GP Joule, 2020). Synthetic knowledge from these experiments is tied to regional actors and their experience. Experimenting creates new niche markets and entrepreneurs specialized in catering to regional demand. Because of the localist mode of business innovation, the experience of many firms in serving foreign markets is comparably limited. This shows that the localist-grassroots configuration with its closely interlinked subsystems is potentially well-positioned for activities based on symbolic and synthetic knowledge bases and for endogenous market formation.

The globalist-dirigiste configuration represents opposite knowledge and market formation dynamics. The generation of synthetic or analytical knowledge is centrally controlled by few organizations governing the innovation process; the diffusion of that knowledge is channeled by their corporate structure. For instance, utilities from outside Magdeburg strategically utilize the region to test novel business models and technologies (e.g. on producing hydrogen from excess wind power), before introducing optimized solutions to their home markets. Enercon initiates on-site visits and face-to-face working groups to manage the exchange of synthetic knowledge on turbine production and assembly between the headquarter, the main production facility in Magdeburg, and subsidiaries in new markets like Turkey or Portugal. Market formation in this regional configuration mostly hinges on extra-regional factors, as TIS actors specialize in price-competitive production of goods or services for an (inter-)national demand. In Magdeburg, turbines are produced primarily for the central European market. The regional TIS thus relies on continued demand from these external regions.

In Oldenburg, the interactive-networked case, spatial resource formation represents a hybrid type, just as the structural characteristics do. On the one hand, exchange of proximity-based symbolic and synthetic knowledge is facilitated through dense social networks and a strong intermediating subsystem. As the TIS is connected to the cross-sectoral RIS, ideas from related regional industries feed into the process of technological development and diffusion. On the other hand, analytical knowledge diffuses into and out of the region through a well-developed science subsystem (Rohe, 2020). Similarly, market formation relates to regional and national factors. Multiple market segments are co-located in the region, but TIS actors simultaneously engage in business abroad. Thus, both national and regional regulations (and, consequently, demand) affect their market advantage (Löhr and Mattes, 2020).

To summarize, knowledge and market formation patterns and the role of geographical proximity varies between the regional TIS/RIS configurations. Accordingly, the ideal types relate differently to the overall TIS. The localist-grassroots configuration provides an independent niche in which symbolic and synthetic knowledge and new markets can be created due to dense co-location of innovating actors and subsystems. The globalist-dirigiste configuration represents a specialist region, serving the specific demands and markets of a maturing, global TIS. Finally, the interactive-networked configuration provides dense local knowledge and market structures that are likewise embedded in the global context.

	Knowledge development and diffusion	**Market formation**
Localist-grass-roots (NF)	• symbolic and synthetic knowledge bases • importance of experimenting and testing	• multiple niche markets • regional demand and market advantages are important • driven by regional entrepreneurs
Interactive-net-worked (OL)	• all knowledge bases • importance of experimenting and testing	• multiple niche markets • both regional and extra-regional demand and market advantages are important • driven by regulation at multiple scales and regional entrepreneurs
Globalized-diri-giste (MD)	• analytical and synthetic knowledge bases • experimenting and testing not important	• no niche markets • extra-regional demand and national market advantages are important • driven by (inter-)national regulation and extra-regional entrepreneurs

Table 3: Dynamics of resource formation within regional configurations (own table)

System challenges for regional configurations

All regional configurations are potentially fragile in the light of disruptions within the overarching transition (Chlebna and Mattes, 2020). As they are confronted with specific system challenges, a one-size-fits-all approach to regional policy would not suffice (Toedtling and Trippl, 2005). Thus, properly understanding these challenges allows us to derive practical implications for how they can be mitigated and possibly solved. Toedtling and Trippl (2005) identify three main barriers to the innovativeness of regions: Organizational thinness, lock-in, and fragmentation. Organizational thinness refers to a lack of innovative actors and support organizations, lock-in to following overcome development paths, e.g. by relying on dated technologies, and fragmentation to a lack of interaction, coordination, and learning opportunities within a region. All these barriers may cause severe systemic problems (Wieczorek and Hekkert, 2012), but their manifestation is contingent upon place-specific structural settings (Toedtling and Trippl, 2005).

The localist-grassroots configuration, illustrated by North Frisia, is confronted with the challenge of further extending the geographical scope of its business innovation activities (Projektgesellschaft Norderelbe, 2019). As these activities are mostly coordinated by an elite group of pioneering individuals and based around a rather narrow set of original business models and practices, integrating newcomers is a challenge. Activities from outsiders tend to be viewed with more skepticism than in other configurations, but more openness could also risk losing the advantages of close-knit and embedded networks. Established organizations possess relatively few structural links to external research institutes or higher policy levels that determine relevant framework conditions. This links to a danger of technological lock-in, as the continued operation of 20-year-old turbines and the viability of the business model of citizen wind parks depends on national regulation. Yet, the region of North Frisia does relatively well in seizing upon its niche market potential and some wind pioneers successfully explore alternative technological solutions and business models.

Oldenburg represents the interactive-networked type and is endowed with manifold actors that are networked within and beyond the region. This ‘organizational thickness’ is an asset. At the same time, there is a constant need for qualified labor, which highlights the importance of the education subsystem. While a well-working interaction is one of the strengths of this type, the inclusive approach can potentially result in loosing focus. As actors tend to feel safe and rely on their comfortable position, network initiatives may lose their attractiveness and hence prove less durable than they seem to be at first glance (Chlebna and Mattes, 2020). This relates to a lock-in situation in which actors do not move beyond those activities that have already been safely established, which might reduce innovativeness. This highlights that this configuration carries severe risks and needs constant care – even though it seems to be a close to the optimal constellation on the surface.

	Organizational thinness	**Lock-in**	**Fragmentation**
Localist-grassroots (NF)	Splintered intermediary and science subsystems that insufficiently promote activities beyond the region; insufficient external lobbying	RIS overly reliant on specific technology	Interaction among dominant individual pioneers is rigid and exclusive
Interactive-networked (OL)	Organizational thickness endangered through constant need of funding and staff	Feeling of complacency might hinder new initiatives	Activities of intermediaries become too fragmented and watered down
Globalized-dirigiste (MD)	Intermediaries are captured and represent single or few TIS actors	Over-reliance on a single corporation and its business model; high dependence on external demand	Lack of interaction and coordination among TIS and RIS structures hampers seizing on technological market advantages

Table 4: System challenges for regional configurations (own table)

The globalized-dirigiste configuration that Magdeburg resembles lacks a coherent network structure and is hence characterized by organizational thinness. Regional knowledge formation is limited and suffers from a lack of interaction among TIS actors and with related sectors. As existing intermediary organizations represent the interests of single or few TIS actors, they are not in the position to foster reliable connections. This goes along with lock-in: The region is over-reliant on a single corporation. Finally, this results in fragmentation based on the imbalanced power contribution between the dominant and other regional actors. Based on the outlined lack of interaction, technological market advantages cannot be seized. The regional configuration is hence not driven internally, but dependent upon external demand.

Discussion and policy implications of regional configurations

To account for regional differences in systemic processes for technological development and diffusion, we integrated insights from RIS typologies into the TIS framework and illustrated the structural characteristics, dynamics, and challenges of three regional configurations. In this section, we summarize the key features of each ideal type (that are of course more pointed than the observed empirical instances) and discuss practical implications – for regional policy makers that aim at a more sustainable regional innovation system, but also from the perspective of advancing a global TIS.

Localist-grassroots configurations are shaped by locally engaged actors, who are linked by vivid personal relations and whose activities have a limited spatial reach. Regional TIS structures make up a significant part of the overall RIS. While the subsystems of finance and the civil society are well-developed and interlinked, the scientific subsystem is rather weak and there are few links between research institutions and firms. This may inhibit this regional configuration to achieve full technological market advantage. Drawing upon its synthetic and symbolic knowledge bases, the localist-grassroots type may host multiple niche markets driven by regional entrepreneurs. Weak linkages outside the region, a lock-in on specific technologies, and rigid and exclusive interactions among few pioneers are potential challenges in this configuration. This analysis provides the starting point for identifying suitable policies: To overcome its relative isolation, regional politicians in localist-grassroots configurations could consolidate and strengthen intermediaries with an outward focus. One of their tasks would be to communicate and draw attention to the locally embedded and often pioneering technological developments in the region; another to lobby for more flexible regulation at the national level, as rigid policies often hamper market formation. Strengthening and specializing the science subsystem would create further (inter-)national linkages, as it draws new actors to the region and contributes to codifying existing knowledge and making it more spatially transferrable. From the perspective of actors in the global TIS (multinational wind companies or relevant policy makers), it is important to identify localist-grassroots configurations and upscale their potential for exploring new technological varieties and niche markets.

The interactive-networked constellation is characterized by well-developed and balanced subsystems. TIS structures interact with other sectors and are integrated into the overall RIS. All knowledge bases are present, and both regional and extra-regional markets are served. Maintaining the high level of activity poses the core challenge: First by provisioning constant funding and staff, second by keeping up the interaction between the involved actors, and third by preventing a feeling of complacency and resting on one's laurels. Hence, policy measures should build on existing regional strengths and stabilize them without endangering their flexibility. A broadly accepted regional vision and targets for the future direction of the transition could help re-fueling and focusing regional activities. Such a long-term strategy can serve as boundary bridging arrangements that ensure the continued cooperation of various subfields (Koehrsen, 2017). To bestow the process of 'envisioning' the necessary gravitas and legitimacy, local politicians (e.g. mayors) need to (re-)engage; the strong intermediary subsystem is well positioned to coordinate the vision's implementation. From the TIS perspective, this regional configuration serves well as a pool of innovative knowledge and can provide the backbone for a global technology.

Finally, the globalized-dirigiste configuration is dominated by a large organization that controls networks and activities in the region. While external linkages are strong and stable, regional governance is weak. Analytical and synthetic knowledge are spatially transferred through corporate channels. TIS actors cater to foreign demand, while technological diffusion in the region is financed and executed by external investors. The scientific subsystem and civil society are hardly active or involved. This shows that the RIS itself is less developed in this ideal type – an observation that points at the interdependence between TIS and RIS structures. Thus, a forceful effort from policy makers is needed to develop a conjoint strategy for better linking TIS and RIS structures and diversifying the technological base. This could include measures like promoting university spin-offs or subsidizing the allocation of external companies with related competences. Local politicians from this configuration rely on coordinated support from higher governance levels to achieve these goals. In the end, a stronger and more diverse region is also beneficial for the dominant corporation itself (cf. also Mattes, 2013).

Conclusion

This paper highlights the diversity of how TIS are regionally bound. Our typology of how a TIS intersects with specific RIS underlines the diverse roles in and functional heterogeneity of regional configurations in developing and diffusing technologies within a maturing TIS: Some locations act as specialists for technology production (globalized-dirigiste), some as hubs for pushing innovation further and linking it to other sectors (interactive-networked), and some as rather independent niche hotbeds (localist-grassroots). While the presented empirical cases mostly fit the theoretical configurations, there is a constant tension between ideal types and the empirical reality. For instance, some locally active and interlinked wind pioneers indeed exist in Magdeburg – although with a relatively small impact and relevance. Likewise, North Frisia shows elements of the interactive-networked ideal type. Building on the outlined characteristics of ideal types, further research could analyze empirical examples in a more nuanced qualitative depth and also develop quantitative indicators to measure the extent to which regional cases fall into the ideal-typical categories.

We do not claim that a global TIS only consists of a collection of regional configurations. Some elements of the system transcend spatial boundaries and exist as emergent and international system elements that form a 'global socio-technical regime' (Binz and Truffer, 2017; Fuenfschilling and Truffer, 2014). What we have shown is that there is no homogenous 'regional level' within a technological innovation system and that distinct regional configurations vary in their connection to and reliance on these global structures. We have also shown that regional configurations vary in respect to their specific knowledge and market formation. Future contributions could analyze how other processes of resource formation play out in the different ideal type configurations. For instance, insights from the emerging debate on the geography of technological legitimacy (Heiberg et al., 2020) could be linked to the regional configurations as to get a more systematic understanding of regional variety in legitimacy formation.

The regional configurations face different challenges and, in turn, need tailored political approaches to be supported and stabilized. In this theoretical paper, we can derive stylized policy recommendations for each ideal type. Future research could take an explicit policy perspective on the regional TIS/RIS configurations and trace the specific policy mixes and measures that shaped each configuration and its trajectory. Such an approach could incorporate a multi-level and a process perspective: Multi-level, as it should not only consider regional policies, but also those from a state and federal level that influence regional trajectories. Process, as it should account in detail for the sequence of policies and decisions that result in different regional TIS/RIS configurations, even in places with similar socio-economic and geographical characteristics. Moreover, as the way technological systems are spatially embedded differs according to their physical characteristics (Binz and Truffer, 2017), future studies could focus on policy advice for TIS/RIS configurations around more standardized technologies (e.g. solar PV). These might be more difficult to stabilize and interlink at a regional level.

There are no optimal solutions for how TIS should be regionally embedded. There is even a contradiction between what might be desirable from the perspectives of regional decision makers and advancing a TIS globally. While the former group aims to improve the innovativeness of their regions and foster their regional innovation system and its ties to local and global TIS structures, from the latter point of view technological development and diffusion is not about "everything in one place" (Markard et al., 2015). A mature and thriving TIS need to be rooted in a variety of TIS/RIS configurations as to draw upon complementary strengths. Because technologies like renewable energy must diffuse globally, this implies that many regions might end up as `installation configurations´. It is not necessary for TIS actors to find well-developed RIS structures everywhere, let alone interact with them. This might, however, raise issues of justice and social desirability, especially in metropolitan regions of the Global South, where a mismatched configuration between global TIS structures and local contexts might result in negative externalities or the emergence of alternative technologies with locally organized governance systems (van Welie et al., 2019a; van Welie et al., 2019b). Further research could thus test and refine our proposed ideal-typical configurations along empirical examples from regions in developing countries, as well as other spatial contexts. After all, a fundamental understanding of how global technological innovations intersect with specific regional innovation systems is a prerequisite for decision makers wanting to influence the direction and speed of technological developments in their constituent region.

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Annex

Table A: Regional Indicators

Region Indicator	**North Frisia**	**Oldenburg**	**Magdeburg**	**Germany**
Included districts	4	9	4	401
Location and Federal State	Western coast of Schleswig-Holstein (SH)	Historic Free State of Oldenburg, now Lower-Saxony (LS)	Saxony-Anhalt's (SA) capital and adjacent rural districts	16 Federal States
Population (2017)	807.700	1.067.400	695.700	82.657.000
Area (in km²)	4,468	5,382	5,572	357,386
GDP / Person (2017, in €)	28,938	34,636	29,029	40,339
Population Density (inhabitants/km²)	181	199	125	232
Unemployment rate (2019)	5,0	5,5	7,2	5,0
Wind turbines (2018)	1.556	900	1,433	30,215
Installed capacity (kW)	2.846.485	1,580,810	2,532,640	51,531,952
Turbine density (Turbines / km²)	0.35	0.17	0.26	0.08
Employment wind sector (Federal State level, 2016)	12,850 (SH)	36,600 (LS)	14,550 (SA)	160,200

(Sources: The Wind Power (2019), Eurostat (2019), Agentur für Erneuerbare Energien (2020), Statistisches Bundesamt (2020))

Table B: Expert interviews per regional case

	Number of inter-views*	**Regional Policy**	**Civil Society**	**Interme-diaries**	**Research & Educa-tion**	**Industry**	**Finance**
North Frisia	26	2	2	7	2	20	3
Olden-burg	30	6	4	6	5	13	3
Magde-burg	24	7	1	5	2	10	1

** Sum of all subsystems is higher than number of interviews per region, as some stakeholders represent organizations from more than one subsystem.*
*** All interviews were carried out between 2018 and 2020 and took between 50 and 120 minutes. A summary document with exemplary and relevant quotes for each regional case will be provided upon request.*

Expert interviews per regional case

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