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Green Transition and the Role of Smart Specialisation in Europe

An Empirical Examination

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Mirko Kruse

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First examiner:

Prof. Dr. Torben Klarl

Second examiner:

Dr. Jan Wedemeier

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Chapter 1

Introduction: on Regional Innovation and Sustainability in European Policy

Author: Mirko Kruse

Abstract

The relevance of innovation for regional development has been increasing in recent years considering the need for structural renewal and a green transition. Accordingly, research has not only shifted in terms of the perception of innovation as an instrument rather than a goal in itself, but also regarding the role regional policy. Starting from industrial districts and innovative milieus, regional innovation policy has come a long way over the last century. Thereby, the theoretical roots of the concept not only show how modern concepts have emerged and how research streams are interlinked and separated. Moreover, recent challenges of making regions fit for a green transition can benefit from a solid theoretical basis. Particularly the European instrument of smart specialisation has become a major lever for innovation policy and the achievement of sustainability goals formulated in the EU Green Deal. The chapter discusses how regional innovation and practical policy have developed in Europe and which challenges are to be addressed, both theoretically and practically.

Keywords: regional innovation; RIS; smart specialisation; sustainability; green transition; Europe.

JEL Classification: R11; O30; P18; Q50.

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1.1 Introduction

"The only thing that is constant is change."

- Heraclitus of Ephesus

It is deeply rooted in the DNA of market-based economies that structural transformations are the rule rather than the exception. Those who are too slow in transforming, be it companies, states, or institutions, come under heavy pressure from competition and will eventually be overtaken by others. On the other hand, change as a result of new ideas and innovations promises improvements of the status quo ante so that the history of the economy is told as a history of advances – occasional setbacks included (Wostner, 2017; Balland et al., 2019). Innovation as the main engine of structural change and economic prosperity has been extensively covered in scientific literature, emphasising its contribution towards productivity, competitiveness, dynamism, improved wellbeing, and contributions to different challenges (Rusu, 2013; Mazzucato and Penna, 2020). Here, the key driving power of innovation is assumed to be knowledge. Accordingly, the generation of knowledge becomes crucial for economic development and prosperity (Lundvall, 1992a). Considering the complexity of the human mind, innovation is far from being a superficial concept and the deduction of practical recommendations for economic policy is far from being trivial.

In practice, it has been noted that innovative processes do not happen uniformly everywhere. Certain areas, particularly agglomeration areas such as cities, are highly innovative and benefit from positive externalities as a result. For decades, academics from disciplines such as social sciences, business management, economics, econometrics, geography, and regional studies have addressed the question why some regions prosper why others do not benefit at all (Hidalgo et al., 2018; Janik et al., 2020). This question is not only crucial in terms of achieving interregional cohesion and reducing political instability. Successful innovation is also relevant when it comes to a green transition of the economy considering the exacerbating climate change. In order to create a climate-neutral economy by transforming existing structures, innovation will be required as an instrument and a bridge towards an economic system within the planetary boundaries (Rockström et al., 2009; Steffen et al., 2015; Richardson et al., 2023). Assuming that innovative regions are not only better equipped to successfully adapt to climate change due to their innovativeness and a predominantly green economic structure, less-developed regions are not only less prepared to deal with structural challenges but also structurally disadvantaged as their economic structure is outstandingly characterised by "dirty" technologies such as extractive industries or primary production sectors. This field of tension makes innovation and the transition towards a green economy also a social question and a task for cohesion policy. This task applies not only on a global level when it comes to support countries in the Global South, but also on national sub-national levels, considering poorer regions.

The present thesis focuses on the intersection between regional economics, innovation, and environmental sustainability in a broader transition process. Here, European regions and EU policies are chosen as the analytical foundation for practical research due to first steps already undertaken on political level and a highly diversified environment of actors and prerequisites, potentially generating learning effects for others. In order to address this diverse topic appropriately, this introductory chapter, as well as four scientific articles (chapters 2 – 5), are provided. The scientific articles address different aspects of regional transition using a variety of empirical methods and data sources. In combination, they shed light on the question how the structural change towards climate neutrality can be facilitated at regional level using established and new political instruments. Chapter 2 provides an analytical foundation by investigating to what extent innovation theory and sustainability aspects are interrelated in academic research, and how both research streams might be combined in further steps. The EU policy instrument of smart specialisation is introduced as a practical example of these differing interests in regional policy. In chapter 3, it is analysed how interregional cooperation in environmental sustainability topics has developed at regional level in Europe by processing data on EU-funded research projects. It is shown which regions are particularly involved in environmental research and which role European policy has played in facilitating this cooperation. Chapter 4 is dedicated to the development of an index to measure the regional development towards a circular economy (CE). Since CE is a major aspect of different relevant policies in Europe, for instance the EU Green Deal, this index allows for a monitoring of regional progress and the identification of yet untapped potential for upscaling. Finally, chapter 5 analyses econometrically which regions tend to develop a specialisation in green technologies and which role is played by structural and exogenous factors such as climate change vulnerability, or sensitiveness for green ideas.

As a beginning, this introductory chapter will provide the foundation for embedding the subsequent chapters in the larger context of regional innovation. Section 2 will introduce innovation and its role played for environmental sustainability. Here, an overview of the history of innovation (2.1) is developed, followed by an in-depth presentation of mission-orientation as a recent framing of innovation policy (2.2), as well as an elaboration of innovation and green transition (2.3). Section 3 is devoted to innovation at regional level, presenting the different and overlapping concepts of industrial districts (3.1), the innovative milieu (3.2), clusters of innovation (3.3), and innovation systems (3.4). This paves the way for section 4 which focuses on European policy in general (4.1) and the policy instrument of smart specialisation in particular (4.2). This European approach to regional innovation policy has been adapted over time as a result of practical implementation (4.3) and is currently discussed as a potential vehicle for implementation of the EU Green Deal and a sustainable regional transition in Europe (4.4). Section 5 gives a detailed introduction to the scientific articles (chapters 2 – 5). Finally, section 6 synthesises the main findings of the introductory chapter, draws conclusions, and provides an outlook on future challenges.

1.2 Innovation and the Pursuit for Environmental Sustainability

While structural change, economic transition, and innovation have been around for decades, current events have again put innovation at the centre of attention. Recently, the COVID-19 pandemic acted as a wake-up call to build a more resilient economy, while exacerbating climate change increasingly calls for a fundamental redesign of economic and societal certainties within a closing time window. The necessary transition towards climate neutrality will require drastic changes in the way how economic policy is designed and which role is attributed to innovation (Tuffs et al., 2020). In line with this development, traditional approaches regarding innovation a goal in itself rather than a tool to achieve larger goals are increasingly challenged. This can be particularly observed regarding the implementation of major challenges and social goals such as the Sustainable Development Goals (SDGs) (Dachs et al., 2015; Mazzucato and Penna, 2020). This perspective is prominently advocated in the demand for mission-orientation in innovation policy as a new theoretical and practical framing. Considering these different approaches to innovation and the increasing discussion of sustainability and innovation in an interlinked manner, it appears important to take a step back and outline the larger picture that the discussions are embedded in. Therefore, in the following, the historical development of innovation, its stages of different framings, and the overlaps to sustainable transition will be outlined and discussed consecutively.

1.2.1 Innovation in the Passage of Time

From a modern perspective, the crucial role of innovation as the origin of structural change and prosperity appears to be a matter of course. Since the planet has been changing constantly, and evolution has shaped the life forms inhabiting it, innovation has arguably escorted mankind since its first steps. However, the conceptualisation of innovation in academic theory is comparably young, particularly in economic theory. Classical economists such as Adam Smith, John Stuart Mill, Jean Baptiste Say, Alfred Marshall, or Karl Marx have been dealing with innovation but without framing the process as such (Fagerberg, 2005; Lundvall, 2007; Burr, 2014; Fagerberg et al., 2013). The first theorist to place innovation at the core of his research, and who is therefore regarded as the grandfather of modern innovation theory, is Joseph Alois Schumpeter. The Austrian economist identified innovation as the central mechanism explaining economic dynamism and thereby replaced the formerly static model of an economy with a dynamic one of permanent change. However, Schumpeter's idea of what the driving forces behind innovation might be, has been subject to change closely related to the academic career that Schumpeter competed (Fagerberg, 2005).

In his early days, Schumpeter placed the individual pioneering entrepreneur on a pedestal, praising his pursuit of innovation to identify and open new markets and create new enterprises. From this perspective, forceful individual action created a dynamism that spread to the rest of the economy as the innovator is followed by imitators copying the original innovation. The motivation to innovation thereby stems from the aspiration to exploit a temporary monopoly and the associated monopoly rent. This process of dissemination of the innovation then leads to a gradually decreasing profit and a new equilibrium. Despite the negative consequences of replacing old technologies and adjustment costs, the process itself is described as a form of creative destruction providing new products and more efficient technologies. This evolutionary theory has been developed in Schumpeter's "Theory of Economic Development" and has become known academically as Schumpeter Mark I (Schumpeter, 1911; Hanusch and Pyka, 2005; Lundvall, 2007; Tödtling and Trippl, 2018). In contrast, Schumpeter Mark II relates to the theories developed in "Capitalism, Socialism and Democracy" which was developed following Schumpeter's stay in Harvard. Here, the author updates the theory of the entrepreneur-initiated development in favour of an analysis of the role played by research and development conducted by experts cooperating in large industrial companies. However, the central idea of an economic system that is undergoing permanent changes and that there is no point in trying to conserve obsolescent industries prevails in Schumpeter's work (Schumpeter, 1943; Lundvall, 2007).

Generally, Schumpeter's research has exerted an enormous impact in economic theory. It was due to his effort that innovation was successfully introduced as the ultimate source of economic growth into economic theory. Although research effort began hesitantly after WW2, the understanding of innovation, its emergence, and its effects began to gradually evolve into a relevant research stream. Particularly the evolutionary theory of economic change was taken up by US scholars such as Richard Nelson, Kenneth Arrow, or Sidney Winter further elaborating on the relationship between R&D and innovation. In Britain, Christopher Freeman started his work of R&D activities of British firms which was later scaled up to an international scale commissioned by the OECD (Fagerberg et al., 2013). Particularly in Europe, Freeman played a key role in establishing modern innovation theory. Here, the interaction within and between organisations was identified as a key aspect for successful innovation, underlining that innovation is to be understood as an interactive process rather than a linear procedure of innovation. Rather than exclusively increasing R&D spending, the generation of innovation required interaction on several levels (Lundvall, 2007). Although subsequent research was not framed as Schumpeterian, the basic ideas have laid the foundation for new research streams. Up until the 21st century there are also efforts to promote a Neo-Schumpeterian research stream by further developing and adapting the theories to modern environments (Hanusch and Pyka, 2005; Gerybadze, 2014; Tödtling and Trippl, 2018).

Over time, however, the understanding of innovation has grown considerably and has increasingly recognised its complexity. In addition to the originally simple model of innovation, new factors were introduced and studied, including the role of cooperation, diversity, technology, or R&D. The study of their influence on the emergence of innovation has gradually broadened the theoretical approach (Bruland and Mowery, 2005). Particularly the conceptualisation of innovation in its broader environment rather than with an exclusive firm-centric focus has given rise to several research streams that will be covered in more detail below (Fagerberg et al., 2013). Thereby, the research on innovation is far from concluded. On the contrary, innovation policy has seen at least three major transformations over the last decades, according to Schot and Steinmueller (2018). The first framing emerged during the aftermath of WW2 and was shaped by an expanded role of the state when it came to scientific research, the government to address market failures, and a general optimism regarding science and technology for prosperity. The second framing of innovation arguably set in in the 1980s and referred to the idea of innovation systems and their significance for knowledge creation and learning. The linear model of innovation was critically examined, new aspects of innovation such as tacit knowledge and the character of technological change were included, and the number of actors to be included in the innovation process was expanded.

The third framing of innovation is currently emerging. This framing challenges the perception of innovation as a goal in itself in favour of an understanding of innovation as an instrument to achieve certain targets and address societal challenges. Moreover, the visibility of differentiated aspects of innovation, such as non-technological innovation, social, and user-driven innovation increases. The participatory aspect, that already emerged in previous framings, is emphasised, and has led to the inclusion of new groups of actors. Additionally, the originally strong focus on the Global North in innovation policy is party rejected when experimentation and a stronger inclusion of approaches in other communities comes into the focus (Schot and Steinmueller, 2018; Kattel and Mazzucato, 2018). Apart from the direction of innovation, also traditional assumptions on innovation are challenged. This includes the dominant focus on individual entrepreneurs as well as the understanding of the innovation process itself. These approaches and their underlying assumptions have led to an underinvestment in R&D, neglected the geographical role of innovation, and did not fully recognise the highly complex nature of innovation. Consequently, the role of the state has been influenced by these perspectives. Traditional innovation approaches have argued in favour of free markets and understood the primary responsibility of policymaking to fix market failures and abstain from intervention apart from that. Recently, the role attributed to the state as a coordinating instance increases as the free-market perspective comes under pressure from both political and academic side (Mazzucato, 2015; Dachs et al., 2015; Kattel and Mazzucato, 2018; Hekkert et al., 2019; Wittmann et al., 2020). Finally, the absolute quantitative rate of innovation, as measured for instance in patent statistics, is decreasing while, on the other hand, the quality and direction of innovation start to shape the discourse. Economic growth, as the result of innovative activity, is increasingly interpreted in terms of its dimension and contribution to overarching targets. While also the previous framings of innovation have recognised societal aspects, the third framing discusses contemporary social and environmental challenges no longer separately but as relevant aspects of innovation policy. The ongoing discussion of mission orientation in innovation policy is closely linked to this recent framing of innovation theory (Schot and Steinmueller, 2018; Kattel and Mazzucato, 2018; Wittmann et al., 2020).

1.2.2 Mission Orientation in Innovation Theory and Practice

In recent years, “missions” and “mission-orientation” have become new buzzword in policy debates (Hekkert et al., 2019). Thereby, mission-orientation is not a new approach in the political sphere and applied innovation policy. Theoretically, the concept borrows from Albert Hirshman’s idea of development through unbalanced growth. Practical approaches following a mission-oriented motivation have already been successfully applied at least since the 1950s. Probably the best-known example would be the Apollo “man on the moon” mission, as unveiled by John F. Kennedy in 1961. This mission, characterised by a geo-political as well as technological dimension, has facilitated a concentration of resources and a coordination of activities across several sectors towards the common goal of sending a human being to the moon (Mazzucato, 2018b; Mazzucato et al., 2019). However, the moonshot was not the only example of mission-oriented policy since most leading economies after WW2 applied comparable approaches. Although market-oriented reforms have made it more complicated to justify missions particularly in the 1970s, popular examples such as the Japanese ministry of international industry (MITI), or the creation of the Silicon Valley in the United States illustrate successful mission-orientation examples. All these examples share a common baseline of wide-ranging networks of different actors cooperating in favour of a common goal (Ergas, 1986; Kattel and Mazzucato, 2018).

However, mission-oriented policy has been subject to changes over time so that the features of old mission-oriented policy, among others a high degree of centralisation, centrally determined goals, and a risk averse behaviour no longer apply to modern policy. Recent approaches emphasise the freedom to experiment, decentralisation, and local decision processes. Afterall, modern policies strive for a balance between top-down directionality and bottom-up creativity (European Commission, 2017). Particularly two key elements of missions are highlighted, namely a coordination of public investments, and a market-shaping policy approach to “crowd in” private investments. As a result, mission orientation is expected to increase the effectiveness of innovation policy, improve strategic investments of public bodies, leverage synergies, and create a multiplier effect by leveraging private capital and create new markets for innovation (European Commission, 2017; Kattel and Mazzucato, 2018; Mazzucato and Penna, 2020). Particularly technological openness for different R&D and innovation projects rather than the preselection of a single approach is identified as a success factor of missions. In addition, the cooperation of different actors rather than researchers alone is emphasised. Arguably, successful missions require an acceptance of failure as an inevitable aspect of action under Knightian uncertainty, and a governance that leaves enough space for experimentation while being focused enough to not become faulty (Mazzucato, 2015; European Commission, 2017; Mazzucato, 2018a; Kuhlmann and Rip, 2018; Larrue, 2021).

In the current debate, the so-called grand challenges, ranging from threats such as climate change, to demographic change, or health-related issues, increase the need for coordinated systemic policy. Assuming that innovation and technology can play a key role in addressing these challenges, mission-orientation becomes a possibly suitable instrument to organise the efforts and harness the power of research and innovation (Mazzucato, 2018a; 2018b). Addressing climate change as a global threat under tightening time restrictions could therefore be a natural use case and several missions of the past have focused on environmental targets. Regarding traditional mission-oriented policies, four general types of missions have been identified, namely (1) science missions such as the moonshot program, (2) technological missions such as the Concorde, (3) transformative missions such as the German “Energiewende”, and (4) umbrella missions such as the German high-tech-strategy. Moreover, four types of new missions complement the picture, focusing on acceleration and transformation (Wittmann et al., 2020). All these different types can be relevant when it comes to addressing the grand challenge of climate change.

While mission-orientation has for a long time remained an instrument which was applied almost exclusively by large countries, the set of actors is becoming increasingly differentiated. Developing countries, for instance, display promising prerequisites for the application of mission-oriented policies due to the greater challenges they are confronted with. In this regard, Mazzucato and Penna (2020) regard mission-orientation as a probable instrument to lift the resource curse and enable less-developed countries to enter a sustainable development path. On country level, bottom-up social movements have been able to influence the directionality of research. This is exemplified by the German "Energiewende", the transition to renewable energy sources while phasing out nuclear power, which would not have happened without social movements pushing for sustainable energy policy. Large private philanthropies like the Gates Foundation have identified missions for themselves to focus their funding and engagement on. Multiple strategies and institutional practices are successfully applied in countries such as Canada, Japan, the Netherlands, Sweden, Ireland, or the United Kingdom. And finally, multilateral organisations such as the EU have identified missions as adequate starting points to reorient their policy (European Commission, 2017; Kleibrink et al., 2017; Kattel and Mazzucato, 2018; Wittmann et al., 2020; Breitinger et al., 2021; Angelis, 2021).

In Europe, the demand for more focused policies against the backdrop of societal challenges has been increasing since the 1990s (European Commission, 2017). The so-called Maastricht Memorandum already called for missions as well as the subsequent Lund Declarations (Lund Declaration, 2009; 2015). In 2006, the so-called Aho Group called for a mission-adequate environment, and in the following years, different groups and resolutions repeated that call. Finally, mission-orientation was chosen as a pattern for the design of the Horizon Europe framework programme (Mazzucato, 2018b; Schot and Steinmueller, 2018; Mazzucato et al., 2019; Larrue, 2021; Kruse and Wedemeier, 2023b). By doing so, one hopes to overcome the disadvantage of a too fragmented policy environment in the different European member states with a common set of missions which would enable to benefit from European economies of scale and increase efficiency (Kattel and Mazzucato, 2018). Afterall, the EU has named five major missions, including adaptation to climate change, the battle against cancer, the restoration of ocean and waters, reaching 100 climate-neutral and smart cities, as well as a soil deal for Europe (European Commission, 2021). It becomes clear that environmental sustainability dominates most of the EU missions underlining that the fight against climate change has become a policy priority. Although not all SDGs can be addressed by research and innovation, both make up a major part of the European strategy to tackle grand societal challenges (European Commission, 2017).

1.2.3 Innovation for a Green Transition

While the number of sustainability-related missions in the past is comparably high, one of the most prominent examples of successful implementation of mission-orientation for a sustainable transition is the so-called

Energiewende in Germany. This example, which has already been mentioned above, could act as a role model for further missions for the green transition in the future. As part of the Energiewende, the set of goals involved phasing out nuclear energy, transforming the energy system in favour of renewable energies, and reducing both greenhouse gas emissions and energy reliance while maintaining industrial competitiveness. To do so, an extensive transformation and the cooperation of sectors and technologies were required. What made the success of the Energiewende possible was arguably the formulation of a clear direction that investment and bottom-up research could focus on. Technological openness was assumed, failures were accepted, and spill-over effects could be noted in technological, social, and behavioural areas. Despite different perceptions, particularly in Germany, the Energiewende in general was an impressive success allowing the breakthrough of renewable energy in Germany and paving the way for an overarching transition (Kuittinen and Velte, 2018; Mazzucato, 2018a; Mazzucato et al., 2019).

As the Energiewende demonstrated, innovation can play a facilitating role when it comes to sustainability transitions. However, this individual example is only part of a larger picture of sustainability and environmental development. In recent years, the urgency to address climate change and push for a drastic reduction of greenhouse gas emissions has been increasing significantly. Since the 1970s, pioneering publications such as the Club of Rome's "limits to growth" or the Brundtland report have called for decisive political action to manage environmental resources, solve energy-related problems and address issues of environmental degradation (WCED, 1987; Meadows et al., 1972). However, for the longest time the scientific perspective has failed to successfully influence the political sphere which continued its previous path of economic growth without consideration of ecological consequences (Kates et al., 2001; Markard et al., 2012; Coenen et al., 2012). However, the newly forming consensus regarding a green economy is not fully motivated by sustainability considerations. While a green transition is sometimes regarded as a necessary shift towards an economy that respects the planetary boundaries, another perspective tends to accentuate the development aspect of the transition when pointing out the potential job creation and capital accumulation associated with a green economy (Doranova et al., 2012; Gibbs and O'Neill, 2017). There is an ongoing discussion whether sustainability requires a transformation of the existing economic system, or whether systemic change is inevitable. Particularly R&D and innovation appear Janus-faced in this discussion, on the one hand as the origin of economic development and the associated environmental downsides, on the other hand as a technical fix to said problems (Freeman, 1996; Kern and Smith, 2008; McCann and Soete, 2020; IIASA, 2020).

The blueprints presented by earlier examples highlight success conditions that can also help considering the current transition towards climate neutrality. In order to live up to the fundamental challenge of fighting climate change, a fundamental transformation of socio-technical systems in a short timeframe is required. It is questionable whether the current systemic conditions, which are still majorly impacted by their neglect of environmental externalities, a lack of price-based incentives to shift to green technologies, and ongoing investments in old and non-sustainable technologies, provide the suitable conditions for the required transition. The required transition therefore involves changes in different areas such as energy, mobility, communication, healthcare, or food and raises systemic concerns. Considering the sheer size of the challenge, the concept of mission-orientation could bear a helping hand as outlined above (Frenken, 2017; Tödtling and Trippl, 2018; Raven and Walrave, 2020; Hassink, 2020).

1.3 Regional Innovation from a Theoretical Perspective

It appears to be a modern universal truth to state that location matters. It is assumed as self-evident that regional development depends on knowledge networks and that spatial proximity is key to production and transmission of knowledge. In times of increasing interregional competition, location aspects decide on where new businesses are created, where transition takes place, and, ultimately, location aspects decide on regional success or failure (Asheim and Gertler, 2005; Coenen et al., 2012). Thereby, the relevance of location is a relatively modern finding. One of the first influential books in this regard was published by August Lösch in the 1930s whose arguments exercised a significant influence on several disciplines ranging from economic geography to regional studies. The framework that Lösch suggested not only covered industrial locations but also regional economic networks, trade, and financial aspects some of which later got rediscovered in spatial economics (Martin, 2015). Regional innovation studies offered a first explanation of real-world examples such as the observation that the industrial revolution occurred in England and spread particularly in North-Western Europe but developed differently among the European countries. These observations posed the question why certain areas were predestined for such an innovative transition while others were apparently skipped (Bruland and Mowery, 2005).

The premise of regional development here is that innovation and location cannot be separated from each other but mutually influence each other. Space, from this perspective, is not an exogenously given fact but a variable that can be influenced (Gordon, 1991; Crevoisier and Maillat, 1991; Shearmur et al., 2018). However, traditional approaches recognised the role of space but developed their theories independently of spatial and temporal contexts (Crevoisier, 2004). In classical location theory, space is primarily regarded in terms of transportation cost implying that producers will move close to their relevant markets under considerations of cost optimisation (Gordin, 1991). Moreover, traditional understandings of innovation applied a linear perspective considering innovation was a linear product of R&D input. Finding that innovation is much more complex and emerges from an interactive exchange between different actors therefore represented a kind of differentiation of innovation research that has split into several different research streams since (Asheim et al., 2018).

Searching for a new model of regional development set in when traditional regional policy plunged into a crisis of structural weaknesses and inequality after WW2. Following from these first initiatives, the 1980s saw several initiatives emerging independently to develop a more differentiated approach to innovation, considering regional factors such as learning, quality of production factors, human capital, culture, of infrastructure. The theoretical transformations are thereby closely related to theories such as the new economic geography, endogenous growth, and institutional economics (Moulaert and Sekia, 2003; Barca et al., 2012). These academic efforts address the concentration of economic activity in core regions, the continuous improvement of products and processes, as well as distribution and concentration of advanced economic activities particularly in metropolitan environments (Farole et al., 2011). Since knowledge spillovers do not travel easily across space, the spatial concentration of innovation and innovative capacity puts the regional and local level at the core of innovation policy (Pinheiro et al., 2022).

Considering the established theories of regional innovation, it appears as if the topic was limited to pre-globalisation times of national manufacturing. However, the relevance in times of a globalised knowledge economy is not only still existent but possibly even larger than before. Innovative activity is not randomly or uniformly distributed geographically and there appears to be a self-reinforcing mechanism between the knowledge intensity of an activity and its geographical clustering. Contrary to predictions, the age of communication technology has not led to a dispersal of innovative activity but underlined that spatial concentration still matters (Martin, 2001; Asheim and Gerler, 2005). The ability to generate and exploit knowledge spillovers has been identified as a distinguishing feature of successful regions (Foray, 2013). This finding is in line with considerable empirical evidence that efforts in innovation and capacity of regional economies to adapt to technological change correlate positively with economic development, can be associated with increases in economic growth, in exports and trade, productivity, income and output, and business profits (Solow, 1957; Romer, 1990; Landabaso, 1997). Although it was first believed that globalisation may reduce the importance of location and distance, it turned out that the conditions for innovation remain important and even increase in relevance.

When it comes to leverages for the promotion of innovativeness in administrative areas, particularly the promotion of interaction, cooperation, and the provision of a suitable institutional and cultural context have been highlighted (Ergas, 1986; Lundvall, 1992a). All these factors are positively influenced by proximity so that sub-national levels such as regions or municipalities come into play. Here, the diversity of actors is high enough for fruitful discourse and creativity to emerge and still the level of trust building on personal relationships is sufficiently large to enable cooperation (Bevilacqua et al., 2020; Di Cataldo et al., 2021). Moreover, regions constitute the most important administrative units when it comes to development policy in the EU and act as the primary implementation level for several policies. This is because regions in many cases combine legislative and regulatory power with a deep understanding of local conditions and stakeholder networks (Arsova et al., 2022).

As a result of the role attributed to innovation for regional development, regional policy is increasingly combined with innovation and technology policy. Building on this premise, different measures of innovation policy have been developed over the years, ranging from financial aid schemes for R&D, over technology transfer and technology parks, up to specific innovation strategies (Hassik, 2020). The diversity of regions, however, also requires a policy design that recognises different regional environments rather than applying a generic approach which is spatially blind (Tödtling and Trippl, 2005; Neto et al., 2018). Otherwise, the regional innovation paradox could be possibly replicated, stating that less-favoured regions benefit to a smaller degree from innovation policies due to a lack of absorptive capacity. Accordingly, a too generic policy runs the risk of increasing territorial disparity rather than reducing it (Oughton et al., 2002; Hassink, 2020). Figure 1 and 2 highlight exemplarily the different starting conditions in European regions looking at the distribution of GDP per capita (Figure 1), and regional research capabilities proxied by employment in technology and knowledge-intensive sectors (Figure 2). A core-periphery-pattern is clearly observable, both on European level and within countries. Governance of innovation, therefore, needs to acknowledge the complex innovation processes and take both a multi-level and a multi-scalar shape. Afterall, research on the geography of innovation has confirmed the crucial role that cities, regions, and spatial proximity play for innovation and regional prosperity (Coenen and Morgan, 2000).

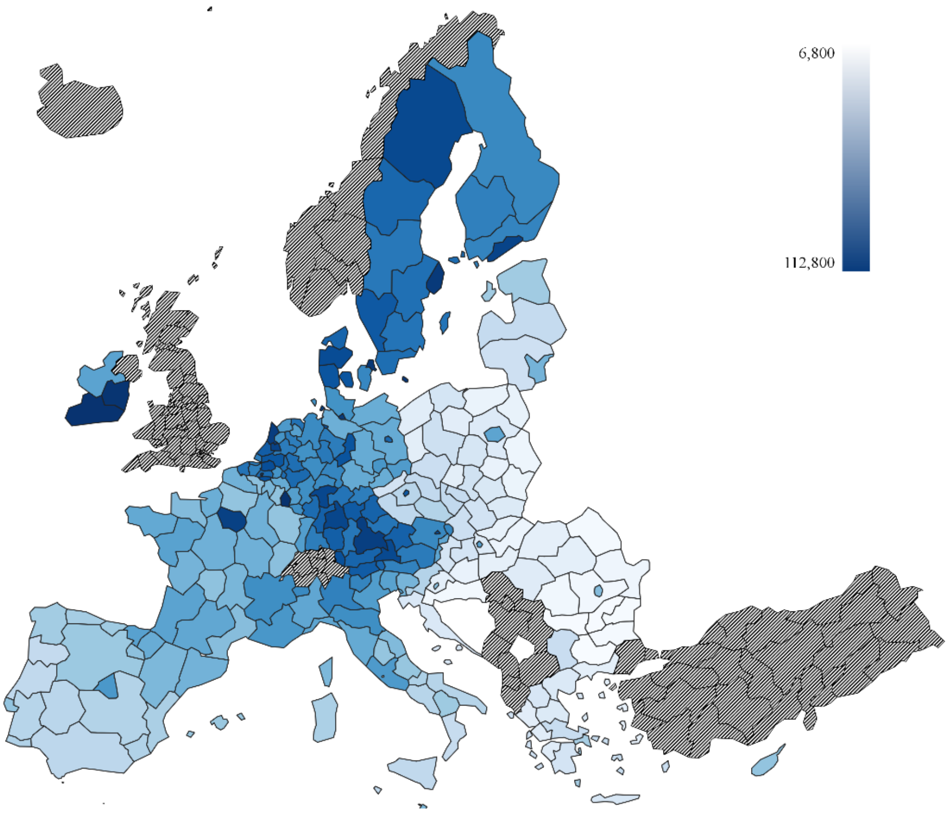

Figure 1: GDP per capita in European NUTS 2 regions, 2021
Data source: Eurostat (2022a)

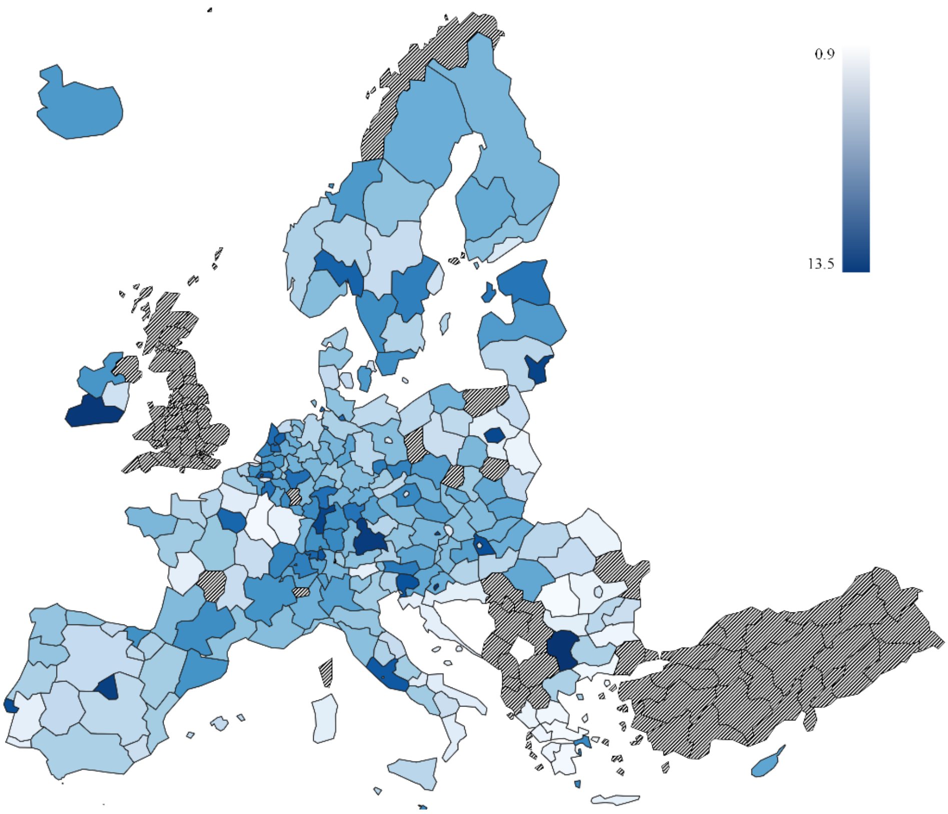

Figure 2: Percentage of employment in technology and knowledge-intensive sectors in European NUTS 2 regions, 2022
Data source: Eurostat (2022b)

Accordingly, the number of theories dealing with innovation and regional development is large and further increasing. Moreover, it is influenced by the zeitgeist, as well as the geographic and academic background of researchers. Because the questions asked were different, also the answers were different as a result, leading to the establishment of different theories over time. The different models of territorial innovation that have developed share a common origin and are therefore easily confused or used in a non-distinctive way. However, clusters, industrial districts, creative milieu, new economic geography, endogenous growth theory, new industrial spaces, creative regions, or local knowledge spillovers, to name a few, refer to different theoretical concepts with different developments, apply different emphases, and answer different questions (Moulaert and Sekia, 2003; Moulaert and Nussbaumer, 2005; Porter and Ketels, 2009; Potter and Watts, 2012; Fedeli et al., 2020). The next sections will carve out the specific characteristics of the individual research streams by outlining the most relevant theories and their development.

1.3.1 Industrial Districts

The history of the industrial district concept traces back to a British origin closely related to Alfred Marshall's agglomeration theory from 1890, and a more recent revival of the concept in post-war Italy. The initial question that led Marshall was why firms tend to agglomerate in geographical proximity (Raffaelli, 2009; Potter and Watts, 2012). On this basis, he identified industrial districts and regional agglomeration of related industries as an important factor to attract specialised workers, to acquire a higher level of specialisation, and to produce

goods of higher quality. These agglomeration economies, resulting from the co-location of similar plants and knowledge spillovers, are therefore identified as a chief cause of the flourishing manufacturing towns of that time. Also practically, factories tended to locate particularly in the outskirts of large towns which led to the formation of industrial districts. This observation emphasised that the origin of the industrial district concept was a practical observation rather than a theoretical development (Marshall, 1920; Potter and Watts, 2012).
This kind of practical observation of certain well-performing regions also explains the rediscovery of Marshall's work in post-WW2 Italy. The meantime had seen the descent of Marshall's economic theory when the research focus shifted and individual attempts to revive industrial district theories in the interwar period failed. However, the first Italian census in 1951 revealed the formation of four major aggregates of small manufacturing companies in certain regions which gave rise to a revival of Marshall's ideas. These regional agglomerations of co-located SMEs primarily focused on the manufacturing of mass goods for a soaring demand in Europe. Increasing competition provided those regions with an advantage that exhibited a strong division of labour along the production chain with multiple dynamic relationships between individual firms, cooperation, and competition, resulting in higher productivity and innovativeness. Naturally, this "economic miracle" in Italy was also due to other reasons such as low labour costs, entrepreneurialism, or good economic policy making. However, the proliferation of individual regions stood out. What from a modern perspective can be identified as the existence of industrial districts or regional clusters was not perceived as such at that time but inspired the Florence and the Modena school to rediscover and reinterpret the Marshallian theory. Particularly the interdisciplinary approach of these schools, striving to connect economy and social aspects of cooperation, brought new life to the research stream that had almost drained before (Beccattini, 2002; Moulaert and Sekia, 2003; Beccattini and Coltori, 2006; Raffaelli, 2009; Porter and Ketels, 2009).

One of the major findings of industrial district research was that location represents not only a geographical area, but that represents a space which is changing and influencing economic activity. Districts therefore have both a material and tangible dimension of enterprises and workers, as well as a scarcely visible dimension of informal knowledge (Guenzi, 2009; Porter and Ketels, 2009). It was found that industrial districts combine certain characteristics that provide favourable conditions for the generation, diffusion, and application of new knowledge. Differentiation and specialisation allow firms to focus on those activities they are particularly competent in, and the proximity of related industries allows for exchanging tacit knowledge via informal relations. After all, industrial districts encourage all dimensions of embeddedness, namely territorial, social, and network embeddedness. However, high levels of specialisation can also limit the ability to change technological trajectories so that too much proximity in industrial districts may not be beneficial but problematic when it leads to inflexibility during structural changes (Robertson et al., 2009). Changing demand cultures and cultural trends in general can undermine the district's competitive edge so that regional prosperity is not a guarantee for the future and a lack of flexibility can still lead to regional descent (Beccatini and Coltori, 2006).

1.3.2 Innovative Milieus

The concept of innovative milieus represents an important approach for the analysis of spatial economics and regional innovation performance. The concept was developed and academically institutionalised in the 1980s, closely related to the research conducted by GREMI ("Groupe de recherche européen sur les milieux innovateurs", or the "European Research Group into Innovative Milieu"). Since 1985, several research teams have grouped around GREMI for a new theorisation of economic space and territorial relationships considering innovative milieus. Building upon previous research on regional innovation, such as district areas or the roots of regional economic success, GREMI addressed the black box of innovative milieus to answer the question why some regions were more dynamic than others. The research group's findings revealed that territorial environments strongly influence innovation networks. This applies to urban systems as well as to regional, national, and community organisations. The success of GREMI led to the formation of several successor projects such as GREMI II which focused on the analysis of linkages between local territorial networks, firms, and their international environment to describe further variables influencing the innovation process. Later, GREMI III placed an emphasis on innovative networks and their functions, while GREMI IV focused on comparing regional trajectories which were active in identical sectors but underwent different types of evolution. Each new perspective shed a new light on the previous black box of regional innovation and led to the conceptualisation of the concept of innovative milieus (Perrin, 1991; Camagni, 1991a; 1991b; Crevoisier, 2004).

Innovative milieu research institutionalises that space significantly influences economic development and is also shaped by it vice versa. A milieu thereby represents a regional network of (informal) social relationships in a given geographical area allowing to enhance local innovative capability. This is due to the success factors of development being positively influenced by spatial proximity, e.g., in terms of reduced transaction costs or the presence of external economies or "district economies" leading to a reduced cost disadvantage for small firms. Proximity also creates a certain sense of belonging, creating an atmosphere of trust that can facilitate synergetic and collective learning processes and can become a generator of creativity and technological innovation. An innovative milieu therefore can improve the innovative capability of the protagonist organisations within the network, create a coherent production system, and provide them with a competitive advantage when it comes to changes in their environment (Camagni, 1991a; Crevoisier and Maillat, 1991; Moulaert and Sekia, 2003; Crevoisier, 2004).

1.3.3 Clusters of Innovation

The term of clusters is generally attributed to Michael Porter who developed the concept in the 1990s. Porter showed that the geographical concentration of production could explain competitive advantages by analysing a large corpus of trade data and product clusters (Beccattini, 2002). Clusters thereby are not a new phenomenon but simply a term for geographic concentrations of trade and production in certain industries which has been noted for centuries, and which have been discussed under different names, and with different emphases. It was clusters, that Porter identified as the central feature of economies' competitive success in particular fields due to knowledge, relationships, and motivation as distinguishing features of certain clusters that distant rivals could not match. Despite globalisation, regional agglomeration appeared to not only be a factor for manufacturing in the past, e.g., in terms of industrial districts, but also of relevance for knowledge-based economies of the present and the future. This perspective is mainly attributed to the fact that competition and its influence on a firm's productivity increases relatively in advanced economies. Clusters thereby influence competition by increasing productivity, driving both direction and pace of innovation, and by stimulating new business formation which further strengthens the cluster (Porter, 1998; 2000; Porter and Ketels, 2009; Doranova et al., 2012; Polverari, 2016; Balland et al., 2018; Shearmur et al., 2018).

Generally, clusters are defined by geographical agglomerations of the different actors in a particular field, including companies, specialised suppliers, service providers, firms in related industries, or associated institutions, which are interconnected by externalities and complementarities. The key dimensions of a cluster include a geographic, an activity, and a business environment dimension. These relate to externalities arising from proximity (geographic dimension), encompassed activity between companies in different industries but interconnected with each other (activity dimension), and cluster-specific conditions arising from individual and collective action (business environment dimension). Clusters provide easier access to information which can raise productivity. Moreover, clusters facilitate complementarities and improve specialisation, which can simplify the access to institutions and public goods and help to solve agency problems arising in more isolated locations. Finally, clusters produce positive effects on innovation and new business formation. By doing so, clusters combine push and pull factors for a qualified workforce and allow for the realisation of scale effects. However, clusters are not uniformly following the same model but can develop from different conditions, are shaped by their specific environment, and exist in different multitudes of configurations. Efforts to artificially create clusters or to copy successful examples have been noticed to fail when the underlying drivers of cluster competitiveness are not adequately addressed. In case of success, however, clusters represent dynamically changing entities and can enter a self-reinforcing cycle of promoting growth (Porter, 1998; 2000; Porter and Ketels, 2009).

There are several similarities between the different theories of regional innovation and localised systems. Particularly clusters and industrial districts are commonly named in the same breath. Thereby, they share a coherent reference to Marshall's theories and share an overlapping focus, but they still analyse different phenomena and answer different questions. For instance, clusters represent a much broader and more general concept while industrial district theory places a stronger emphasis on examining mechanisms that underpin regional agglomerations. From a theoretical perspective, industrial districts are a specific kind of a cluster (Moulaert and Sekia, 2003; Porter and Ketels, 2009). However, clusters remain a concept that is regularly applied in modern theory and policy practice. For instance, the European Cluster Memorandum refers to clusters as an environment conductive to innovation and as enablers for open innovation and new ideas in cooperation networks (Sölvell et al., 2009).

1.3.4 Innovation Systems

Innovation, from a modern point of view, is recognised to be a complex process of interaction that requires different kinds of actors, networks, institutions, and technologies. This perspective represents the outcome of decades of innovation research and rejects the traditional understanding of innovation as a linear process. The linear model revealed several analytical gaps such as the absorption capacity of firms, or behavioural characteristics. Modern innovation theories address these gaps by highlighting the cooperative, systemic, and synergetic nature of innovation. Innovation is therefore not generated by firms or individual entrepreneurs in isolation, as stated by Schumpeter MARK I, but is regarded from an evolutionary perspective as a creative process (Moulaert and Sekia, 2003). This also has implications for the policy focus which must go beyond increasing R&D spendings or correcting market failures but needs to focus on the facilitation of networks to allow for an interplay of different elements (Tödtling and Trippl, 2005; Bergek et al., 2008; Asheim et al., 2018). Two research streams prominently address the socio-technical nature of innovation and the networks associated to it: innovation systems and the multi-level perspective (MLP). MLP particularly focuses on regimes defined as a complex of factors such as regulation, technologies, scientific knowledge, or user needs. The concept looks at shifts in these regimes by analysing processes at different levels (Coenen and Truffer, 2012; Coenen et al., 2012). However, because innovation system theory has been more successful in making its way into policy designs, the focus below will be on this concept although certain overlaps to MLP cannot be avoided altogether.

Innovation systems distinguish themselves from antecedents like industrial districts or clusters and represent a superordinate theory on their own. While clusters as a concept include industrial districts, innovation systems can involve one or more clusters. Innovation system research emerged simultaneously with the rediscovery of the industrial district research stream in the 1980s, both referring to the theoretical origins of Marshall and the systemic perspective of territorial innovation (Asheim et al., 2011; 2018). On this basis, innovation system research assumes that also knowledge, and not only industries, is facilitated in networks and tends to be concentrated in a certain area (Hidalgo et al., 2018). The breakthrough of the concept of innovation systems could be noticed about a decade after it was initially presented when innovation system research emerged to be a common analytical tool in international organisations such as the OECD and UNCTAD, as well as in a number of countries (Lundvall, 2002; Lundvall et al., 2002). Increasingly, also other academic disciplines adopt the study of spatial dimensions of networks in innovation processes (Boschma and Frenken, 2010).

The first widely diffused publications on innovation systems focused on the national level and emerged in the 1980s. These publications were the product of a growing interest on why national growth rates tended to differ and an according shift to research systems as a possible answer based on empirical findings. The most influential publications in this regard were an analysis of a national innovation system (NIS) in Japan presented by Christopher Freeman, a comparison of technology policy and institutions in the USA, Japan, and Europe, presented by Richard R. Nelson, as well as a publication introducing the term of "innovation systems" by Bengt-Åke Lundvall analysing relationships and interaction between R&D organisations and the production system. Thereby, Freeman refers particularly to Friedrich List (1841/2008) and his concept of "national systems of production" that focused on the role of a set of different institutions and networks to create regional prosperity (Freeman, 1995). This reference to List, sometimes complemented by referrals to Adam Smith and other classical economists, underlines that the concept of national innovation systems is new in design but benefits from roots that date back long in time (Lundvall, 1985; 1992c; 2002; 2007; Lundvall et al., 2002). The research on NIS revealed that the differences in innovative capability between countries are associated to differences in attributes such as economic structure, R&D base, or institutional set-up (Tödtling and Trippl, 2005).

Apart from a national perspective, the innovation system concept has also been successfully applied at other administrative levels. The most famous application is probably the regional innovation system (RIS) literature which analyses how different actors and institutions cooperate with each other (Mazzucato, 2018a). The different groups of relevant innovation actors on a regional level are subsumed under the quadruple helix concept (industry, university, government, civil society), underlining that innovation requires the combination of different agents' resources which are interdependent and might not be as successful acting in isolation. Thereby, the contribution of the different actors is not equal, but studies imply that advanced innovator regions notice a stronger role of industry and civil society as innovation pullers while medium innovator regions see an even lower contribution of government and universities (Afonso et al., 2012; Parveen et al., 2015; Cavallini et al., 2016; Tödtling et al., 2021). Conceptually, RIS overlap with other concepts like clusters and are frequently confused. Here, it needs to be clarified that RIS represent a wider concept including usually more than one cluster in one RIS. Moreover, the theoretical aspect of RIS is more elaborated compared to cluster analyses (Tödtling and Trippl, 2005; Asheim et al., 2011).

Interest in RIS has been growing steadily over the last decades, motivated by advances in theoretical analyses, the suitable framework that regions provide for innovation, and a growing interest in innovation as a potential instrument to address regional inequality (Asheim et al., 2011). The differences between regions become particularly visible when analysing the innovative capacity. This perspective reveals a clear advantage of larger agglomerations, while lower R&D intensity, lower share of patents, and an overall lower innovative capacity tend to be concentrated in peripheral regions. Since innovation is assumed to be an instrument to facilitate regional development, the uneven distribution would imply a continuation of regional disparities (Tödtling and Trippl, 2005). On this basis, the RIS concept has been established as an approach to understand new knowledge creation and its economic exploitation for the benefit of particularly less-developed regions (Asheim et al., 2011). The specific role of RIS in this regard is related to the fact that regions differ in their preconditions, characteristics, and opportunities for structural change so that innovation policies need to adapt regionally (Tödtling and Trippl, 2018). Depending on individual regions, also the kind of RIS differs. Old industrial regions face different challenges than service-oriented regions, while regions with a monothematic economic structure perform differently than regions with several strong clusters covering several sectors (Isaksen and Trippl, 2014).

The focus on the regional level in innovation system research is also due to the increasing role of knowledge in the modern economy. Since knowledge is partly tacit and thus difficult to transfer over distance, shorter distances make cooperation easier due to the facilitation of personal contacts to build trust. Regional innovation systems therefore have a certain advantage over national level approaches when it comes to their explanatory value. Apart from that, RIS attribute a more important role to informal institutions than NIS while both share the understanding of innovation policy as a central instrument to shape regional innovation conditions (Tödtling and Trippl, 2005; Asheim et al., 2018). The crucial aspect of proximity for collective learning processes, however, is facilitated on a regional level (Moulaert and Sekia, 2003). The basic shortcoming of NIS, namely the difference between regional characteristics and the non-applicability of a one-size-fits-all-approach, represent a major contribution by the RIS concept which recognises regional specifics (Oughton et al., 2002). This is one of the reasons why the RIS concept emerged in the 1990s as a continuation and differentiation of previous territorial innovation models such as NIS. Since regions are often the playground for innovation taking place and since both policies and administrative competences address the regional level, RIS have established as a viable concept (Tödtling and Trippl, 2005; 2018).

Considering the role of knowledge flows and cooperation, regional boundaries can represent obstacles to the exchange of ideas and expertise and therefore hamper the facilitation of innovation (Lundvall, 1992b; Trippl, 2008). Answers to this finding include the scaling up of innovation systems, for instance to global innovation systems (GIS), technological innovation systems (TIS), or an analysis of cross-border cooperation between RIS (Coenen et al., 2012; Gosens et al., 2014; McCann and Ortega-Argilés, 2015; Stuck et al., 2016; Binz and Truffer, 2017; Tödtling and Trippl, 2018). In this regard, concepts like cross-border regional innovation systems (CBRIS) come into play focusing on closely connected cross-border regions. The basic idea here assumes that a larger knowledge pool improves innovativeness and inhibits the potential to exploit synergies. Widening the RIS perspective addresses criticism on the RIS concept to too limited in its conception of space (Coenen and Morgan, 2020; Cappellano et al., 2022). Chapter 3 will further elaborate on this topic.

Another point of criticism regarding RIS is based on new developments in research and innovation that challenge traditional concepts of both innovation in general and innovation systems in particular. These new developments include an increasing relevance of service innovation, digitalisation, and virtualisation as well as shortcomings such as a strong focus on highly successful regions and a lack of flexibility (Tödtling and Trippl, 2018). Moreover, an overall trend is noticeable that regards innovation as an instrument to address societal challenges which also influences the debate on reforming RIS (Tuffs et al., 2020; Molas-Gallart et al., 2021). In this regard, the critical rethinking of regional innovation leads to the approach of mission-orientation for transformational innovation aiming for solving specific challenges. Incorporating these new perspectives into the concept of RIS has the potential of addressing weaknesses of traditional RIS, such as a lack of strategic orientation and policy coordination (Foray et al., 2012; Tödtling and Trippl, 2018; Tödtling et al., 2021; Larrue, 2021). Under the assumption that mission-oriented innovation policy can be more effective at regional and local level, RIS concepts emerge as potential leverage points (McCann and Soete, 2020). This is due to the fact that innovation systems focus on the involvement of all relevant actors and their interaction. This approach is shared by mission-oriented approaches which have their own specific structure of governance and are sometimes framed as “mini-systems of innovation” (Larrue, 2021).

Accordingly, an extension of RIS is proposed academically, framed as “challenge-oriented RIS” (CoRIS) which include a more differentiated view on innovation and directionality and expand the perspective also to national, European, and global scales in terms of knowledge exchange (Tödtling et al., 2021; Isaksen et al., 2021). A similar approach is labelled as “dedicated innovation systems” that highlight transformation as the primary target of innovation and underline sustainability as the direction (Pyka, 2017). Almost the same model has been presented as “mission-oriented innovation systems (MIS)” focusing on the network aspect of innovation systems to implement a certain societal mission (Hekkert et al., 2019). As the possibly largest societal challenge, the green transition has also found its way in RIS theory recognising that green innovations are more likely to develop in innovative regions with working RIS (Hübner et al., 2000; Cooke, 2010; Chapple et al., 2011; Corradini, 2019). The same expansion is discussed for cross-border innovation systems to focus on sustainability (Korhonen et al., 2021). Chapter 2 will dive deeper into refocusing RIS in the context of new challenges.

1.3.5 Regional Innovation and the Green Transition

Regarding the practical implementation of a transformative change, geographical and administrative levels will be at the core with a particularly important role played by the regional level. Although the climate crisis represents a global phenomenon and emissions do not recognise national or regional boundaries, regions combine the administrative capability and the economic conditions to generate, practically implement and diffuse environmental innovations (Losacker et al., 2021). These initial conditions are also considered to be promising from an academic point of view, as an opportunity for further cross-fertilisation between innovation theory and economic geography (Grillitsch and Hansen, 2019). However, the opportunities of regional innovation policy and green transition remain underexplored despite initial approaches in individual regions and individual projects. Particularly the regionally different effects of eco-innovation, differing regional preconditions and economic specialisations, and questions of disparities being overcome or even increased as a consequence of the transition process, present open research questions (Bours et al., 2022; Hassink et al., 2021; Bugge et al., 2022; Moreno-Ocampo-Corrales, 2022).

When it comes to suitable preconditions to develop regional specialisations in green technologies, a research stream has evolved around the notion of technological relatedness, related variety, diversification, and technological complexity. This research is based on the notion of path dependency and the important role played by the already existing knowledge base in a region determining the possible acquisition of new specialisations for instance in green technologies. Research on regional economic diversification has been evolving since the 1980s revolving around the questions which regions tend to diversify their economic structure and how this knowledge might be applied to facilitate structural change also in other regions (Farhauer and Kröll, 2012; Iacobucci, 2012; Isaksen and Trippl, 2014; Boschma, 2017; Corradini, 2019; Boschma et al., 2020; Deegan et al., 2021; Rigby et al., 2022). Following from this research, the role of existing capabilities is confirmed which led to the assumption that regions with an existing specialisation in complex technological, particularly central and urban regions with a high income, have it easier to strengthen their specialisation and improve their fit to major challenges, while regions with a more basic economic specialisation, particularly peripheral and rural regions with a comparably low income, are disproportionally challenged to adapt to current challenges (Hidalgo and Hausmann, 2009; Hidalgo et al., 2018; Balland et al., 2019; Davies and Maré, 2019; Perruchas et al., 2020; Pinheiro et al., 2022). This relation can be understood as an example of the "innovation paradox" stating that already prospering regions have it easier to flourish (Oughton et al., 2002).

Looking at green specialisation in regions, the same relationship can be observed. Environmental technologies are considered complex and often highly innovative, so they are not uniformly distributed across regions and regions are disproportionally equipped to deal with the upcoming green transition. It has been subject to academic research which factors determine successful regions that are able to adapt successfully and develop green specialisations. An additional contribution to this entity of research will be provided in chapter 5 of this thesis when different factors determining green specialisations in European regions are econometrically analysed. While structural factors such as GDP, population size, or technological specialisations explain parts of newly developing green specialisations, also regions with different starting conditions must not be neglected. A transformative path is required for all types of regions that recognises their existing capabilities and allows for technological upgrading for the purpose of long-term economic prosperity (McCann and Ortega-Argilés, 2016b; Corradini, 2019; Xiao et al., 2018; Santoalha and Boschma, 2020; Deegan et al., 2021). Although the current economic reality is shaped by a dominant role of cities and urban regions outperforming less-developed regions in terms of innovation, empirical results indicate that the pursuit of sustainable structural change can be successfully accomplished even in regions that have been dominated by fossil fuel technologies (Landabaso, 1997; Provenzano et al., 2020; Van den Berge et al., 2020). In this context, the instrument of smart specialisation has become particularly relevant as a tool of regional innovation policy in Europe and will be looked deeper into further below (Santoalha, 2019; Balland and Boschma, 2021).

1.4 The Instrument of Smart Specialisation

European innovation policy has undergone significant transformations over the last decades when it comes to its logic, nature, and implementation (Fedeli et al., 2020). Thereby, the constitution of a common European policy has been a process in itself and the current set of different policy approaches, particularly for the purposes of innovation and cohesion within regions, is the result of said process. Probably the most important instrument in this regard smart specialisation, a concept building upon regional innovation system literature and influences from several other research streams. To get an idea about the concept, its targets, strengths and weaknesses, and current discussions in relation to green transition, it is necessary to dive into the development of European policy in general and the establishment of smart specialisation over time in particular. Since a uniform policy for the whole EU has not been in place from the beginning, the steps of continuous development tell important details when it comes to an assessment and classification of today's policies.

1.4.1 A long Way of European Innovation Policy

Beginning in the 1960s, the Council of Europe has been increasingly facilitating cross-border cooperation with the primary target of diffusing democracy and improving relations between European countries. Still, it took until the 1970s to form different legal frameworks and associations. Shortly afterwards, the first Euro-regions emerged at the Dutch-German border, Lake Constance, Rhine valley, Benelux area, and Scandinavian countries. In the aftermath, a set of financial instruments were designed in order to promote cooperation between regions (De Sousa, 2013). The cross-border aspect of cooperation has been steadily increasing also in recent years considering the importance of creating an integrated innovation space to compete in a globalised knowledge economy (Lundquist and Trippl, 2009). The aspirations for a common European approach are similar when it comes to cohesion, a European research area, or a common innovation policy (Marimon et al., 2008). However, the policies to achieve these targets thereby have been subject to change over time.

The origins of an independent innovation and cohesion policy in Europe can be traced back to the 1990s. Thereby, the motivation for a stronger role of the European Commission as a central administrative and political unit could be found in a reform of the structural funds in the 1980s which involved a shift towards endogenous development and innovation. Since that reform, the principle of cohesion and socio-economic convergence between less-developed and higher-developed regions has been promoted to one of the key principles of European policy and can be named as the formal initiation of European cohesion policy (Farole et al., 2011; Charles et al., 2012; Hassink and Gong, 2019). Over the following years, the policy has undergone several metamorphoses related to the different programming periods that focused on different themes and promoted different targets (Medeiros, 2017). However, in 1996 a summit of the European Council asked the Commission to develop an action plan to facilitate innovation for growth and employment which then became the first action plan for innovation in Europe and the basis for all plans to follow (Fujimoto and Lecler, 2012).

Nevertheless, the priority attributed to cohesion as the primary target of common European policy prevailed until the 2000s. Here, a phase set in that focused more on growth and employment as paradigms and innovation as an instrument. A critical assessment of previous policy schemes revealed that innovation policy tended to further increase the technology gap within Europe by supporting innovative regions and neglecting weaker regions. This led to the formation of a few geographical concentrations of R&D while most regions stagnated or even declined. This analytical background is closely related to the development of the "Lisbon Strategy" (initially launched in 2000, renewed in 2005, lasting until 2010) that became famous with its target of making the EU the most advanced and competitive knowledge economy in the world by 2010. Generally, the European economy was rather healthy when the Lisbon Strategy was developed but structural weaknesses of the economy started to manifest. For instance, unemployment rates remained at a high level and the productivity gap in comparison to competitors like Japan or the US tended to increase. To address these disadvantages, it was envisaged to channel 3% of GDP to R&D and implement several support programs at European level (Landabaso, 1997; Fujimoto and Lecler, 2012; European Commission, 2014; Medeiros, 2017). These quantitative targets, however, were never achieved. Moreover, the levels of inter-regional disparity in Europe continued to increase regardless of cohesion policy approaches which led to a certain level of scepticism regarding the impact of the Lisbon Strategy. Although the strategy was redesigned in 2005, in retrospective the Lisbon Strategy is generally regarded as a failed strategy. It did not succeed in reducing the European productivity gap, failed to leverage private R&D investments, and could not overcome the fragmented nature of research and innovation in Europe (Farole et al., 2011; Capron, 2012; European Commission, 2017; Fedeli et al., 2020).

The learnings from the Lisbon Strategy boosted the development of a new European strategy that became known as the "Europe 2020" strategy and was presented in 2010. Here, the three goals of smart, sustainable, and inclusive growth were highlighted as levers to improve the EU's competitiveness while strengthening its model of a social market economy (Doranova et al., 2012; European Commission, 2014; Medeiros, 2017). The strategy was developed in the context of a more troubled economic environment, namely the financial crisis of 2008/09, an increasing pace of globalisation, and a rapidly deteriorating economic and social environment. An important impetus for strategy development was provided by the Barca report published in 2009. This pioneering publication, commissioned by the European institutions, analysed the structural reasons for Europe's failure to capitalise on its innovative and research-related potential. According to the report, overcoming the weaknesses of the past would require a new strategic design for a more efficient distribution of funding and the generation of more tangible results. Particularly the fragmented nature of policy frameworks and investments were identified as barriers for structural change preventing the creation of a Europe-wide critical mass in commonly agreed priorities (European Commission, 2007; Barca, 2009; McCann and Soete, 2020).

Accordingly, a place-based approach was recommended to incorporate regional characteristics and empower regional strengths to provide a more efficient distribution of resources and overcome the previous supply-side fragmentation. This also involved a stronger role being attributed to sub-national administrative units such as regional and urban levels, as well as the involvement of the various actors and stakeholders at these levels. This approach was based on the recognition that territorial cohesion constituted a process that required not only the involvement but also the cooperation of different levels in order to be successful. Thereby, the risks of such as strategy, namely risks of misallocating resources, the creation of a dependency culture, or favouring rent seeking behaviour over innovation, have been clearly outlined. As a consequence of the Barca report, the European cohesion policy turned to a place-based approach which it has been promoting since. Moreover, a new policy instrument was introduced as a conditionality which later became famous as "smart specialisation" and which will be presented in further detail below (Barca, 2009; Atkinson, 2015; Larosse et al., 2020; McCann and Soete, 2020; Berkowitz, 2020). It was also this context that the "Innovation Union" flagship initiative emerged from. This initiative was introduced in 2010 at the beginning of the Europe 2020 phase and aimed at the realisation of EU-wide economies of scale particularly in knowledge-intensive and high-tech sectors. Regional policy in the scope of Europe 2020 is primarily understood as an instrument to unlock growth potentials by facilitating innovation in all regions (European Commission, 2010b; McCann and Ortega-Argilés, 2015; Fedeli et al., 2020; Larosse et al., 2020).

Today, cohesion policy expenditure accounts for about a third of the annual EU budget although the results in terms of territorial cohesion between regions have remained limited. It appears as if Europe adopted a "convergence club" development pattern with regions sharing similar structural characteristics following a convergence path while widening disparities are observable between regions with different structural capacities (Farole et al., 2011; Schulz, 2019). Particularly peripheral regions are still less able to benefit from economic development opportunities arising from technological innovation. The structural disadvantages in comparison to core regions, among others spatial concentration of innovative capacity, limited resources and institutional capacity, and unfavourable economic specialisations, prevail. Investment and policy efforts remain to be fragmented although improvements are observable (Camagni and Capello, 2013; Medeiros, 2017; Bevilacqua et al., 2020; Larosse et al., 2020)

In addition, the focus of cohesion policy has been shifting again in recent years due to the increasing pressure exerted by external challenges and development trends such as the digital transition, health topics, space and defence, or the green transition (Berkowitz, 2020; Oppido et al., 2020; European Commission, 2022). Thereby, the relevance of adapting to climate change and facilitating a low-carbon economy has already been highlighted about a decade ago. Its particular significance for cohesion policy in recent years arises from the assumption that, although climate change represents a global phenomenon, its impact is regionally differentiated. Moreover, the capacities of individual regions in light of a sustainable transition are different. Particularly less-developed regions in Eastern Europe require support to stabilise socio-economic processes and facilitate the relevant processes of a transition towards sustainability (Pîrvu et al., 2019). This melange increases the importance of cohesion policy and provides it with a new target dimension of sustainability as was already proposed by Barca (2009) and outlined by the European Commission (2007), which underlines the crucial role of interregional cooperation in this regard.

Already the Europe 2020 strategy from 2010 included an explicit environmental dimension complemented with quantitative targets related to energy efficiency, emission reduction, and resource efficiency on a way towards resource efficiency and climate neutrality. This novel focus was based on an economic analysis that found increasing pressure on resource prices, a lack of security of supply and price volatility, as well as a deteriorating environmental quality across Europe. Regarding the desired development path towards sustainability, the relevance of technology and innovation was highlighted with the goal to increase economic resilience to climate risks, the upscaling of clean and efficient energy, and improved resource efficiency. Moreover, additional targets in the areas of employment, research and development, education, and the fight against poverty were defined. Accordingly, sustainability and the aspiration to become climate-neutral until the mid of the century have been implemented as parts of the long-term policy agenda of the European Commission. Here, it is agreed upon that Europe should become a leading force in the transition to a healthy planet, the digital economy, and sustainable development (European Commission, 2010a; 2014). However, it should be noted that sustainability and a green economy are regarded primarily from an economic point of view rather than from an ecological motivation (McCann and Soete, 2020).

Generally, the Europe 2020 strategy was a frontrunner when it came to presenting a growth model that went beyond an exclusive focus on GDP maximisation (European Commission, 2014). Recently, this already promising approach in terms of environmental sustainability in European policy was strengthened and deepened following the introduction of the EU Green Deal (EGD). This policy strategy, which was presented in 2019, aims to transform the European economy towards climate neutrality aims for the realisation of economic growth decoupled from resource. Assuming that environmental sustainability has been a motivation in previous EU policies, the EGD has finally institutionalised sustainability as the core and raison d'être of a European policy. The EGD combines the fight against climate change with a multitude of other challenges, such as improving economic resilience, increasing pressure on resources, an ageing population, relatively low growth levels, and interregional disparities. In this regard, the EGD can be considered an umbrella strategy to subsume different targets under the premise of green transition whereby innovation is regarded as the primary lever to achieve these targets (Gulc, 2015; European Commission, 2017; 2020; Berkowitz, 2020; Bevilacqua et al., 2020).

1.4.2 Theoretical Foundations of Smart Specialisation

It was already mentioned above that smart specialisation has become one of the key instruments for innovation and cohesion policy in Europe. Smart specialisation, or "regional innovation strategies for smart specialisation (RIS3)", has been argued to be the "largest policy experiment in the world" (Radosevic and Ciampi Stancova, 2015: 263) and has shaped innovation policy in Europe for over a decade. The concept basically emerged from two different streams of discussion, namely an academic discussion focussing on how to adapt and upgrade RIS concepts to address the European challenges, and a political discussion on how to change European policy to better fulfil its policy targets. Much of what smart specialisation is, what it strives to do, and which inconsistencies exist, can be explained by its development as well as the inclusion of different perspectives and targets via various reforms and updates over time.

The growing productivity gap between Europe and its main competitors, particularly the United States, became an increasingly discussed topic during the 1990s and the early 2000s. It was found that the different speed of productivity development, to the disadvantage of the European economy, could be explained by a lack of innovative and entrepreneurial dynamism, also leading to economic growth differences (Rusu, 2013; Janik et al., 2020; Mazzucato, 2018a). The policy implications following from this analysis included improving the R&D basis in Europe to prevent losing R&D-oriented companies (Mora et al., 2019). Accordingly, the debate on reforming EU cohesion policy was extended by the question how to address the innovation-related shortcomings via political instruments (McCann et al., 2015). Against this background, it was found that European policy largely suffered from being too general and inadequate regarding regional specifics (Janik et al., 2020). Until that point, specialisation in European regions mainly followed the same pattern of spreading investment thinly across several technologies or copying seemingly successful examples without paying sufficient attention to regional capabilities (Foray et al., 2011; Balland et al., 2019; Gianelle et al., 2020a). As a consequence, less-developed regions did not benefit from cohesion and innovation policy measures as intended so that the overall innovative potential was not exploited, and the cohesion aspect of bridging development differenced was not met either.

The shortcomings of R&D policy in Europe led to the establishment of an expert group that became known as the "knowledge for growth (K4G)" group. The group consisted of innovation economists, macroeconomists, and econometricians and had the task of providing advice to refocus European cohesion policy. The group's activities were completed in 2009 and the recommendations soon entered the policy discussion on European level (Foray, 2009; 2019; Rusu, 2013; Mora et al., 2019; Esparza-Masana, 2022). At about the same time, a reform of cohesion policy was discussed whereby an analysis of the drawbacks of previous policies brought forward the idea of a place-based policy approach with a more strategic and inclusive focus. These suggestions were based on lessons learned from the failed Lisbon Strategy (Tuffs et al., 2020). The demands for a future cohesion policy thereby met the outlines formulated by the K4G group so that both concepts were merged as a result (Gianelle et al., 2020a). Practically, the initially academic concept of the K4G group was complemented by introducing new aspects and ideas and branded as "smart specialisation" as a tangible label. It is one of the major sources of conceptual ambiguity that smart specialisation quickly turned into a political instrument while a serious theoretical and empirical base was developed ex post rather than constituting the foundation from the very beginning (Foray, 2013; 2019; McCann and Ortega-Argilés, 2014; Janik et al., 2020). Dominique Foray, one of the theoretical founding fathers accordingly described smart specialisation as an ideal example of "policy running ahead of theory" (Foray et al., 2011: 1).

The smart specialisation concept was upgraded to one of the central pillars when European cohesion policy was reformed in 2014 (Di Cataldo et al., 2021). Here, the fast and sweeping regional implementation of smart specialisation was facilitated by making the concept an ex-ante conditionality for the allocation of structural funds. This made it compulsory for European regions to develop and present a regional innovation strategy for smart specialisation in order to be eligible for financial funding from the EU (Janik et al., 2020; Larosse et al., 2020). The success of the approach is highlighted by the fact that about 120 smart specialisation strategies (S3) were developed simultaneously in a relatively short time, marking a milestone for European innovation policy (Tuffs et al., 2020; Larosse et al., 2020). Moreover, the concept has found an echo in OECD discussions in the aftermath of the global financial crisis in 2008/09 and similar strategic approaches are discussed and developed in other regions of the world, for instance on the African continent (OECD, 2013; McCann and Ortega-Argilés, 2014; Hassink and Gong, 2019; Di Cataldo et al., 2021; Dosso et al., 2022; Kruse and Wedemeier, 2023a).

Academically, the concept that was proposed by the K4G group was inspired by various research streams on regional development. At the beginning, it was assumed that innovation is a key factor for regional prosperity, that knowledge is a key for the production of innovation, and that interaction is a key for knowledge creation. Smart specialisation therefore does not represent a new concept but more of a novel policy application (Foray et al., 2011; 2013; Polverari, 2016; McCann and Ortega-Argilés, 2015; 2016b; Trillo, 2016). As the term "regional innovation system for smart specialisation (RIS3)", as the official title of smart specialisation strategies in Europe, implies, large parts have been inspired by RIS research. Generally, smart specialisation is considered an enhancement of the RIS theory rather than representing a new direction (Charles et al., 2012). However, it was not clear from the beginning that smart specialisation would become as successful as it did. At the same time of its conceptualisation, a similar concept was discussed under the term of "Constructing Regional Advantage (CRA)". The assumptions of both approaches were partly comparable as well as the raison d'être of addressing innovation policy shortcomings in Europe. Still, smart specialisation was more successful in convincing policymakers in Europe and gathered full support by them. As a consequence, CRA vanished as an individual concept while some aspects were included in smart specialisation (Boschma, 2014).

The recognition of the important role of regions and regional cooperation, as another basic assumption of both smart specialisation and RIS theory, was complemented by an aspect of economic specialisation. This aspect was inspired by cluster theory and rests on the recognition that not every region can do everything to the highest degree of perfection, arguing in favour of some kind of specialisation. Regarding the European reality, it was found that public investment was too fragmented to create a real effect so that a prioritisation was advised (Foray et al., 2009; 2011; Radosevic and Ciampi Stancova, 2015; Larosse et al., 2020). This prioritisation was advised to be constructed upon those economic areas where a region holds a comparative advantage in, and which show a high potential for future growth. This future-oriented perspective constitutes a novelty compared to traditional cluster theory which places a stronger emphasis on the status quo. This new turn made smart specialisation a transformative process of updating existing strengths and discovering new opportunities rather than a structure-preserving strategy. The outcome of smart specialisation therefore should be encouraging diversity rather than economic monoculture. This fact addresses one of the major shortcomings of cluster approaches which are criticised for being too static and not R&D-oriented enough. Also, the weakness of earlier European strategies, which did not recognise the uniqueness of individual regions, was addressed. Taking the cooperative aspect from RIS theory and implementing it into political reality added an additional feature for the selection of regional strategies. Moreover, joining forces between different regions in terms of specialisation was identified as a possible source of scale effects and for the creation of a physical innovation ecosystem to support the regional specialisation (Charles et al., 2012; Foray, 2013; Foray and Goenaga, 2013; McCann et al., 2015; Gulc, 2015; Asheim et al., 2016; Trillo, 2016; Janik et al., 2020; Esparza-Masana, 2022; Foray et al., 2021).

The multitude of target dimensions, however, made it complicated for policy makers to conduct the selection themselves. Instead, a process of entrepreneurial discovery was put forward, meaning the involvement of regional experts from different backgrounds from the triple (respectively quadruple) helix structure (OECD, 2013; Rusu, 2013; Kroll, 2017; Fedeli et al., 2020; Veldhuizen, 2020). Since smart specialisation aims towards upgrading existing regional specialisations, the discovery process should focus on the identification of yet untapped regional potential and niches with a high added value for further development (Asheim et al., 2016). Accordingly, a bottom-up entrepreneurial discovery should ensure a matching between positive development opportunities of market and technology trends, and the existing regional structure (Foray et al., 2011; Foray and Rainoldi, 2013; Foray, 2013; McCann and Ortega-Argilés, 2016b; Vezzani et al., 2017). However, it is this matching that runs a risk of creating inefficiencies when political influences, wishful thinking, or a missing empirical foundation may lead to the selection of future specialisations that do not align with the state of the regional economy (McCann and Ortega-Argilés, 2015; 2016b; Kruse and Wedemeier, 2019; Larosse et al., 2020). Naturally, regional experts also remain biased so that relying on bottom-up expertise is not a guarantee to receive an objective result anyway (Iacobucci, 2012). Nevertheless, entrepreneurial discovery and a solid ex-ante analysis of regional capabilities are regarded as an improvement of previous selection processes and constitute only the first steps of developing a smart specialisation strategy, followed by the design of transformational roadmaps and the practical implementation through an action plan (Foray et al., 2021).

1.4.3 Transitioning from Theory to Practice

Regarding an evaluation of smart specialisation, it needs to be recognised that the concept is still relatively new, being first implemented on a larger scale in the programming period 2014-2020. All efforts of evaluation will therefore remain preliminary and subject to further changes of the concept (Di Cataldo et al., 2021). Some striking findings involve the gaps between the original ideas and the practical outcome. For instance, when it was initially brought to the table, smart specialisation was advertised as particularly relevant for less-developed regions and the new European member states to bridge the development gap in comparison to Central Europe (Radosevic and Ciampi-Stancova, 2015). However, the idea of initiating a catch-up process was objected over time by several researchers who pointed out that the realisation of an entrepreneurial discovery process, the development of an individual regional strategy without copying others, and its successful implementation require a high level of institutional and governance capacity which was not available in every region (Iacobucci, 2012; Charles et al., 2012; McCann and Ortega-Argilés, 2015). Particularly those regions that could benefit most from the concept – namely less-developed regions with an old-industrial base looking for a structural transformation towards future-oriented sectors with a strong knowledge foundation – appear to be those that do not provide the conditions to facilitate the required process. Indeed, some years after implementation, smart specialisation scholars recognised that the concept might not be beneficial for all regions to the same degree. They expressed their scepticism particularly regarding the largest and most advanced regions because these regions frequently already had implemented comparable processes by themselves. Moreover, the least advanced regions lacked the minimum capacities for implementation (Polverari, 2016; Foray, 2019). Rather than bridging the development gaps, smart specialisation ran the risk of reinforcing disparities between regions, contradicting the idea of cohesion policy (Schulz, 2019).

Moreover, the organisation of an entrepreneurial discovery process proved to be difficult and underutilised in some regions (Kroll, 2017). As a consequence, the quality of regional specialisations has undoubtedly improved through the implementation of smart specialisation. However, there remains to be a disproportionally high number of certain domains being pursued in almost all regions leading to the conclusion that these selections were not fully objective and empirically justified. Instead, some kind of copying mechanisms apparently remained in place and wishful thinking of politicians could not be fully overcome (Polverari, 2016; Di Cataldo et al., 2021; McCann and Soete, 2020). It seems like regions have found ways to circumvent the rationale of smart specialisation. Regions in the same country tend to choose a similar set of priorities, implying a certain level of copying mechanisms instead of developing individual strategies (Deegan et al., 2021). The potential reasons for the contradiction of smart specialisation principles include lobbying activities, political considerations, risk-averse attitudes, a lack of adequate capacity, or a dysfunctional incentive structure (Gianelle et al., 2020b; Marrocu et al., 2023).

As several regions complained about the high complexity in the early development phase of smart specialisation, and some regions initially expressed their scepticism whether the concept could really make a difference, the problems can partly be explained by construction faults (Kroll, 2013; 2016). This also involved several obscurities that had to be answered en passant, among others whether the focus was specialisation or diversification, the embeddedness in existing regional innovation policies, the differences in comparison to traditional cluster theories, the role of entrepreneurial discovery, or the monitoring of progress (Hassink and Gong, 2019). Considering that smart specialisation became a political requirement without being asked for by the regions which had to implement it, the early years were characterised by a strong gap between theory and practice. Related to the bumpy start, the empirical effects of smart specialisation are ambiguous as a consequence. Kroll (2016; 2017) identifies nascent positive development with several beneficiaries in Southern European where smart specialisation has provided a new impulse for the governance of innovation while D'Adda et al. (2022), evaluating the implementation of smart specialisation in Italian regions, did not find strong evidence of substantial changes in the allocation of European funding. On the other hand, Larosse et al. (2020) found that a small number of regions took advantage of the opportunity to restructure their innovation systems around certain priorities while most regions performed the tasks solely to extract additional European funding. Applying a smart specialisation index, Rigby et al. (2022) found that European cities following development paths close to smart specialisation perform better than those that abandoned the smart specialisation framework.

Afterall, the general approach of applying a place-based strategy was generally appreciated and the introduction of a planning logic and entrepreneurial discovery positively noticed (McCann and Ortega-Argilés, 2015; Hassink and Gong, 2019; Foray et al., 2021; Hassink and Kiese, 2021; Barbero et al., 2022). Because of its flaws, an update of smart specialisation is advised in order to close backdoors and improve the outcomes (Gianelle et al., 2020a). A better use of statistical analyses, monitoring and evaluation schemes, as well as improved consultation processes in terms of entrepreneurial discovery are expected to benefit the instrument (McCann and Soete, 2020). Also, the strict nature that was originally attributed to the development of S3 was softened in favour of giving regions the freedom to develop their own approach (Foray, 2019). However, each region provides different characteristics and environmental so that each strategy will be shaped by the individual institutional and governance context, rejecting the idea of a single smart specialisation blueprint (McCann and Ortega-Argilés, 2014). Generally, the initially academic concept of smart specialisation saw relevant changes in its approach when it was its implemented on a large basis (McCann and Ortega-Argilés, 2016a).

1.4.4 Making Smart Specialisation fit for a Green Future

About a decade after its introduction, smart specialisation is qualified for a critical analysis of its achievements, weaknesses, and potentials that could be exploited in the future. This need is even more urgent as the development of smart specialisation lacked an extensive theoretical and empirical foundation and followed a more pragmatic path of political decisions. Accordingly, the instrument's effects are ambiguous, and several questions arose on what smart specialisation could be able to achieve and what its primary focus should be (Corpakis, 2020; Esparza-Masana, 2022). Apart from that, the environment that innovation policy operates in has changed in the last decade which needs to be institutionalised also on instrumental level. When smart specialisation was conceptualised, a new approach to cohesion policy was aspired to ensure a more targeted use of public funding. The place-based nature and entrepreneurial aspects of smart specialisation here represented significant milestones that remain important. However, what is required now is not a singular cohesion policy instrument but a governance tool for the European transformation of the future, as well as a deepening of smart specialisation (Larosse et al., 2020; Landabaso, 2020). Thereby, the identification of shortcomings of smart specialisation until now represent potential leverage points for reforms. Among these shortcomings are a lack of flexibility, a need for a clear direction, a lack of a social and an environmental dimension, as well as an inward-looking orientation of strategies (Neto et al., 2018; Benner, 2020; Landabaso, 2020; Tuffs et al., 2020; Woolford et al., 2021).

An inward-looking orientation of strategies can be problematic as it risks falling short in terms of potential in modern, interconnected knowledge economies. This is because identifying economic trends that would make a suitable regional specialisation cannot be limited to the regional scope alone. As innovation networks rely on cooperation and policy increasingly goes beyond borders, also smart specialisation should recognise the larger picture (Uyarra et al., 2014). This is somewhat counterintuitive as RIS implies a regional focus but, as has been outlined above, also RIS are increasingly discussed in a cross-border and inter-regional contexts (McCann and Ortega-Argilés, 2016b; Wostner, 2017). This is motivated by the fact that the assessment of regional strengths requires a comparison with other regions. Moreover, the construction of partnerships with regions sharing a similar specialisation, even without geographical proximity, helps to address regional challenges. Particularly less-developed regions are expected to benefit from interregional and international cooperation by leveraging complementarities and realising learning effects. However, the outward-looking perspective of smart specialisation is frequently mentioned as a target but remains to be under-theorised despite various policy approaches on EU level. Since enlarging transnational collaboration is among the factors that the European Commission highlights as a requirement of cohesion and innovation policy, changes in smart specialisation conceptualisations can be expected (Uyarra et al., 2014; McCann et al., 2015; Radosevic and Ciampi Stancova, 2015; Barzotti et al., 2019; Larosse et al., 2020; Rakhmatullin et al., 2020; Esparza-Masana, 2022; Woolford et al., 2021; Ghinoi et al., 2021; Giustolisi et al., 2023).

On the other hand, there remains a theoretical discussion that calls to reconsider the original focus of smart specialisation, namely the implementation of a bottom-up innovation process on regional level. This perspective argues in favour of untapped optimisation potential, for instance regarding the organisation of an entrepreneurial discovery process or the governance of S3. Accordingly, it is advised not to overload smart specialisation with ever greater expectations such as facilitating interregional cooperation or a contribution to green transition but to focus on the essentials instead. To do so, a more elaborate focus on qualitative and quantitative analyses and monitoring is advised rather than political discussions of what smart specialisation could be additionally used for. This argument is motivated by the assumption that not every region has a realistic opportunity to become a leader in green technologies. Accordingly, the green transition can be a suitable development strategy for some regions – but not a general concept for all of Europe (Benner, 2020). However, communication by the European institutions suggests that the thematic focus of smart specialisation is more likely to be further expanded instead of a stronger focus on its core virtues.

Contrary to arguments calling to focus on the essentials of smart specialisation, a discussion is gathering pace regarding the use of smart specialisation for new targets such as social and sustainability aspects. This discussion is clearly fuelled by the new European funding period 2021-27 but the underlying motivation has already been mentioned when smart specialisation was conceptualised (Foray, 2009; Foray et al., 2012; Meyer, 2022). First analyses imply that smart specialisation can be a moderating instrument to connect the different European targets of smart, inclusive, and sustainable growth (Montresor and Quatraro, 2019). Also, the transition towards a climate resilient, resource efficient, and greener economy is a crucial task for Europe in order to maintain its competitiveness (Foray et al., 2012). Accordingly, innovation and research will need to stronger address areas such as climate, health, transport, agriculture, and environment which also needs to involve innovation policy (European Commission, 2020).

Particularly the discussion on mission orientation in innovation policy has left its marks in smart specialisation discussions. While place-based approaches that recognise the uniqueness of regions and the need for individual policies have already benefited innovation research, the provision of a direction for development promises to further improve the benefits from specialisation and agglomeration by joining forces. In this context, smart specialisation is framed as one type of the newly developing mission-oriented policies (Foray, 2018; Isaksen et al., 2022). Also, RIS and cross-border innovation systems are increasingly discussed in the context of grand challenges and mission orientation towards resilience and sustainability (Korhonen et al., 2021; Isaksen et al., 2022). Additionally, it is emphasised that smart specialisation could represent the vital instrument to implement the EU Green Deal (EGD) through its combination of top-down directionality and bottom-up engagement (McCann and Soete, 2020; Larosse et al., 2020; Miedzinski et al., 2021). The EGD here is regarded as a turning point for the industrial and innovation policy in Europe as it strives for a fundamental transformation of the European economy. It combines the ambition for climate neutrality with social aspects such as employment, growth, and price stability while claiming to push breakthrough technologies for a green transition, such as green hydrogen (Wolf et al., 2021).

Generally, the experiences collected with smart specialisation, namely the involvement of policymakers and different stakeholders at regional and city level, can become a crucial factor for the successful implementation of the EGD (Steen et al., 2018; Tuffs, 2021). Moreover, smart specialisation has been developed to ensure an efficient distribution of investments to those sectors offering the highest return on investment for regional development. Therefore, this instrument might also be applied in terms of coordinating investment in sustainable sectors, green technologies, and environmental innovation (Gianelle et al., 2020a). Finally, the smart specialisation aspect of designing individual strategies based on regional characteristics as well as the identification of regions facing similar challenges can become even more important in light of the green transition in Europe and its regional execution (Montresor and Quatraro, 2019; Larosse et al., 2020; Esparza-Masana, 2022). Although the EGD has not been initially designed to exploit the potential of smart specialisation, both would make a suitable combination. Smart specialisation could help to manage the complexity of a European transition, leveraging its strengths (Corpakis, 2020; Larosse et al., 2020).

This discussion aligns with a suggestion to transform the “old” concept of S3 (smart specialisation strategies) to a “new” S4 (smart specialisation strategies for sustainability) or S4+ (smart specialisation strategies for sustainable and inclusive growth). This proceeding would broaden the narrative of smart specialisation from innovation as a goal in itself towards innovation as an instrument for a superior goal such as sustainable development. To do so, the full cycle of smart specialisation would have to be reconsidered, ranging from design of strategies, their implementation, and the monitoring stage. Such a new generation of smart specialisation would have to ensure that regional specialisations not only align with regional strengths and development opportunities, but also contribute to, or at least do not contradict, objectives of EGD and SDGs (Gifford and McKelvey, 2019; Interreg Europe, 2020; Nakicenovic et al., 2021; McCann and Soete, 2020; Miedzinski et al., 2021). First steps towards the development of S4 are already undertaken in the EU with the goal of combining directionality with bottom-up energy in order to mobilise transformative potential and synergies to contribute to a green and digital economy. Thereby, S4 remains a voluntary choice for the moment rather than a conditionality, as opposed to the initial introduction of smart specialisation (Smart Specialisation Platform, 2021; Nakicenovic et al., 2021).

Although the theoretical interconnections between sustainability and smart specialisation are evident, the practical examples remain limited so far. For instance, Polido et al. (2019) analyse the degree of embeddedness of sustainable development aspects in smart specialisation using a Portuguese region as an example. The authors find that the UN SDGs and Agenda 2030 goals are well embedded in the specific regional strategy which, however, remains isolated to a certain degree. Analysing smart specialisation in Serbia revealed that the strategy already focuses on the SDGs whereby the equivalent strategy in Slovenia puts enabling conditions for environmental transitions in the focus (Nakicenovic et al., 2021). Several regional examples across Europe are presented by Harding et al. (2021) who were looking at exemplary developments of green smart specialisation strategies whereby the majority focuses on circular economy approaches. The opportunities of exploiting smart specialisation to facilitate the regional implementation of circular economy approaches, as a subsystem of environmental sustainability, are also highlighted in other papers (e.g., Hristozov and Chobanov, 2020; Tsipouri et al., 2020). Moreover, smart specialisation has been successfully applied to foster renewable energy and the transition towards a more sustainable energy system in Europe (Steel et al., 2018). Despite these scattered examples, the connection between smart specialisation and environmental sustainability remains to be researched on a broader basis to make a point whether the instrument can be a suitable lever for the green transition process in Europe and beyond.

1.5 An Overview of the Dissertation Papers

This section provides an outlook of the following chapters of this dissertation. Table 1 illustrates the four different studies with a focus on their main characteristics. All papers are concerned with regional innovation, smart specialisation, and sustainability in Europe; however, they set themselves apart from existing research. It is argued that research on how smart specialisation can contribute to a green transition on regional level remains to be scanty while also environmental topics in regional studies remain a niche (Montresor and Quatraro, 2019; Morales and Dahlström, 2022). Also methodologically, there appears to be a strong restriction as most papers apply qualitative methods in region-specific case studies rather than quantitative research designs (Fellnhofer, 2017; Gibbs and O'Neill, 2017). While quantitative approaches are comparable scarce, the majority of these papers are constructed on the basis of patent data. Despite the benefits of patent data, they suffer from several limitations such as that patents cover only a certain kind of knowledge and that patents lead to a structural bias of technologically developed regions (Frenken, 2017; Montresor and Quatraro, 2019). Using primarily qualitative research designs and restricting to one kind of data in quantitative papers to draw the picture of green transition in European regions fails to recognise a whole colour palette and falls short of covering all nuances.

The following chapters strive to address the topic of regional innovation and sustainability from different angles by exploiting new data sources and applying new analytical methods. The first article (chapter 2) is concerned with an analysis of the role of environmental sustainability in both regional innovation and smart specialisation research by applying a bibliometric approach. The second article (chapter 3) focuses on interregional cooperation in environmental innovation in Europe by constructing cooperation networks based on data on Horizon 2020 research projects. The third article (chapter 4) takes the circular economy as an example of a regional policy for environmental sustainability and develops a novel index to quantify regional performance in this regard. The fourth article (chapter 5) constructs an econometric model on basis of patent data to demonstrate that this regularly used data can still reveal new information on the factors that determine regional green specialisations. The chapters recognise the call for novel metrics for inform policies and strategies and in each case discuss the policy implications of the respective findings (Barbieri et al., 2022).

Table 1: Overview of the dissertation papers by their main characteristics

Chapter	Title	Data	Temporal Scope	Geographical level	Data source
2	On Sustainability in Regional Innovation Studies and Smart Specialisation	Bibliometric analysis	1998-2022	/	SCOPUS, Web of Science
3	Inter-organisational Sustainability Cooperation among European Regions and the Role of Smart Specialisation	Network analysis, Correlation analysis	2014-2020	NUTS 2	CORDIS, Eurostat
4	Quantifying the Circular Economy in European Regions: a Bridge towards Smart Specialisation?	Index construction	2012, 2018	NUTS 2	Eurostat, PATSTAT, ESPON, European Commission, JRC
5	What makes Regions go Green? Insights from a Spatial Model on European Patent Data	Econometric analysis	1991-2021	NUTS 2	PATSTAT, Eurostat

1.5.1 On Sustainability in Regional Innovation Studies and Smart Specialisation

This chapter studies the academic history of regional innovation and sustainability. As the current discussion to exploit regional innovation policy as a leverage for a green transition, the question arises whether both areas are compatible and might give rise to mutual benefit. Regarding the status quo, the perspectives on this question are diametrically different. While one group of researchers calls for the pure doctrine of regional innovation and a focus on gradual improvements of existing instruments, another group argues in favour of a fundamental reorientation of existing approaches considering grand societal challenges such as the climate crisis. While the chapter so far has presented how regional innovation research has changed over time and how it is increasingly addressed with a focus on environmental topic and green transition, an analysis of the connection between both areas appears to be missing so far.

To provide the ongoing discussion – as well as the subsequent chapters – with an academic foundation, this chapter constructs a bibliometric analysis based on data extracted from the Scopus and Web of Science (WoS) databases. Different search strategies were applied spanning over a time frame of two decades. By qualitatively checking and merging the results, a novel overview of the recent history of regional innovation theory in Europe was constructed. In the following, the datasets were analysed for interconnections between sustainability and regional innovation over the years and how the situation was affected by the emergence of the European instrument of smart specialisation.

The analysis reveals that sustainability is anything but a recent development in regional innovation studies. Instead, both research areas have been addressed in combination by different researchers already decades ago. However, this finding does not provide an evaluative perspective about the quality of said interconnections. Nevertheless, the findings reject the initial claim that sustainability and a green transition discourse were alien to the regional innovation literature. Although the decision whether to integrate a sustainability perspective in existing regional innovation instruments such as smart specialisation is a political one, the current debate can draw on several papers focusing on sustainable development via innovation at regional level.

It is shown that the relevance of the sustainability discourse in regional innovation studies is, in some quantitative kind, related to the emergence of smart specialisation. Thereby, this instrument and its multifaced history have overcomplicated the ongoing debate. As smart specialisation is both an academic and a political concept, a level of fuzziness remains and spreads to the broader discussion on regional innovation and sustainability. The chapter explains this confusion by tracing the development of smart specialisation over time and integrates the current sustainability discourse accordingly. It becomes clear that the controversial discussion whether to focus on deepening the original idea of smart specialisation or to open for new dimensions such as sustainability is structurally rooted in the different ideological streams that the concept has emerged from. The current discussion can therefore benefit from this analytical recognition when scholars recognise the origin of their respective position. The apparently diametrical positions do not necessarily contradict each other but can be deployed to a mutual benefit.

1.5.2 Inter-organisational Sustainability Cooperation among European Regions and the Role of Smart Specialisation

This study was motivated by the key role that cooperation plays for innovativeness. At regional level, not only intra-regional but also inter-regional cooperation is increasingly addressed as a facilitating factor. This is because these linkages provide regions with external knowledge leading to new ideas and structural renewal (Camagni, 1991a; Balland and Boschma, 2021). The relevance of interregional cooperation also stretches towards the policy instrument of smart specialisation, which aims to promote an outward-orientation among regions to allow for cooperation and the avoidance of technological lock-ins. Thereby, particularly the grand challenges such as actions against climate change reach beyond the scope of regional or even national action and should therefore be addressed collaboratively between stakeholders at different levels (Doranova et al., 2012; Ocampo-Corrales et al., 2021).

Due to being interested in interregional cooperative patterns in environmental sustainability, a dataset was constructed based on European research projects focusing on environmental sustainability. Such projects were considered that were funded under the Horizon 2020 (H2020) scheme. This scheme is increasingly discussed also in relation to mission orientation and is characterised by a high level of directionality and challenge orientation (Mazzucato, 2018b). While most papers analysing interregional cooperation in certain technologies are based on patent statistics – including the well-known drawbacks of patent data – this chapter pledges to provide new perspectives to the literature by novel data, a focus on sustainability, and a practical focus by constructing a subset of data for Northern Germany. Methodologically, a social network analysis (SNA) as well as different correlations were calculated.

The chapter makes three distinct contributions to the existing literature on research cooperation in sustainability in Europe: firstly, the involvement in interregional research projects on environmental sustainability is strongly concentrated in certain regions. These regions with a high interregional commitment are generally characterised by an urban structure as well as a higher GDP and population density. While on the first glance this results in a European pattern of a strong concentration in Western Europe and less involvement in the East, the data also reveal that the regional scores are highly determined by smaller administrative regions such as individual cities. Under this recognition, it becomes clear that Eastern European regions are not structurally uncoupled but the geographical area is rather shaped by a limited number of highly cooperative regions and many regions not being involved yet. Secondly, the subset for Northern Germany makes clear that H2020 has succeeded in establishing cooperative ties between regions which would not have cooperated naturally due to high distances (geographically but also culturally). Neighbouring regions are characterised by a strong cooperation with Northern German regions, as suggested by the proximity hypothesis which states that geographical, cultural, and other kinds of proximity play a facilitating role for cooperation. Nevertheless, cooperative ties are also observed with regions in distant parts of Europe, as a result of H2020 aiming towards bringing together different kinds of regions. Thirdly, smart specialisation strategies (S3) seem to play a minor role for explaining which regions get involved in interregional environmental research projects. While smart specialisation aims to facilitate interregional cooperation and the focus on future economic trends such as green innovation, the actual data are only partly in line with the regional S3.

The policy recommendations following from the analysis include to update the policy of smart specialisation in order to exploit its potential for interregional cooperation and as a tool for the implementation of environmental policies in Europe. Moreover, European policy should strive to include a larger number of yet uninvolved regions in interregional research and cooperation. As the ongoing green transition will require cooperation and knowledge exchange not only inside but also between regions, particularly less-developed regions have the potential to benefit from this cooperation which makes the task an opportunity for cohesion policy and the further development of a European research area.

1.5.3 Quantifying the Circular Economy in European Regions: a Bridge towards Smart Specialisation?

This chapter studies the performance of European regions in terms of a circular economy (CE). While circularity is becoming increasingly important under the premises of economic resilience, sustainability, and scarce resources, the progress at regional level is hard to track. This is because CE represents an umbrella concept involving all different aspects of sustainability, namely economic, ecological, and social dimensions. While statistics such as resource intensity of production are theoretically measurable, despite suffering from data limitations at regional level, aspects such as product design or public perspectives on consumption can hardly be quantified. This lack of a thorough methodology makes it difficult to assess policies and to evaluate development patterns. Therefore, the paper describes the development of a novel methodology based on already existing approaches in Europe and beyond while explicitly addressing previous gaps and shortcomings by proposing new aspects. The methodology of 29 individual indicators in six dimensions is, to the best of our knowledge, the largest and most diverse methodology on CE in European regions.

The analysis reveals that the actual picture of CE performance at regional level is much more differentiated than previous papers have assumed. This is because earlier approaches have either analysed national levels or relied on a limited number of indicators. As a result of these shortcomings, it has often been overlooked that regions are highly diversified which can also be studied when it comes to CE. As distinguished from analyses at national level, the results reveal no clear division of Europe, neither between East and West nor between North and South. By contrast, the dividing line – if anything – is to be drawn between different types of regions. Urban capital regions in Eastern Europe do not drop in circular performance compared to urban regions in Western Europe. Moreover, it could be shown that even regions with comparable structural characteristics differ in terms of their CE performance. This indicates that there is no automatism that certain regions are predestined to prosper while others face a dead end. Although structural characteristics such as a high GDP or a certain agglomeration level provide an advantage, the actual circular performance is not fully explained by these factors. By applying a trend index covering the development of the regional circular performance over the last years, a certain development dynamic to be benefit of urban and peripheral regions while Central European regions, particularly in Germany, apparently struggle to keep pace.

The main contribution of the chapter is to develop an objective benchmark regarding the transition towards a CE in European regions. The findings can be applied to identify interesting regions which are structurally comparable but differ in terms of their performance. These characteristics can be used to deduct the success factors by qualitative analyses in further studies. Moreover, the findings can help to assess previous CE policies in Europe and to better design upcoming policies. One example would be smart specialisation which is already applied by certain regions, particularly in Scandinavia, to promote circularity as a specialisation. Although it is methodologically challenging to determine whether a specialisation is the result or the foundation of a strong CE performance, it can be concluded that regional policies such as smart specialisation can contribute to the development of a CE at regional level. These findings should be recognised when it comes to updates of European CE policies which have been lacking a regional dimension until now (Borrett et al., 2020; Arsova et al., 2021; Arauzo-Carod et al., 2022).

1.5.4 What makes Regions go Green? Insights from a Spatial Model on European Patent Data

This study is dedicated to the question what factors facilitate the emergence of green innovation at regional level. Innovation is neither uniformly nor randomly distributed geographically since innovativeness is the outcome of a complex process influenced by various factors. Since innovation is claimed to be crucial for structural renewal, economic development and therefore a green economic transition in general, studying factors for successful implementation becomes increasingly relevant (Horbach, 2014). Thereby, the question is not only of academic relevance but also for the practical design and update of regional strategies in light of the current battle against grand challenges such as climate change (Conti et al., 2018). For instance, the current debate on reforming smart specialisation in order to better exploit its transformative potential can benefit from analyses of green transition at regional level.

The dataset was constructed using European patent data on green technologies in the period 1991-2021. Although patent analyses are common to study cooperation networks, effects of innovative activity, or as a proxy variable to study the emergence of innovation, research gaps remain (Jovanović et al., 2022). The chapter addresses some of these gaps by first adding existing variables which have not been analysed, by including specifically constructed variables, and by and testing established variables using different methodological approaches in order to contribute to the literature on green regional innovation. To test the research hypotheses, the chapter presents a baseline methodology, an intensive, and an extensive margin which are based on a fixed effects model analysis, a generalised method of moments (GMM), as well as a dynamic spatial durbin model (DBS). The results are found to be robust through different tests.

The analysis shows that structural factors play a major role for the emergence of green innovation in European regions while other variables have little or no influence. For instance, the exposure to climate change impacts such as heat events does not significantly influence a green transition, just as little as a public attitude towards green topics. Instead, structural factors such as an industrial basis or the age structure of the population have been found to be highly relevant. Moreover, factors such as higher education, or spending on research and development contribute to the generation of green innovation. While certain findings are in line with previous research, certain differences occur regarding details of the role played by an industrial economic structure which require further analyses. Generally, the results provide new insights for ongoing research on regional innovation and have important implications for regional innovation policy as certain structural factors which have been identified as highly relevant can be influenced by instruments like smart specialisation (Steen et al., 2018; Esparza-Masana, 2021). Although it can be deduced that a certain economic structure makes it easier for a region to enter a path of green development, these factors are not necessarily required. By choosing the right policy and adequately designing innovation instruments, every type of region has a chance to successfully go green.

1.6 Conclusion

Innovation is one of the most important levers for development and successful economic transition. Researchers have focused on the surrounding environments that innovation emerges in when it was observed that some regions and cities tended to be more successful in producing innovation and attracting new businesses. As a consequence, different streams of regional innovation theory developed over time, for instance regarding industrial districts, clusters or regional innovation systems. All these approaches address the regional level as it combines administrative competencies with spatial proximity and can therefore provide a facilitating environment. It is for this reason that regional innovation systems (RIS) remain to be discussed prominently in terms of structural change and increasingly in terms of a green transition. As adamant as grand challenges such as the battle against climate change and an economic transition towards climate neutrality appear to be, innovation will undoubtedly play a crucial role, for instance by generating green technologies. It will be important for the success of the green transition to ensure an innovative environment. On the other hand, the aspect of interregional balance must not be neglected. A small group of regions benefiting while the majority of regions is left behind would undermine the political consensus and public approval for transition.

However, research on the role of regions in this transition is still relatively limited and additionally suffers from methodological limitations. This is even more true when looking at the European policy instrument of smart specialisation which is arguably an important delivery channel for the green transition in Europe but remains under-researched. The thesis at hand addresses this research gap and contributes to a growing body of literature with studies on the connection between regional innovation and sustainability (chapter 2), the role of interregional cooperation in green technologies (chapter 3), the regional implementation and development of circular economy (CE) (chapter 4), and regional conditions that facilitate the emergence of green innovation and specialisations (chapter 5). The results show that combining regional innovation and sustainability is not an artificial approach motivated by current political debates. Instead, both research streams have overlapped and have been jointly addressed for decades (chapter 2). Although this finding does not make a claim for the efficiency of combining both research streams, the current debate can benefit from an established academic foundation and earlier papers as role models. The analysis also reveals that the introduction of the instrument of smart specialisation has intensified the debate of applying regional innovation as a leverage for societal challenges such as cohesion or a green transition.

Although first attempts to utilise smart specialisation in that sense have been noted, the impact of the instrument to facilitate green trends such as CE appears to be limited (chapter 4). Also, regarding other ambitions of smart specialisation, such as the facilitation of interregional cooperation, the reality is less euphoric (chapter 3). When it comes to cooperation in terms of green research projects, European funding programmes have succeeded in creating new cooperative ties, but smart specialisation still tends to over-emphasise endogenous factors of regional development rather than cooperation with other regions. These findings are in line with other studies but reveal first successes as starting points for reforms (Uyarra et al., 2014; McCann et al., 2015; Rakhmatullin et al., 2020; Woolford et al., 2021; Giustolisi et al., 2023). While smart specialisation as in instrument is not yet perfect but needs to be further adjusted to become a tool for the roll-out of a green transition among European regions, also other regional factors must be kept in mind for this transition. Some of the factors relevant for the emergence of green innovation, such as the age structure of a region's population, can hardly be addressed by regional policy while others, such as the regional economic structure or expenditure on R&D, can be leveraged when they are prioritised by policymakers. It appears that green innovation is largely a product of adequate policy rather than the outcome of factors which cannot be influenced such as climate change impacts (chapter 5).

Hence, there are three main conclusions that can be drawn from the research conducted in this thesis: first, analyses focusing on regional rather than national level paint a much more differentiated picture. Innovativeness and green technologies are not per se lower in certain countries but there are successful regions in almost every European country in all aspects analysed. Secondly, no region is doomed to be left behind in the green transition. Although there are structural factors that give some regions, particularly urban regions with a high development level, an advantage, also regions with other structural preconditions have proven to be successful and innovative. Success or failure are determined by policy rather than structural determinism. Thirdly, the green transition as a major challenge requires a suitable framework and facilitating policies. Smart specialisation could become an instrument for this task but is not yet prepared to do so. Further adaptations are required to exploit the transformative potential.

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Chapter 2

On Sustainability in Regional Innovation Studies and Smart Specialisation

Author: Mirko Kruse

Abstract

Innovation is expected to play a key role for the green transition of existing economic structures. In Europe, this fact relates particularly to the concept of smart specialisation which is the key EU instrument for innovation and cohesion policy. While an increasing number of policy papers argues in favour of updating smart specialisation, considering particularly the European Green Deal, others advise not to overcharge the instrument and focus on its original purpose. In this context, the article shows how smart specialisation has undergone several transformations since its proclamation and how its purpose has been adapted over time. A bibliometric analysis on the development of environmental sustainability in regional innovation highlights that both areas are interlinked since decades. On this basis, it is concluded that regional innovation and green transition can mutually benefit. Leveraging the transformative and collaborative nature of smart specialisation might constitute the basis for successfully rolling out the European Green Deal at regional level.

Keywords: regional innovation; RIS; smart specialisation; sustainability; green transition; Europe.

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2.1 Introduction

It is widely acknowledged that climate change and environmental transition are among the key challenges of the current generation, if not the most urgent ones. In the European Union (EU), this topic is currently addressed by the European Green Deal (EGD) aiming to make the European society more prosperous, the economy more resource-efficient and competitive while driving down greenhouse gas emissions. Thereby, the means to achieve these targets are research and innovation (Doranova et al., 2012; European Commission, 2020). This observation enters a melange of related discussions including the need for a new innovation narrative, a green transition of the European economy, cohesion challenges in the scope of transition, and reforming the available policy instruments in Europe (Santoalha and Boschma, 2020; Corradini, 2019; McCann and Soete, 2020). Particularly changing the innovation policy narrative of research and innovation policy as an instrument to achieve societal goals rather than representing a goal in itself is gaining traction in Europe. Here, these discussions all relate to the central instrument of European innovation policy: smart specialisation. This concept was developed by a group of innovation economists in 2009 and has seen quite a career since then, until becoming an official EU strategy (Larosse et al., 2020).

A whole choir of academics has evolved around smart specialisation. This article strives to add an additional voice to it by discussing the potential of smart specialisation for a green economic transition. While some authors, particularly in policy papers, argue in favour of reforming smart specialisation for the green transition of European regions (e.g., McCann and Soete, 2020), others, particularly academics, demand a focus on the original goals of coherent innovation processes (e.g., Benner, 2020). The fundamental nature of this dissent calls for an objective analysis separating the political and the academic spheres of discussion. Throughout this paper, it is to be analysed what smart specialisation is, where it has emerged from and what it might be used for as a political instrument. On the other hand, the broader picture will be painted by analysing the theoretical origins of smart specialisation in regional innovation studies which also witness an emerging discussion on their role in a green economic transition (Fellnhofer, 2017; Montresor and Quatraro, 2018). Both, regional innovation theory as an academic concept and smart specialisation as a political tool are analysed by applying a bibliometric analysis. This approach aims to embed existing research to identify potential linkages to the current debate on green transition. The current dissent will be addressed by presenting, clarifying, and classifying the different perspectives, providing them with an analytical foundation. Against this background, the discussion of reforming European policy instruments considering the Green Deal will be integrated.

The remaining of the article is structured as follows: the second section presents an overview of the concept of smart specialisation, its development, and its theoretical origins of regional innovation studies. This section is followed by a quantitative and qualitative analysis of academic publications which to provide a basis for a subsequent discussion on potential reforms of smart specialisation in the scope of green transition. The article closes with a concluding outlook.

2.2 The History of Smart Specialisation

2.2.1 The Concept

The concept of smart specialisation is place-based, meaning that it builds upon the recognition that context matters, and that innovation policy needs to acknowledge regional characteristics (McCann and Ortega-Argilés, 2015; Di Cataldo et al., 2020). As there is no "one-size-fits-all"-solution to policy, also the economic structure of European regions should not be characterised by technology monoculture but by a promotion of diversity based on regional strengths (Foray et al., 2012). Here, smart specialisation introduces a policy prioritisation framework to assist regions choosing those economic focuses that best suit their regional structure and development prospects (McCann and Ortega-Argilés, 2016c). The main aspects introduced by smart specialisation are (1) a vertical identification of technological specialisations, (2) a focus on transformation rather than conserving structures, and (3) a bottom-up selection process of entrepreneurial discovery (Foray, 2013; 2019; Janik et al., 2020).

Specialisation institutionalises the realisation that not every region can do everything in terms of science, technology, and innovation at the same time. Instead, concentrating resources in a limited number of domains is expected to generate economies of scale and scope as well as spill-overs (Giannitsis, 2009; Foray, 2013). It was found that, before the introduction of smart specialisation, too many European regions had selected the same technology mix which implied that regional characteristics were inadequately represented. Instead, areas for innovation policy intervention should be focused on those sectors and technologies that constitute a regional comparative advantage and make the regional knowledge system unique and potentially superior to others (Foray et al., 2011). As opposed to cluster theory, smart specialisation is not about preserving existing structures but focuses on processes and transformation (Foray, 2019). This transformation should be based on diversification in domains related to the existing economic structure and not only allow for gradual innovation but also for disruptive change and structural transformation (D'Adda et al., 2018; Südekum, 2021; Foray et al., 2021). Rather than by top-down planning, identification of the most promising domains for future-oriented regional specialisation should involve an interactive process of entrepreneurial discovery (Foray and Goenaga, 2013; Foray, 2013). This process involves regional actors from the quadruple (formerly triple) helix to explore and assess regional specialisations (Gianelle et al., 2020a). As this process requires an extensive assessment of a region's knowledge structure, capabilities, and competences, smart specialisation has provoked significant academic effort of regional analyses (Hidalgo and Hausmann, 2009; McCann and Ortega-Argilés, 2015; Xiao et al., 2018; Balland and Boschma, 2021; Kruse and Wedemeier, 2022).

2.2.2 Development

The history of smart specialisation in Europe goes back to the identification of several shortcomings of European policy. One of the most prominent weaknesses to be addressed was the increasing productivity gap between Europe and competitors such as Japan or the United States in the 1990s. This observation was identified as a limitation for economic growth and its reasons were found to be not so much a lack of financing but its targeted use (Landabaso, 1997; O'Sullivan, 2007; Kroll et al., 2014; Gianelle et al., 2020a). Inefficient spending among sectors and regions is thereby not only a concern in terms of limited financial capacity but also in terms of successful transformation, competitiveness, and interregional inequality (Rusu, 2013; Barca, 2009). Particularly the inclusion of new, generally less developed, member states into the EU has brought up the issue of overcoming disparities as a challenge of European policy (Veugelers and Mrak, 2009; Radosevic and Ciampi Stancova, 2015). This setup of challenges has been further intensified by external shocks such as economic crises, global megatrends, and societal challenges (Tödtling and Trippl, 2018). These considerations formed the background for the discussion about new policy tools. The emergence of smart specialisation can be described as both a political and an academic process which started independently, emerged in parallel, and finally merged into a blend concept.

The political discussion on reforming innovation instruments recognised the limited success of previous approaches in Europe and called for a more focused, place-based approach (Barca, 2009). Criticism particularly concerned the Lisbon Strategy introduced in 2000 which proclaimed a mutual governmental strategy focusing on ecologically, economically, and socially sustainable growth. However, the strengthening of the scientific and technological base in Europe was not achieved as planned (Larosse et al., 2020). The political answer was the subsequent Europe 2020 strategy introduced in 2010. This new strategy aimed towards building a smart, sustainable, and inclusive economy and promised to overcome the supply-side fragmentation in terms of funding instruments by a stronger focus on specialisation (European Commission, 2010a; McCann and Soete, 2020). Prioritising investments in research, innovation, and transformation was identified as a key for competitive strength and as an answer to challenges associated with the European research environment (McCann and Ortega-Argilés, 2015; Medeiros, 2017; Tuffs et al., 2020). At the same time, a group of innovation economists, macroeconomists, and econometricians, known as the *"Knowledge for Growth (K4G)"* group, formed on behalf of the European Commission, discussed a reform of European innovation policy. Among the targets to be addressed were the transatlantic productivity gap and the question how to improve the R&D situation in Europe (Foray, 2009a; Mora et al., 2019; Foray, 2019). Starting from the analysis of thinly spread investment across a variety of research fields resulting in a limited impact, the group suggested focusing investment on programs complementing a country's already existing assets (Foray, 2009a). This primarily academic discussion identified concepts of regional innovation strategies as a suitable starting point (Esparza-Masana, 2021).

The policy prioritisation thinking in political and academic discussions pointed into the same direction so that both discussion streams were merged at some point (McCann et al., 2015). Thereby, the original academic concept was rapidly recast and complemented by different researchers and divisions of the European Commission. Aspects of industrial and development policy, of related variety, and a clear objective of contributing to regional economic transformation were added (McCann and Ortega-Argilés, 2016b; Foray, 2019). The revised concept then soon became part of the 2014 reform of European Cohesion Policy with smart specialisation being introduced as an ex-ante conditionality for regions in allocation of structural funds (European Commission, 2010b; 2014; Di Cataldo et al., 2020; Janik et al., 2020; Larosse et al., 2020). However, it quickly turned out that the academic idea of smart specialisation did not fully match the requirements of practical policy on the ground. European regions applied different approaches of implementing the ideas of smart specialisation, depending on their specific institutional context. If there ever was a single blueprint of smart specialisation implementation, it did not stand the proof of practice (McCann and Ortega-Argilés, 2014; Gianelle et al., 2016; Foray, 2019). The process of changing considerations, corrections and supplements makes smart specialisation an example of policy running ahead of theory (Foray et al., 2011; Foray, 2013; McCann and Ortega-Argilés, 2016c).

Looking back, the introduction of a mandatory new governance model for European regions was not particularly requested by regional authorities and consequently only hesitantly accepted at first. The initial expectation that regions would drop their long-established models in favour of the new approach did not turn out true (Laranja, 2022). Particularly economically weaker regions, which were expected to be the largest profiteers, apparently lacked the capabilities to fully implement the new process (Polverari, 2016; McCann and Ortega-Argilés, 2016a; Foray et al., 2021). This phenomenon has also become popular as the innovation paradox of regions which would benefit most from fostering innovation are the least able to absorb funds to do so (Oughton et al., 2002; McCann and Ortega-Argilés, 2015; Barzotto et al., 2019). Therefore, only a small number of regions, particularly those with better institutional capacity, took full advantage of smart specialisation to refocus and transform their innovation system (Kroll et al., 2014; Larosse et al., 2020; D'Adda et al., 2022). Popular criticism points towards the embeddedness in existing regional innovation policy, the distinction towards cluster policy, lock-in challenges, and measurement of effects (Hassink and Gong, 2019; Foray, 2019). Nevertheless, the introduction of smart specialisation has apparently improved prioritisation and participation processes in European regions. Moreover, the concept also found an echo in OECD discussions and regions beyond Europe (OECD, 2013; Polverari, 2016; Kruse and Wedemeier, 2023).

2.2.3 Theoretical Origins

Smart specialisation as an instrument of innovation economics is embedded in early works on research and development as important sources of economic growth, productivity, and competitiveness (Solow, 1957; Aghion and Howitt, 1992; Giannitsis, 2009; Mazzucato and Penna, 2020). For a long time, innovation was framed in a linear way, as a result of market-driven processes, or alternatively from a Schumpeterian perspective with a focus on firms innovating in isolation, before, in the 1990s, innovative milieux and regions, territorial innovation, industrial districts, clusters, and knowledge spill-overs introduced an additional geographical aspect. By now, the understanding of innovation has significantly expanded to a non-linear process with systemic character built upon collaboration between different actors whereby the crucial role of knowledge for the generation of innovation remained a base line of theory (Tödtling and Trippl, 2005, 2018). The connection between innovation and geographical areas has been growing in importance since the 1980s when regional and technology policy began to merge (Barca et al., 2012; Südekum, 2021). It was this connection of cooperation of different actors that later gave rise to regional innovation policy and theories of innovation systems (Hassink and Gong, 2019: Hassink, 2020). These theories of systems of innovation differentiated in technological innovation systems (TIS), global innovation systems (GIS), national innovation systems (NIS) and were further developed to regional innovation systems (RIS). Concepts of innovation systems focused on the importance of regional environments to explain spatially differentiated patterns with a persistent character in terms of economic structure, R&D base, institutional set-up, or innovation activity (Tödtling and Trippl, 2005; van den Heiligenberg et al., 2017; Tödtling et al., 2022). Particularly the interest in innovation systems with a regional perspective has been growing steadily over the past decades (O'Sullivan, 2007; Asheim et al., 2011; Isaksen and Trippl, 2014). However, the expanding research on innovation systems has also led to a broadened understanding of the concept and diverse applications, blurring the concept's boundaries (Rakas and Hain, 2019).

While theories of innovation systems have emerged from cluster theory, innovative milieux and other streams, smart specialisation as a sub-division of innovation system research additionally introduces new aspects, for instance from economic geography (Asheim et al., 2011; McCann and Ortega-Argilés, 2015). Thereby, the success of smart specialisation as a concept of regional innovation policy was not predestined. Competing ideas such as Constructing Regional Advantage (CRA) followed a comparable approach of institutionalising place-based characteristics in regional innovation policy (Boschma, 2013; Asheim et al., 2016). The short history of smart specialisation in Europe has been full of advancements, adaptations, new turns, and additional perspectives, leaving no time to consolidate a concluded concept.

2.3 Sustainability and Regional Innovation

The basic concept of smart specialisation did not mention sustainability as a primary motivation but has emphasised the transformation of existing economic structures. Recently, calls for a closer connection between innovation policy and sustainability have become more frequent, leading authors like Benner (2020) to apprehend an overloading of innovation policy with societal goals. This brings up the question how smart specialisation, regional innovation literature and sustainability interrelate and whether sustainability really constitutes an additional facet. This question is dealt with in the following by conducting a bibliometric analysis on sustainability in regional innovation and smart specialisation research to elaborate on the theoretical interconnections.

Analyses on smart specialisation using a similar methodological approach have been presented already in several cases. Among others, Fellnhofer (2018), Janik et al. (2020), Gómez-Núnez (2014), and Mora et al. (2019) conducted different bibliometric analyses on smart specialisation. More focused bibliometric analyses were conducted on the relationship between innovation ecosystems and mission-oriented innovation (Jütting, 2020) and sustainability transitions (Markard et al., 2012). However, a bibliometric analysis of sustainability topics in smart specialisation or regional innovation appears to be missing.

2.3.1 Materials and Methods

To answer the research question of a possible interconnection of sustainability and regional innovation, a longitudinal bibliometric analysis was conducted. As databases for the analysis, SCOPUS and Web of Science (WoS) were selected due to their common application in comparable studies. Both databases are academically focused and provide an extensive overview of peer-reviewed journal articles, book chapters, conference papers, and other kinds of publications. The search strategy for both databases consisted of different key word combinations covering the theoretical streams of regional innovation, namely "national innovation system", "regional innovation system", and "regional innovation", each in combination with either "green" or "sustainab*". A focus on smart specialisation was introduced with the search strategy of "RIS3", "RIS", and "smart speciali*ation", each again combined either with "green" or "sustainab*". The specifications allowed for both American and English spellings as well as singular or plural variations of the key words. No restrictions were imposed regarding language, document type, or time frame.

The search strategy produced 1,277 results from the SCOPUS database and 2,039 results from WoS. These results were individually screened by analysing their abstract for relevancy on the desired topic which means a relation to regional innovation and environmental sustainability. Where the abstract did not suffice, the full text was analysed, when available. After merging the Scoups and WoS datasets and elimination of irrelevant results and doublings, 319 articles remained for further analysis. Additionally, a subset of 101 articles focusing on smart specialisation was excluded for a separate in-depth analysis. This subset included exclusively those findings associated to the key words "smart speciali*ation" and "RIS3". Missing information in the dataset, for instance in terms of author countries or publication year, were complemented separately, if available. The subsequent analysis is conducted in three steps: (1) a descriptive analysis of the datasets, (2) a combination of network analyses, (3) a qualitative discussion of selected publications. Visualisation of the network analyses was conducted using the VOSviewer software tool (version 1.6.17) which allows for the creation of networks based on a distance-based visualisation approach (van Eck and Waltmann, 2010).

2.3.2 Results and Discussion

The full data set included 319 publications covering the time frame of 1998 to 2021. Among these publications, 78 were conference papers which make up the majority of publications in the data set. Regarding the journals, “Sustainability” (30 articles), “European Planning Studies” (15 articles), “Regional Studies” (7 articles), “Renewable & Sustainable Energy Reviews” (5 articles), and “Research Policy” (5 articles) prevail. Regarding the subset on smart specialisation, 101 publications were included covering the time span 2013 to 2021. 19 of these publications were conference papers while regarding the journals “Sustainability” (9 articles), “Regional Studies” (6 articles), and “European Planning Studies” (3 articles) prevail.

Focusing on the years of publication, it becomes clear that the research stream on regional innovation and sustainability started in 1998 at the latest and has been growing steadily since then. After 2013, publications on smart specialisation and sustainability started to establish as a research stream of its own. A significant increase in the research stream of regional innovation and sustainability can be recognised after 2018 with high growth rates also in the following years (see Figure 1).

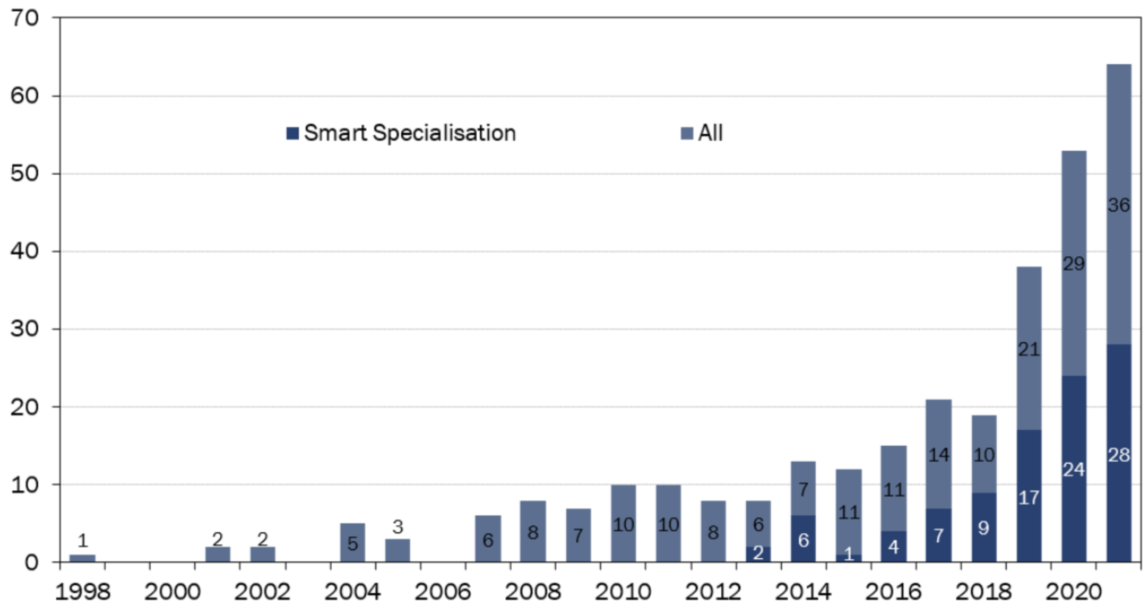

Figure 1: Publication years of works on regional innovation and sustainability
Data Source: SCOPUS and WoS

To visualise the countries of authors and co-authors of publications as well as their cooperation in the full data set, a network analysis was conducted. Here, a threshold of 4 minimum documents per country was introduced to ensure clarity of the illustration which was met by 27 of 69 countries. In terms of absolute publications, China and Russia stand out, followed by the UK and other European countries such as the Netherlands, Germany, Italy, and Sweden. The absolute number of publications per country is represented in the size of the nodes. However, applying the average citations as a weight, it becomes clear that the high volume of publications from Russia and China is not associated with an accordingly high academic consideration. The average citation weight is represented by the different colours in the figure. The most influential articles were produced in Germany, Switzerland, the United States, South Korea, and the United Kingdom which are also well-connected in terms of cooperation networks (see Figure 2).

To produce a co-occurrence analysis, involving all keywords associated to the publications, a threshold of 7 minimum occurrences of a keyword was introduced. This threshold was met by 47 of 1,783 keywords in the full data set. It can be seen that regional innovation and sustainability merge in different research streams such as sustainable development, innovation systems, or transition studies. Additionally, the publication year was used as a weight. This approach reveals that regional innovation and sustainability discourses have been shifting over time. The concept of national innovation systems was first to introduce a sustainability aspect on a large basis, followed by the, later evolving, stream of regional innovation systems. Smart specialisation entered the discourse relatively late due to being the most recent concept (see Figure 3).

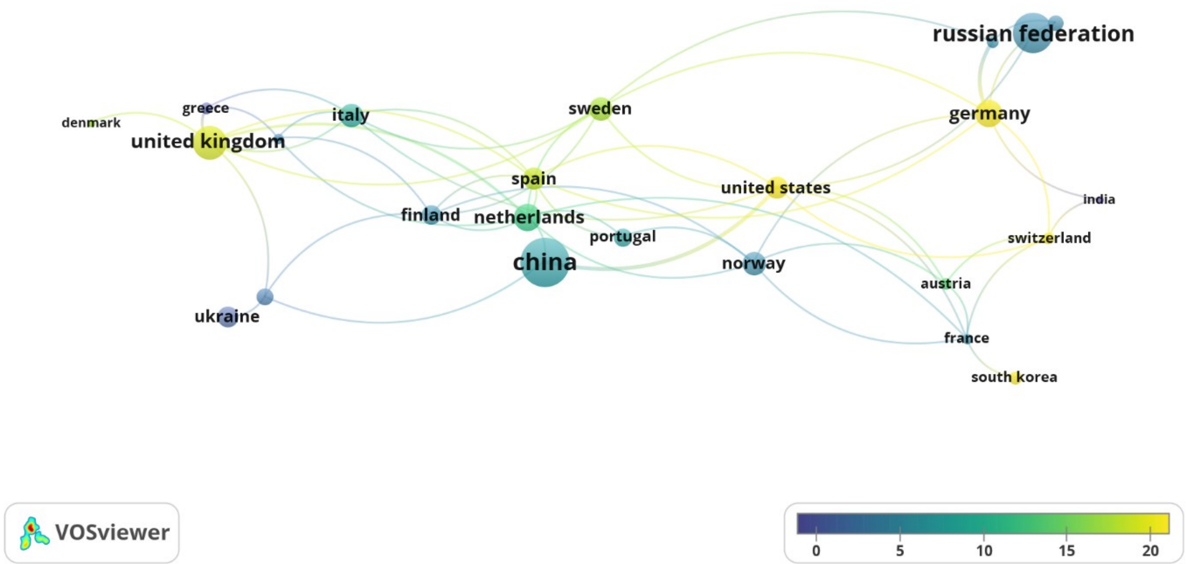

Figure 2: Country network of authors in regional innovation and sustainability literature

Data Source: SCOPUS and WoS

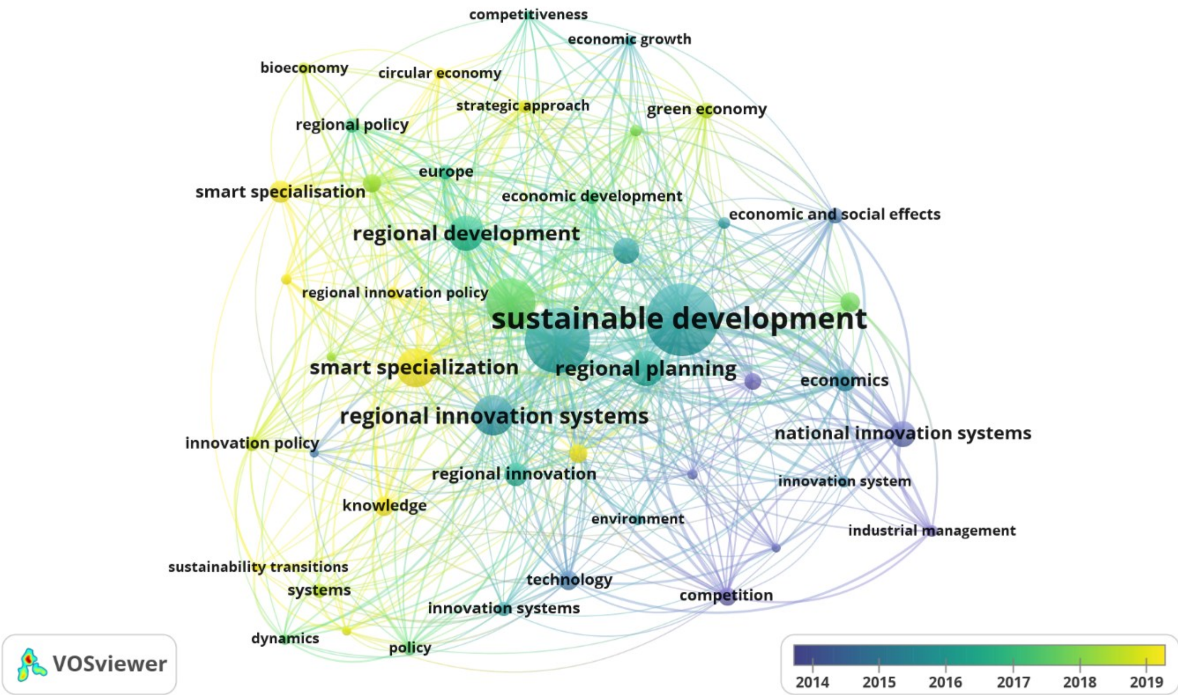

Figure 3: Co-occurrence network of keywords in regional innovation and sustainability literature

Data Source: SCOPUS and WoS

The subset of articles specifically related to smart specialisation and sustainability was separately analysed with a threshold of 4 keywords which was met by 28 of 644 keywords. Using the publication year as a weight reveals that smart specialisation and sustainability were initially analysed from a development perspective, becoming more differentiated in later years with a focus on implementation in regional planning and regional innovation policy. The aspect of sectoral implementation appears to be relatively new, starting with a connection to circular economy (see Figure 4).

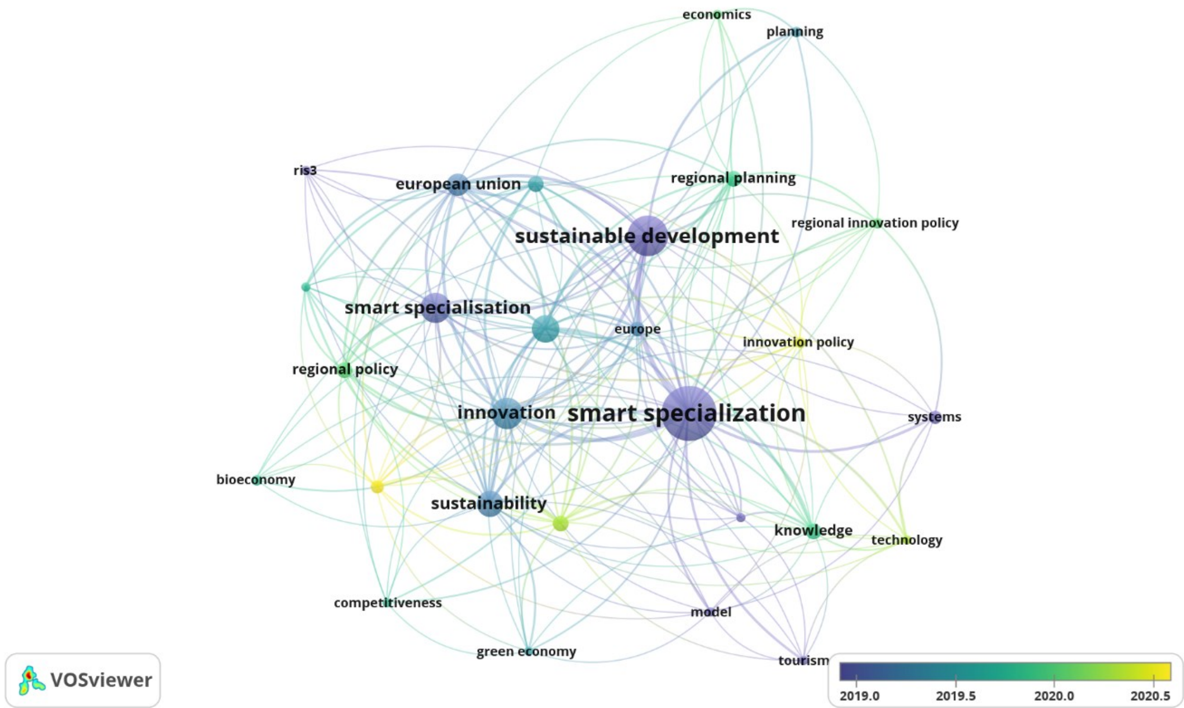

Figure 4: Co-occurrence network of keywords in smart specialisation and sustainability literature
Data Source: SCOPUS and WoS

The bibliometric analyses reveal that the regional aspect of ecological modernisation has already been discussed long before the implementation of smart specialisation, for instance by Brand and de Bruijn (1999). A spatial dimension of sustainability transition has been outlined by Hübner et al. (2000) describing a greened innovation system. Gerstlberger (2004) seconds by pinpointing the emergence of attempts to integrate innovation system structures and sustainability in the 1990s. Regional innovation systems as a basis for green regional transition were promoted by Cooke (2010a; 2012), also identifying already existing "green regional innovation systems" in Scandinavian regions (Cooke, 2010b). The stream of regional innovation systems and sustainability was further developed, among others, by Antonioli et al. (2016) discussing the role of regional systems for a green transition and Trippl et al. (2020) analysing how green restructuring works in regions and which role regional innovation system structures play in this regard. A local perspective on innovative ecosystems was provided by Trillo (2016), while van den Heiligenberg et al. (2017) focused their research on the different types of experimentation and success factors for regional sustainability experiments. Another paper indicating the need to incorporate sustainability concepts in regional innovation systems was presented by Mosurović Ružicić et al. (2021) who analysed energy efficiency in the Serbian construction industry as a case study. Further case studies were presented on the manufacturing sector and the progression of the green industry in Malta (Damato, 2019), or the importance of eco-innovation in regional innovation strategies in Finland (Panapanaa et al., 2014). Also, regions in the United States have been examined in the context of regional innovation systems and sustainability (Chapple et al., 2011). Moreover, Australia has provided several regional cases analysing networks of sustainable businesses for a regional transition towards sustainability

(Potts, 2010). Finally, a particularly strong emerging case for the significance of sustainability and regional economic development is to be found in China (Fu and Ng, 2020).

Theoretically, the topic of regional industry development and path dependency has been discussed particularly in economic geography, innovation studies and thematically related research fields such as transition management (Isaksen and Trippl, 2014; van den Heiligenberg et al., 2017). Since green transition depends on local characteristics and cooperation systems, a cross-fertilisation of different theoretical streams is identified for the past and demanded for the future (Grillitsch and Hansen, 2019; Ghosh et al., 2021). The innovation system literature can thereby benefit from streams such as system transition theory which already in the 1990s called for a new model of innovation to contribute to a new and sustainable pattern of growth (Freeman, 1996). This stream of sustainability transition theory has noticeably increased in past decades (Jänicke, 2008; Markard et al., 2012). Nevertheless, the criticism of Truffer and Coenen (2011) regarding an insufficient treatment of sustainability in economic geography and regional studies was recently renewed by Losacker et al. (2021) and Gibbs and O'Neill (2017), although a positive trend has been observed in the meantime (Schulz and Bailey, 2014).

When it comes to smart specialisation as a specific instrument, the relevance of sustainability has been steadily increasing in recent years. For instance, the Estonian smart specialisation framework has been discussed in the context of structural change towards sustainability (Prause et al., 2019). Also, an article focusing on energy-related priorities in smart specialisation strategies in Europe with the aim to assess regional capability of using place-based strategies to foster renewable energy was presented (Steen et al., 2018). On a sectoral level, smart specialisation has been analysed in the context of blue biotechnology (Doussineau et al., 2020), and circular economy (Tsipouri et al., 2020). While Loeffler (1998) already pointed towards the coherence between policies for innovation and technological development and policies for sustainable development, sustainable development has now become a requirement in EU structural funds and green economy will be part also in the coming programming period 2021-2026 (Máhr et al., 2017; Medeiros, 2017). Apparently, the academic discussion has successfully arrived also in practical policy. The discussion is also ongoing beyond Europe, for instance in the Ukraine (Sychevskiy et al., 2020), or Rwanda (Dosso, 2020).

2.4 Updating Regional Innovation Policy for Sustainability

It has been shown that the idea of regional innovation becomes increasingly connected to sustainability and green economic transition. Against this background, there is an ongoing discussion to update both innovation policy in general and smart specialisation in particular in light of a green transition and environmental sustainability. The scientific discussion to adapt innovation policy is thereby not a fully recent one. Historically, two framings of innovation policy can be distinguished since the aftermath of WW2, namely one focusing on innovation for growth and one on national systems for innovation. Both were shaped by the requirements of their time and brought in new aspects such as innovation as an interactive model rather than a linear process (Schot and Steinmueller, 2018). A third framing of innovation policy is currently evolving and places a stronger emphasis on missions rather than fixing market failures or improving market conditions (Mazzucato, 2015; Kattel and Mazzucato, 2018; Hassink et al., 2022). This framing of mission orientation combines a direction of economic activity, induces cross-sectoral learning, and includes various stakeholder. Thereby, the missions do not define how to reach a defined target but allow for bottom-up experimentation and creativity to develop the most feasible solution (Mazzucato, 2018a; Mazzucato et al., 2019). Mission orientation builds upon criticism regarding previous innovation policy approaches which are regarded as being too narrow, particularly when considering environmental and social challenges such as climate change (Tödtling et al., 2022). Assuming that innovation is a crucial aspect to address the grand challenges, mission orientation can help to focus innovation efforts on the common target of sustainable transition (Foray, 2009b; Grillitsch and Hansen, 2019; Bours et al., 2021). This sense of urgency in redefining innovation is further intensified by the corona pandemic (Breitinger et al., 2021; Abi Younes et al., 2020; Tuffs, 2021). In this context, environmental technologies and societal challenges might replace old targets of successful mission-oriented innovation such as defence, nuclear, or aerospace (Mazzucato, 2018a; Jütting, 2020). Mission orientation also aligns well with innovation systems leading to different proposals to combine both approaches, including "dedicated innovation systems" (Pyka, 2017), "challenge-led innovation policies" (Raven and Walrave, 2020), "mission-oriented innovation systems" (Hekkert et al., 2020), or "challenge oriented regional innovation systems" (Tödtling et al., 2022). Most of these concepts particularly highlight sustainability and the battle against climate change as the desired direction. In the context of grand challenges, several calls recommend transforming innovation systems as building blocks (Kuhlmann and Rip, 2018; Fagerberg and Hutschenreiter, 2019; Weber and Rohracher, 2021; Larrue, 2021). Case studies of the role of regional innovation systems in green transformational change have been provided, among others, by Bugge et al. (2021) and Hassink et al. (2022) focusing on Norwegian and German regions. Mission orientation can therefore be understood as a potential connecting link between innovation studies and sustainability.

European policy has also already been concerned with the direction of innovation by pursuing smart, sustainable, and inclusive growth (European Commission, 2010a; 2017; 2021). Moreover, aspects of mission orientation have been implemented in the scope of the Horizon research framework and the European Green Deal (EGD) is inspired by a sense of mission orientation towards sustainable development (Bevilacqua et al., 2020). At the same time, the investments focus on improving resilience, contributing to cohesion, competitiveness, or overcoming the fragmented status of the European research system (European Commission, 2017; Kattel and Mazzucato, 2018; Mazzucato, 2018b; Pîrvu et al., 2019; Berkowitz, 2020). Regionally, different European states such as the Netherlands, Ireland, or Sweden have implemented mission-oriented approaches (Mazzucato et al., 2019; Hekkert et al., 2020; Angelis, 2021). These experiences are taken up again by calling for a mission-oriented framework to achieve sustainability targets such as a plastic-free ocean (Miedzinski et al., 2019). Also on a general level, innovation in Europe is increasingly regarded as an instrument to address societal challenges such as climate change (European Commission, 2022).

When it comes to smart specialisation, a stronger focus on societal challenges, and the transformation of economic structures has been suggested (Frenken, 2017; Foray, 2018; Neto et al., 2018; Polido et al., 2019; Berkowitz, 2020; Gianelle et al., 2020a; Gerlitz et al., 2020; Esparza-Masana, 2021). However, discussions to reform smart specialisation have already emerged before in the context of another understanding of innovation and to address previous shortcomings of the concept (Tödtling and Trippl, 2018; Mazzucato, 2018a; Balland et al., 2019; Di Cataldo et al., 2020; Laranja et al., 2020; Larosse et al., 2020). This discussion is complemented by demands to strengthen the sustainability dimension of smart specialisation (Gianelle et al., 2020b; Landabaso, 2020; Interreg Europe, 2020; Doussineau et al., 2021; Harding et al., 2021). This discussion blends into its equivalent when it comes to reforming regional innovation systems in light of green transition challenges (Isaksen et al., 2022).

By now, the effort to develop place-based innovation strategies for sustainability has also been politically recognised with the announcement to shift smart specialisation strategies (S3) to S4 by adding a sustainability dimension. A related concept is currently under development by the EU (Nakicenovic et al., 2021). Such a concept could leave in place the constituting elements of smart specialisation, such as prioritisation, stakeholder engagement, or diversification, while introducing a stronger directionality (McCann and Soete, 2020). First S4 pilots are already established (Smart Specialisation Platform, 2021). Moreover, it is argued that the EGD might benefit from an updated version of smart specialisation since it arguably lacks a delivery channel at the local and regional level and a governance mechanism to coordinate investment which could be provided by smart specialisation (Gianelle et al., 2020a). Particularly the participatory quadruple helix and bottom-up experimentation approach of smart specialisation can possibly be beneficial to green transition while exploiting the opportunities of an already established concept that stakeholders are accustomed to (OECD, 2013; Gifford and McKelvey, 2019; Veldhuizen, 2020; Corpakis, 2020; Larosse et al., 2020; Tuffs et al., 2020; Tuffs, 2021).

As there are various policy papers arguing in favour of a new S4 concept, academical criticism is vocalised by authors such as Benner (2020). This criticism advises not to overcharge regional innovation policies with global responsibilities and instead focus on the optimisation of the designing regional innovation strategies and on the evidence-based process behind it. The choice of regional priorities should exclusively rely on sound evidence and regional entrepreneurial discovery instead of a definition of global challenges. It is recognised that smart specialisation can contribute to tackling global challenges in some regions but not sufficiently as an exclusive tool (Kroll, 2017; Benner, 2020). A related academic argument is made with underlining that a crucial driver of green diversification appears to be relatedness whereby political support mostly plays a moderating role (Boschma, 2017; Montresor and Quatraro, 2018; Santoalha and Boschma, 2020).

The dispute between a scientific and a political perspective how to optimally apply smart specialisation is rooted in the concept's nature. Smart specialisation links different policy concepts such as innovation and regional policy with differing interests. Moreover, different scientific disciplines have contributed to shape the concept, as has been shown in the bibliometric analysis. Consequently, innovation instruments such as smart specialisation are loaded with a variety of interests that go beyond the initial idea of ensuring an effective use of public funds (European Commission, 2010b). Over time, the concept of smart specialisation has also been changing constantly. The original academic concept has evolved to be a practice-oriented tool (McCann and Ortega-Argilés, 2016a; Foray, 2019). The original focus on R&D has been dropped in favour of a broader concept of innovation and regional competitiveness (Iacobucci, 2012). Smart specialisation of today is a political rather than an academic tool so that there is no "original" concept to be taken as a role model (McCann and Ortega-Argilés, 2014; Kroll et al., 2014). Also, the targets of smart specialisation have been changed in favour of a general governance tool for economic transformation in Europe (Landabaso, 2020).

Based on the bibliometric analysis in this paper, the argument of smart specialisation as a neutral innovation concept which should not be mixed with transformation can be rejected. As has been shown, sustainability has been a topic in regional innovation for decades and is also not new to smart specialisation. Addressing the grand challenges such as climate change has been discussed already when smart specialisation was conceptualised (Foray, 2009a). Also, the transition towards a resilient and green economy has been named as a priority of smart specialisation, combined with a call to integrate sustainability in regional strategies (Foray et al., 2012; Doranova et al., 2012; Montresor and Quatraro, 2018). By now, more than 90 per cent of smart specialisation strategies contain explicit references to tackling climate change (Prognos and CSIL, 2021; Nakicenovic et al., 2021). Whether smart specialisation is a suitable channel to implement the EGD or regional sustainable transition is beyond the scope of this article, but the connections are long established and far from being a recent development. Nevertheless, the sustainability dimension of regional innovation calls for more research efforts (Gibbs and O'Neill, 2017; Hassink and Gong, 2019; Hassink and Kiese, 2021; Losacker et al., 2021). The mismatch of this topic being covered primarily in policy papers rather than in research articles remains a challenge to be addressed. Since smart specialisation is neither exclusively political nor exclusively scientific, both perspectives should be recognised more equally.

2.5 Conclusion

Climate change and environmental transition are key challenges, and both research and innovation are expected to play an important role in addressing them. The EU has constructed a set of measures in this regard, framed as a European Green Deal (EGD) and plans to update its political instruments accordingly. Against this background, particularly smart specialisation as the primary instrument of innovation and cohesion policy in the EU is subject to increasing debate. This is due to the fact that smart specialisation originally was designed as an instrument of regional transition focusing on development potentials and identifying those economic sectors promising the most favourable development potential. As the concept has been around for only roughly a decade and regional transition processes work out in longer temporal horizons, the efficiency of smart specialisation is still subject to debate. However, its cooperative and inclusive approach to identification of regional strengths as well as its broad institutionalisation among European regions currently put smart specialisation in the centre of attention. Policy projects such as the EGD are characterised by the sheer monumentality of their goals and a comparably short time to deliver. Accordingly, using established instruments as delivery channels might be an option of reforming existing policies rather than developing new ones (see Isaksen et al. (2022) for a more detailed overview of this debate).

While an increasing number of policy papers argues in favour of redirecting smart specialisation to become a delivery channel of sustainable transition on regional level, academic publications advise a stronger focus on the efficient implementation of innovation policy without overcharging it with societal challenges. This dissent is rooted in the multi-layered origins of smart specialisation as a political tool embedded in academic theory. What this tool is able to achieve and how its purpose can be adapted for sustainability transitions is therefore strongly influenced by different perspective. The short time frame that smart specialisation is around, and the high number of changes and new aspects added to it, do not help to paint a clear picture either. There is basically a debate on principles whether to take the time to monitor smart specialisation and work out details to optimise its function as an instrument of regional innovation or to use the existing foundation and re-direct the concept to contribute to the green transition challenge as well.

In this context, the bibliometric analysis in this paper has shown that sustainability is not a new topic neither for regional innovation nor for smart specialisation. Instead, the theoretical foundations on leveraging innovation systems for green transition have already been scientifically established and therefore could provide a basis for new developments manifesting at the moment. It becomes clear that both extremes in current discussions on smart specialisation, namely the "instrument is purely structural without a sustainability perspective" versus "the sole purpose should be enabling a green transition" neglect important nuances. It is beyond the scope of this paper to analyse whether smart specialisation is a suitable framework to implement sustainable transitions at regional level but both areas, smart specialisation and sustainable transition, have the potential to benefit from each other. To exploit this potential, further research on the geographical aspect of green transition, respectively the sustainability aspect of regional innovation is required. First qualitative analyses on smart specialisation as a regional instrument to leverage a sustainable transition have already been presented (e.g., Hassink and Kiese, 2021). Certain regions, for instance in Sweden, have also already implemented sustainability as a core target of regional smart specialisation strategies (e.g., Nakicenovic et al., 2021).

It can be drawn as a finding of the analysis in this paper that the current discussion on implementing a green transition in Europe can benefit from earlier research focusing on sustainability in regional innovation systems. The same holds for the ongoing debate on updating smart specialisation which repeats discussions that have already been brought up several decades ago. It can be recommended to take the articles into account that have been identified as relevant throughout this paper to leverage the potential to enrich the current debate with new perspectives and make use of practical examples that have already been gathered. After all, it will be an ongoing task for all disciplines involved – geography, innovation, transition, sustainability among others – to produce an answer if and, if yes, under what circumstances smart specialisation and sustainable transition align and to provide policymakers with the according recommendations.

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Chapter 3

Inter-organisational Sustainability Cooperation among European Regions and the Role of Smart Specialisation

Author: Mirko Kruse

Abstract

Innovation represents one of the most crucial levers for regional prosperity and sectoral renewal. Additionally, it is applied to address challenges such as a sustainable transition and the battle against climate change. Since innovation is the result of cooperation between different actors with different backgrounds, the topic is increasingly studied from a systemic perspective. Here, not only internal cooperation but also cross-border connections between regions become important. While smart specialisation, a European policy for innovation and cohesion, highlights the role of interregional cooperation, practical manifestations and research on this aspect have remained limited so far. This article addresses this gap by discussing the relevance of interregional cooperation for knowledge creation and presents empirical evidence on cooperation between organisations in different European regions in the field of environmental sustainability. The underlying dataset was constructed from Horizon 2020 (H2020) research projects with Northern Germany as an exemplary set of regions chosen as the core of a social network analysis (SNA). The findings reveal that involvement in interregional projects is concentrated particularly in urban regions and correlates with GDP and population density. On the other hand, also organisations in regions with different structural characteristics are involved in interregional cooperation and H2020 managed to introduce new cooperation patterns. Finally, the empirical data do not adequately match the regional smart specialisation strategies (S3) which raises questions on updating smart specialisation as a policy.

Keywords: smart specialisation; innovation policy; Europe; interregional cooperation; Horizon 2020; social network analysis.

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3.1 Introduction

The economy in market-based societies is subject to constant structural change. Here, innovation and knowledge creation are key factors for companies, sectors, regions, and countries to successfully adapt to technological change (Landabaso, 1997). This recognition is even more true nowadays considering the multitude of severe events calling for adaptations of production processes, consumption patterns, value chains, or regulatory frameworks. Among these events are the Covid-19 pandemic, geopolitical tensions, the emergence of disruptive technologies, or the increasing urgency for a sustainable transition of the economy in accordance with planetary boundaries (Gong et al., 2022). Successfully managing said transition will require exploiting innovative capacity at all levels to develop new solutions and create new technological pathways. Innovation here functions as an instrument to tackle grand challenges including, but not exclusively, the sustainable transition of the economy (Fagerberg and Hutschenreiter, 2019; Losacker et al., 2021). Thereby, the distribution of innovative activity in space is not randomly distributed but tends to be spatially concentrated. As a consequence, the geography of innovation receives increasing attention (Coenen and Morgan, 2020).

In Europe, the European Commission has introduced the European Green Deal, a package of ambitious targets, specific policies, incentives, and directives, to achieve several objectives: overcome the pandemic-related recession, increase resilience against further crises, as well as the battle against climate change and the aspiration to become climate neutral (European Commission, 2021). The central levers to address these objectives are research and development (R&D) and innovation. Accordingly, the concept of smart specialisation, one of the key strategies of European innovation policy, comes into the spotlight again (Doranova et al., 2012; European Commission, 2020a). This approach was inspired by theories of regional innovation systems and the exploitation of place-based potential and has seen a remarkable career in the last decade following its implementation (Doranova et al., 2012; Van den Heiligenberg et al., 2017; Giustolisi et al., 2022). The concept has provoked academic criticism primarily because its origins are both political as well as theoretical, creating a certain level of fuzziness. As the concept now is increasingly discussed again in the context of the Green Deal and the sustainable transition of European regions, several questions must be answered, and shortcomings are to be addressed. One of the most severe shortcomings of smart specialisation so far is its outward orientation, meaning the relevance of external cooperation and knowledge flows between regions. While the positive effects of knowledge transfer and mutual learning have been demonstrated empirically and smart specialisation conceptually strives to facilitate interregional cooperation (e.g., Guastella and Van Oort, 2015; Mitze and Strotebeck, 2018; Balland et al., 2019), practical implementation and empirical analyses have remained limited.

Thereby, deepening interregional cooperation is also crucial for the political goal of a gradual European integration and might become even more important as the current phase of globalisation appears to come to an end and internal cooperation increases in importance (Brodzicki, 2017; Gong et al., 2022). The fragmented nature of the European research system has been identified as a major weakness preventing Europe from exploiting its full potential and catching up with more unified competitors such as the United States (European Commission, 2017). To exploit the full potential of European cooperation, which is also required to successfully address the grand challenge of climate change, existing policies such as smart specialisation will have to change as well. The paper at hand aims to contribute to this discussion by providing empirical evidence on interregional cooperation in Europe in the field of environmental sustainability. Thereby, a novel dataset to quantify cooperation is constructed analysing cooperative patterns between organisations in different European NUTS 2 regions. As regions are no actors in a narrower sense, organisations within these regions are used as a proxy. While the majority of previous studies in this particular field rely on qualitative studies (e.g., Fellnhofer, 2017), further empirical tools such as social network analyses and statistical methods are applied to provide a thorough overview and allow for deeper insights. To do so, the remaining of this paper is structured as follows: section 2 introduces the policy of smart specialisation in the context of European innovation policy in general and discusses its recent relevance in the context of sustainability. In the following, interregional cooperation and its embeddedness in innovation system studies is outlined and discussed with regards to smart specialisation. Afterwards, section 3 presents the data and methods used for the analysis before the findings are presented. The paper closes with a concluding outlook in section 4.

3.2 Smart Specialisation, Sustainability, and Interregionality

3.2.1 The Idea of Smart Specialisation

Smart specialisation represents one of the central strategies of European innovation and cohesion policy. The theoretic foundation of the concept is to be found in literature on regional innovation systems (RIS). This approach emphasises the crucial role of the regional level and geographical proximity between regional innovation actors for the generation of new knowledge and innovation (Trippl, 2008). The RIS concept was developed in the 1990s and builds upon the foundations of preceding theories such as national innovation systems (NIS), transition studies, innovative milieux, or industrial districts (McCann and Ortega-Argilés, 2015; Tödtling and Trippl, 2018; Rakas and Hain, 2019). Thereby, the rationale of smart specialisation as a policy goes back to the identification of, one the one hand, a manifesting productivity gap between Europe and other economic areas such as the United States, and, on the other hand, internal development gaps within Europe, particularly in the process of the Eastern enlargement (Janik et al., 2020). At the same time, it was discussed how to increase the efficiency of European cohesion and innovation policies as it showed that previous attempts had resulted in fragmentation and inefficient overlaps (Larosse et al., 2020; McCann and Soete, 2020). Previously, regional funding was invested thinly across several sectors without resulting in significant impact on innovation capability and structural renewal as a result (Gianelle et al., 2020a). Smart specialisation came into play as the result of merging the two streams of discussion on interregional inequality and updating European cohesion policy (Foray et al., 2011; Kruse, 2023).

Content wise, the pivotal idea of smart specialisation is place-based, meaning that the idea of a "one-size-fits-all" solution in terms of innovation policy is rejected. Instead, it is argued that each region needed to find its own niche and develop its own strategy to innovation instead of trying to emulate experiences from apparently successful regions (Gianelle et al., 2020a). As regions are unique in their economic and social structure, a successful strategy for one region might be a dead-end for others (Di Cataldo et al., 2020). Thereby, smart specialisation should motivate regions to prioritise and focus their resources on those innovative sectors which they are specialised in, and which offer the highest probability of performing well in the future (Rusu, 2013; Foray, 2014; Mora et al., 2019). By doing so, comparative advantages are to be built and potential agglomeration benefits can be realised (Gianelle et al., 2020a). Thereby, the choice of priorities should recognise the structural renewal of existing specialisations by focusing on complementing industrial and technological activities (Foray et al.; 2009; Vezzani et al., 2017; Balland et al., 2019). The selection of said investment priorities should not come from top-down planning but emerge from a process of entrepreneurial discovery, meaning the explorative involvement of regional experts from different backgrounds (Foray, 2013; Foray and Goenaga, 2013; McCann and Soete, 2020).

After its establishment, smart specialisation witnessed a remarkable career in European policy, being promoted as a fundamental pillar of cohesion policy in 2014 and as an ex-ante conditionality for territories to be eligible for European funding (European Union, 2013; Janik et al., 2020; Di Cataldo et al., 2020). By now, most regions in Europe have applied the smart specialisation concept by developing individual smart specialisation strategies (S3), and the variety and quantity of research has increased remarkably (McCann and Soete, 2020). However, recent studies imply that smart specialisation is only partially implemented in regions and persistence remains to change established processes on a regional level (e.g., Gianelle et al., 2020b; Larosse et al., 2020; D'Adda et al., 2021). Moreover, the fast success story of smart specialisation made the concept an example of *"policy running ahead of theory"* (Foray et al., 2011: 1) and several shortcomings have been outlined in recent years. One aspect of criticism refers to the term "specialisation" which often leads to the misunderstanding of interpreting smart specialisation as a modern kind of Porter-inspired cluster policy whereby the concept aims towards diversified specialisation (Asheim et al., 2016). Further criticism revolves around the questions which regions do benefit. When smart specialisation was established, it was promoted as a measure to support less-developed regions while it later became clear that those regions benefit to a smaller degree as they lack the institutional capacity to implement the concept and conduct the process. Nevertheless, the basic idea of smart specialisation is widely received to be positive, underlining the place-sensitive approach, the focus on knowledge and innovation, and the involvement of regional actors in entrepreneurial discovery (Hassink and Gong, 2019; Foray, 2019).

3.2.2 Smart Specialisation and Environmental Sustainability

The partial implementation in practice and ongoing clarifications in theory underline that smart specialisation is far from being a completed concept. As the programming period 2014-2020 recently terminated, the discussion how to update cohesion policy and smart specialisation for 2021-2027 has been extensive and remains ongoing. It is agreed that the update process should involve a critical evaluation of the past as well as a discussion which targets to address with smart specialisation (Tuffs et al., 2020a). In this regard, the primary task of smart specialisation has been to support innovation in regions helping them to shape structural change (Gianelle et al., 2020a). Recently, the discussion accelerated again to apply regional innovation strategies in order to foster green growth and support certain challenges such as renewable energy or eco-innovation (Foray et al., 2012; Esparza-Masana, 2021). While support in this challenge is required in every region, particularly less-developed regions which have been suffering from regional decline and are frequently specialised in non-green technologies that are likely to suffer from structural change, might benefit (Pîrvu et al., 2019; Provenzano et al., 2020).

The idea to deploy innovation policy to address certain targets is not new but aligns with earlier strategies such as Europe 2020 which called for not only growth in itself but smart, inclusive, and sustainable growth (McCann and Soete, 2020). This aspiration has recently been taken up by the idea of mission-oriented innovation policy as a new paradigm that regards innovation as an instrument to address larger societal missions. As previous missions have focused on topics such as defence, one of the most recent and pressing challenges to be addressed is climate change (Mazzucato, 2018a; Mazzucato et al., 2019). In this context, it is discussed whether smart specialisation might play a role for the implementation of the European Green Deal by integrating the targets of the Sustainable Development Goals (SDGs) and structural renewal in regional innovation strategies (Montresor and Quatraro, 2018; Gifford and McKelvey, 2019; Larosse et al., 2020; Nakicenovic et al., 2021). The discussion goes so far as considering renaming smart specialisation strategies (S3) into smart specialisation strategies for sustainability (S4). This need for reinterpretation, redesign, and reintegration of smart specialisation is also officially recognised by the European Commission (McCann and Soete, 2020; Nakicenovic et al., 2021). Although sustainability and smart specialisation have already been intertwined over time, the idea of including additional dimensions rather than strengthening the core idea first has also provoked criticism (Benner, 2020; Kruse, 2023).

However, research on how smart specialisation could contribute to sustainable development at regional level is still limited but increases gradually. At the same time, the attention towards environmental innovation and sustainability is also growing in related fields such as regional studies and economic geography (e.g., Truffer and Coenen, 2011; Markard et al., 2012; Gibbs and O'Neill, 2017; Montresor and Quatraro, 2018; Losacker et al., 2021). In the context of smart specialisation and sustainability, existing research has been focusing on the opportunities for regional innovation offered by circular economy approaches (Hristozov and Chobanov, 2020), renewable energy (Steen et al., 2018), or structural change in old industrial areas (Prause et al., 2019) with certain regions as examples (Polido et al., 2019).

3.2.3 Interregional Cooperation in Europe

Interregional collaboration concepts are based on the recognition of a crucial role of regions for innovation. This assumption is backed by economic geography and extensive research analysing the concentration of economic activity in time and space (Audretsch and Feldman, 2004; Guastelle and van Oort, 2015; Hidalgo et al., 2018). Accordingly, regions exhibit a critical mass of economic actors interacting in a regional innovation system allowing for a free flow of knowledge and the emergence of innovation. Since spillovers do not easily travel across space, spatial concentration of innovative activity is the result. This effect is likely to be self-enforcing represented in the fact that most of the growth in Europe in the last decade has been concentrated in cities (Asheim et al., 2018; McCann and Soete, 2020; Pinheiro et al., 2022). Therefore, regions are also discussed as ideal starting points in the context of sustainable transition (Potts, 2010; Montresor and Quatraro, 2018).

However, regions do not act in isolation and positive effects do not only arise from intra-regional cooperation but also from inter-regional cooperation with other regions. Such external cooperation contributes to innovativeness, particularly in less-developed regions, shapes regional development and diversification, allows for the exploitation of synergies, and prevents regional lock-in effects through the promotion of diversification (e.g., Benneworth et al., 2014; De Noni et al., 2017; Santoalha, 2018; Mikhaylov et al., 2018; Schulz, 2019). Particularly in a globalised learning economy, the external aspect of cooperation should therefore not be left out of consideration. This is even more true as the recent framing of innovation policy with a stronger focus on transformative change also highlights the relevance of interregional cooperation (McCann and Ortega-Argilés, 2016; Schot and Steinmueller, 2018; Giustolisi et al., 2022). Grand challenges, such as a sustainable economic transition, require different perspectives and diverse knowledge to be addressed and lay beyond the scope of individual regions or even countries (Attolico and Scorza, 2016; van den Heiligenberg et al., 2017; Angelis, 2021). Empirically, it is suggested that knowledge spillovers depend on distance and different kinds of proximity – among others geographical, relational, functional, institutional, cognitive, social, or technological proximity – between regions (Lundquist and Trippl, 2009; Boschma and Frenken, 2010; Basile et al., 2012).

Accordingly, innovation systems, focusing on the role of interaction between different actors, stretch across borders. Concepts of global innovation systems (GIS), national innovation systems (NIS), or technological innovation systems (TIS) have adopted a cross-border approach from early on (Carlsson, 2006; Shapiro et al., 2010; Binz and Truffer, 2017). For instance, Chesnais (1992) demonstrated how the operations of multinational enterprises influence the structure of NIS. regional innovation systems (RIS) have for a long time been analysed in isolation rather than in cooperative cross-border settings (Gosens et al., 2014; Li et al., 2022). Stepwise, the approach has been broadened leading to the establishment of the concept of cross-border regional innovation systems (CBRIS). Conceptually, CBRIS incorporate informational exchange and knowledge diffusion across borders and can be understood as the most advanced form of integration between regions towards an integrated innovation space (Lundquist and Trippl, 2009; 2011; Asheim et al., 2011; Pietrobelli and Rabellotti, 2011; Korhonen et al., 2021). Interregional cooperation across borders can also relate to a worldwide level, associated with foreign direct investment (FDI), or global value chains (GVC) concepts (Audretsch and Feldman, 2004; Asheim and Herstad, 2005; Boschma, 2021). However, cross-border cooperation is a more common topic in the literature, referring to the high level of proximity between neighbouring regions (Lepik and Krigul, 2014; Scott, 2015).

In Europe, research on cross-border cooperation is long established as it can be understood as an aspect of European integration (De Sousa, 2012; Del Bianco and Andevy, 2015). The process of transnational and interregional cooperation in Europe increased in the 19th century and took off after World War 2 resulting from a political will for integration (Van der Vleuten and Kaijser, 2005; Scott, 2015). This understanding was facilitated by agreements such as the Maastricht Treaty and institutionalised in cross-border cooperation agreements, or the establishment of "euroregions" and "macroregions" as testbeds for practical transregional and transnational cooperation (Lina and Bedrule-Grigoruta, 2009; Hudec and Urbancikova, 2010; Studzieniecki, 2016; Noferini et al., 2020) Moreover, an additional incentive to E cooperation across regions is the prospect to fully exploit the potential of the European internal market by overcoming its fragmentation. The establishment of a European research area with coordinated and integrated interregional research activities has been promoted as a vision in this regard (Frenken et al., 2007; European Commission, 2020b; Rakhmatullin et al., 2020). Interregional projects such as INTERREG or HORIZON represent an institutionalisation of this aspiration (Cassi et al., 2008; Martin-Uceda and Vicente Rufí, 2021; European Commission, 2022). Also, European instruments such as smart specialisation cannot be separated from the idea of interregional cooperation. However, since smart specialisation has emerged from RIS studies, the limitations described above apply equally and the almost exclusive focus of smart specialisation on endogenous knowledge flows is among the most common criticisms mentioned in academic research and policy documents (Tuffs et al., 2020b; Woolford et al., 2021).

Until now, the majority of smart specialisation strategies (S3) do not include or facilitate interregional cooperation despite an "outward-looking" orientation being named as a constituting element of the approach from the very beginning (Foray et al., 2012). This aspired outward orientation was backed by the fact that structural change and regional innovativeness both benefit from cooperation, external connectedness, and knowledge exchange with regions facing similar challenges. Moreover, the resources and knowledge that a region needs for its development might not be available at home but outside the region. Different regional characteristics therefore allow for different perspectives and solutions, as smart specialisation highlights with its focus on finding the niche and regional competitive advantage for future specialisation (McCann et al., 2015; Mariussen et al., 2019; Foray, 2018). Also, the cohesion aspect of smart specialisation is addressed by extra-regional collaboration since particularly less developed and technologically lagging regions often lack the internal capabilities and networks that they require for a catch-up process (Radosevic and Ciampi Stancova, 2015; Barzotto et al., 2019; Ghinoi et al., 2020). The same holds for the focus on grand challenges such as climate change which require the cooperation of different regions. In this regard, Castellani et al. (2022) found indications of a positive influence of different forms of FDI on regional specialisation in green technologies, indicating a positive influence of cooperation for a green transition. Most likely, an exclusive focus on European regions might not suffice but an improved European research cooperation appears to be a necessary foundation for a successful implementation of the Green Deal targets (Woolford et al., 2021; Tuffs et al., 2020a). Instead, also cooperation with non-EU regions considering certain challenges might come into play (Uyarra et al., 2014).

However, not only implementation but also research on interregional cooperation and smart specialisation has remained limited so far (Radosevic and Ciampi Stancova, 2015; Balland and Boschma, 2021; Weidenfeld et al., 2021). Apart from policy papers and qualitative studies, for instance by Muller et al. 2017, authors like Gianelle et al. (2014), Girejko et al. (2019), and Kruse and Wedemeier (2021) present methodologies to identify common priorities between regions as a foundation for common smart specialisation strategies (S3). However, these papers do not empirically test the efficiency of cooperation and confine to offering a theoretical toolkit for policymakers to assess the potential of cooperation with other regions. Other, more qualitatively oriented, papers presented by Sörvik et al. (2016), or Mueller-Using et al. (2020) place an emphasis on the factors that motivate or prevent regions from cooperation. As a result of these shortcomings, transnational collaboration and strengthening the outward orientation of smart specialisation are among the demands when it comes to updating cohesion policy and smart specialisation (Esparza-Masana, 2021; Woolford et al., 2021). This also includes strengthening the already existing interregional partnership platforms on smart specialisation and SDGs which the European Commission has been working on since 2015 and previous approaches to interregional collaboration such as the Vanguard initiative (Rakhmatullin et al., 2020; Smart Specialisation Platform, 2022a). Moreover, the interregional innovation investment (I3) instrument represents an additional European attempt to promote interregional investment particularly in areas relevant for transformation. The future interconnection with smart specialisation and other instruments, however, is still under development (Tuffs et al., 2020b).

3.3 Interregional Scientific Collaboration in Europe

3.3.1 Materials and Methods

The most common approach in academic research to quantify and map interregional knowledge flows is the application of patent statistics and co-patenting analyses involving different regions. With a focus on Europe, Greunz (2005), Sebestyén and Varga (2013), Guastella and Van Oort (2015), Montresor and Quatraro (2018), Santoalha (2018), Bazotto et al. (2019), Balland and Boschma (2021), and Li et al. (2022) apply patent-based analyses. Moreover, von Proff and Brenner (2011) deploy this approach for German regions, and Yang et al. (2019), and Dosso and Lebert (2020) do the same for co-patenting on a worldwide level. Co-patenting data are also used in China, e.g., by Ye and Xu (2021) to construct inter-city cooperation networks, by Cao et al. (2021) to map the technological field of energy saving, or by Sun and Cao (2015). However, it has extensively been discussed in the literature that patent data come with several limitations. One of the most striking ones is that not all kinds of research necessarily lead to patents as not all inventions are patentable or patented (Grilliches, 1998). Moreover, patenting activity differs significantly across scientific disciplines and technologies (Hoekman et al., 2008). This leads to a regional bias with less-developed regions being structurally neglected in patent-based analyses (Kakderi et al., 2020). Therefore, other measures of interregional cooperation are suggested and applied, e.g., co-publications (Hoekman et al., 2008; Acosta et al., 2011), foreign direct investments (FDI), or monetary flows (Makkonen et al., 2016; Todeva and Rakhmatullin, 2016). Interregional trade data flows in Europe are assessed by Gianelle et al. (2014) or Basile et al. (2016), each based on data from PBL Netherlands Environmental Assessment Agency. Wall and van der Knaap (2011) construct a data set of multinational companies and their ownership linkages with international subsidiaries, while Mitze and Strotebeck (2018) deploy a commercial industry directory to assess research collaborations in the German biotechnology industry. Less common are qualitative approaches in interregional analyses. Here, interview-based studies are presented by Miörner et al. (2018), and Uyarra et al. (2018), while cooperation networks in cross-border regions are qualitatively analysed by Fratczak-Müller and Mielczarek-Zelmo (2020).

To empirically assess interregional cooperation at regional level, particularly in the field of environmental sustainability, an appropriate dataset is required. For the European case, this task is challenging for two reasons: on the one hand, the European statistics department Eurostat does not provide regional trade data which would make a good indicator of interregional involvement and interregional networks. On the other hand, sustainability is a cross-cutting topic which cannot be assigned to traditional sector classifications such as the NACE classification. The majority of the previously described analytical approaches falls short of the task of constructing a regional level database on sustainability cooperation. Instead, it was decided to use the CORDIS (Community Research and Development Information Service) database for this task. The CORDIS database contains information on research projects funded by the EU under the HORIZON and FP7 programmes. Although there are other funding schemes such as INTERREG which particularly focus on interregional cooperation, these data are less accessible and not compatible with CORDIS and have been dropped for these reasons. Here, it needs to be remarked that cooperation between organisations is tracked rather than cooperation between regions as such. The geographical location of these organisations in different NUTS 2 regions, however, allows to apply inter-organisational cooperation as a proxy for cooperative patterns between regions although the analytical level is different, and organisations rarely address policies or strategies as regions do as a motivation.

One of the advantages of CORDIS in comparison to other approaches is that the project data can be transformed to a quantitative form and filtered thematically. For this paper, the projects funded under the Horizon 2020 research and innovation programme were analysed (last update 21.01.2022). Horizon 2020 was running from 2014-2020 with a budget of about €80 billion to fund multi-national research and innovation projects in Europe dealing with societal challenges (Mazzucato, 2018b; Giarelis and Karacapilidis, 2021). These programmes have a scientific focus and include diverse organisations from different regions primarily from Europe but also from beyond (Boezeman and de Coninck, 2018). The CORDIS database lists qualitative information about projects, their focus and results, as well as about participating organisations, their type, location and role. Since the programming period recently ended and Horizon 2020 was replaced by Horizon Europe, the list can be assumed to provide a complete overview (CORDIS, 2022). However, it has to be noted that Horizon 2020 primarily addressed technology-oriented project partners. While Interreg might have provided a more general picture, analysing Horizon data inevitable involves a technology bias.

To produce a subset of those projects related to environmental sustainability for later analysis, a two-step approach was applied: 1) projects were selected on basis of funding calls related to environmental sustainability (see Annex 1). 2) the project list was filtered for the key terms "green" (1,622 projects), "sustainab*" (1,538 projects), and "environment" (9,179 projects) in their title or abstract. Finally, both lists were merged, doublings eliminated, and each project abstract qualitatively checked to exclude projects not fitting the desired criteria of environmental sustainability. This allowed to reduce the set of 23,378 projects involving 172,730 organisations funded by Horizon 2020 to 9,777 projects and 39,519 organisations. The postcodes associated with the organisations involved in the projects were then used to link each region to the respective NUTS 3 and NUTS 2 region. Afterall, 72 organisations could not be linked to a NUTS region due to missing information. Moreover, each project was attributed to a textual topic to allow for further differentiation. 517 projects were related to "bioeconomy", 114 projects to "blue economy", 451 to "circular economy", 410 to "climate research", 85 to "sustainable construction", 1,429 to "renewable energy", 555 to "sustainable mobility", and 307 to "sustainable technology" (see Annex 2). The numbers give an impression of the internal focus of environmental sustainability projects in Horizon 2020.

To gather information about interaction between organisations and regions within the dataset, a social network analysis (SNA) was conducted. SNAs are receiving increasing attention particularly in economic geography and regional innovation studies as they allow for an empirical analysis of inter-organisational interaction as well as knowledge flows inside a network (Tel Wal and Boschma, 2009; Stuck et al., 2015). Studying the relationship between actors promises to reveal additional information compared to studying the actors independently. Moreover, SNAs are regarded as an appropriate tool to analyse cross-regional and interregional innovation systems (Cooke, 2001; Stuck et al., 2015). Common analytical aspects of SNAs involve the identification of the role of actors in a network and their relationship among each other as well as the identification of hubs, communities, or authorities via quantitative graph analysis (Wasserman and Faust, 1994; Bandyopadhyay et al., 2010; Alamsyah et al., 2013; Tabassum et al., 2018). SNAs can be constructed on different kinds of data that involve various regions (Cidell, 2020; Ghinoi et al., 2021). Also, CORDIS data have previously been used for SNA, for instance by Ertan (2016), based on project data from the 7th Framework Programme, the predecessor of Horizon 2020, or by Bralić (2018), Doussineau et al. (2020), and Morisson et al. (2020) each based on Horizon 2020 data.

In this paper, the full dataset of cooperation is additionally broken down to a regional subset covering Northern Germany (involving the NUTS 2 regions DE50 – Bremen, DE60 – Hamburg, DE80 – Mecklenburg-Vorpommern, DE91 – Braunschweig, DE92 – Hannover, DE93 – Lüneburg, DE94 – Weser-Ems, DEF0 – Schleswig-Holstein). Constructing a subset was motivated by the fact that the full dataset would be too large to analyse individual connections so that a focus had to be applied. Thereby, Northern Germany qualified itself through the diverse nature of regions including large cities (Hamburg, Bremen) one the one hand and more rural regions (Lüneburg, Weser-Ems) on the other hand. Also, the region has been analysed in the context of sustainable transition, matching the focus of this paper (Hassink et al., 2021; Kruse and Wedemeier, 2022). This regional subset complements Morisson et al. (2020) who conducted a network analysis based on the Italian region of Calabria. Constructing a network with the eight Northern German NUTS 2 regions as the core and without modelling connections among the partner regions with each other results in an SNA with 9,179 edges and 357 unique combinations of the eight regions cooperating with each other and other regions around the world. Calculations were conducted using the R Studio programme (version 4.2.0) including the igraph and sna packages (Csardi and Nepusz, 2006; Butts, 2020). Graphical illustrations were prepared using the Gephi programme (version 0.9.5 202205022109).

3.3.2 Results

In a descriptive way, Figure 1 and Figure 2 illustrate the absolute number of organisations involved in projects on environmental sustainability in European regions. Thereby, it was decided to abstain from a differentiation subject to certain years as the analysed projects have different durations. Moreover, project funding received was not included as a weight since it did not match with further analytical steps of SNA. Instead, the number of organisations was accumulated per region as a measure of the strength of interregional involvement in sustainability research (for the list of regions and number of identified organisations on NUTS 2 level, see Annex 3). The geographical mapping follows the NUTS classification ("nomenclature of territorial units for statistics") provided by Eurostat (2021). As can be seen, the distribution is not even but organisations involved in interregional projects are highly concentrated in certain regions. Generally, there is no clear West-Est or North-South picture as the intensive of cooperation is highly shaped by individual hotspots (see Figure 2). While these hotspots tend to be capital regions or highly urbanised areas, they are found in all parts of Europe. A dominance of Western or Northern Europe, as found in other European studies (e.g., Kruse et al., 2022), is not observable here. However, in Eastern Europe, many regions have not been involved in projects on environmental sustainability so far which represents a potential still to be tapped.

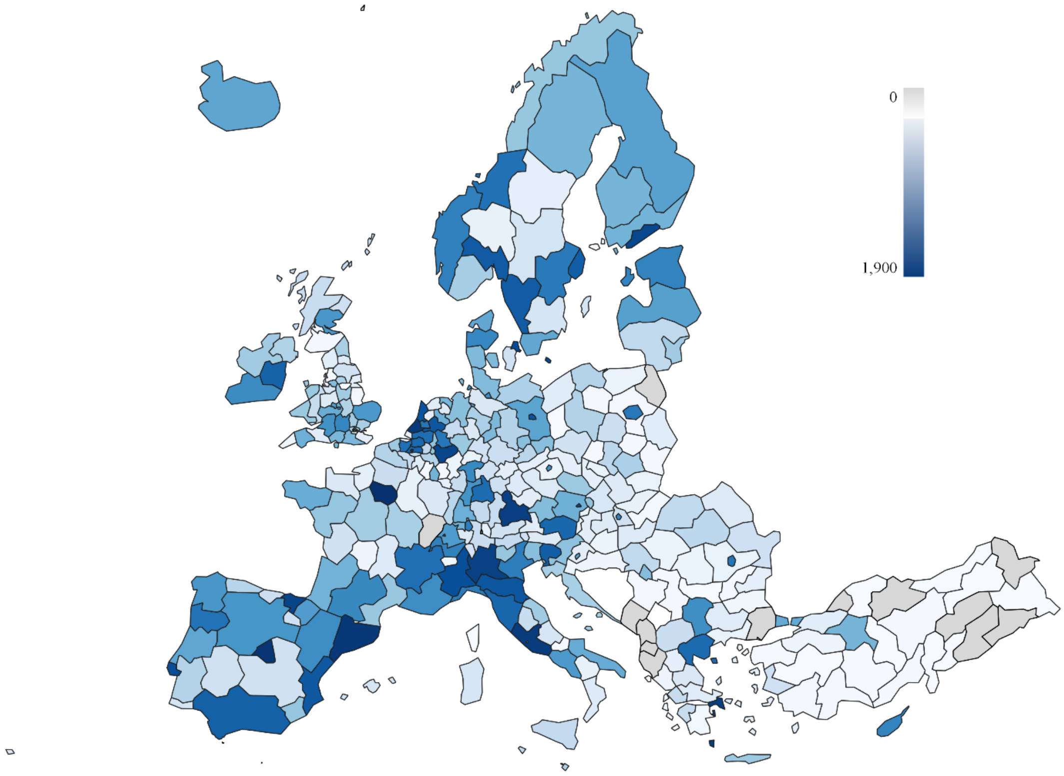


Figure 1: Organisations involved in interregional H2020 Sustainability Projects, NUTS 2 Level, 2022
Data source: CORDIS (2022)

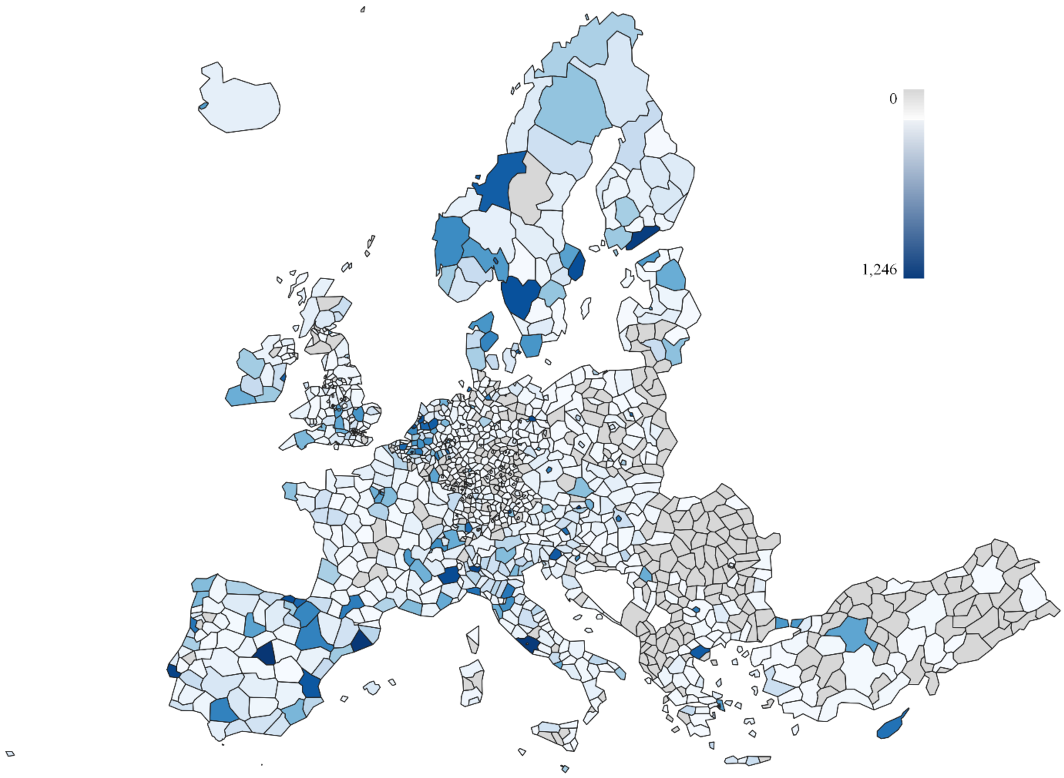


Figure 2: Organisations involved in interregional H2020 Sustainability Projects, NUTS 3 Level, 2022
Data source: CORDIS (2022)

To empirically test whether certain structural characteristics of regions influence the number of organisations involved in interregional research, a Pearson's product-moment correlation was calculated and tested using NUTS 2 level data (see Table 1). The tested variables included GDP per capita at current market prices (*GDP*) and gross value added (*GVA*) which allow for a quantification of the development stage of the regional economy. The indicators for median age of the population (*AGE*), and population density (*DENSITY*) describe regional structures while gross domestic expenditure on R&D (*GERD*) refers to the relevance attributed to research in regions. Moreover, indicators were analysed that can function as a proxy for environmental aspects. Since the availability of environmental data for Europe is limited, particularly at regional level, these data can only be an approximation. An indicator was included measuring the employment in waste collection, treatment and disposal activities as well as materials recovery (*WASTEEMP*) as well as an indicator measuring the amount of municipal waste in tonnes (*WAGEGEN*). The latter data come from a pilot project and therefore are only available for 2013 while all other data refer to 2019 as the base year. The generation of waste gives an idea of the public awareness towards environmental affairs. Finally, an index was included measuring the need for additional cooling of buildings as an indicator of regional climate change impact (*COOLING*) (Eurostat, 2023a; 2023b; 2023c; 2023d; 2023e; 2023f; 2023f; 2023g). Naturally, testing data of a single year does not yield a sufficient number of observations to provide empirical significance. However, the correlation test helps to interpret and classify the results.

The p-value of the results implies correlations of different strengths between the engagement of regions in environmental sustainability research projects and the tested variables. For the interpretation of results, the effect strength suggested by Cohen (1988) is applied. Based on this assumption, GDP and GVA underline that the involvement in interregional projects is affected by economic strength. Interestingly, the spending on R&D (*GERD*) is only moderately correlated allowing to conclude that research projects are also initiated in regions which are still in the process of transformation towards a knowledge economy. Also, the population density is only moderately correlated as well as the median age of the population with a weak negative correlation. These results suggest that highly urbanised regions are more equipped to get involved in interregional cooperation, but an urban structure does not represent a definite requirement. Finally, the environmental indicators are moderately (*WASTEGEN*) and highly correlated (*WASTEEMP*). This can be seen as an indication that the involvement in interregional sustainability projects does indeed reflect regional environmental awareness to a certain degree and the involvement can be interpreted also as a measure of regional sustainability relevance. On the other hand, the regional impact of climate change (*COOLING*) does not significantly influence whether regions get involved in related research projects.

Table 1: Pearson Correlation and Test Results

	GDP	GVA	AGE	DENSITY	GERD	WASTEEMP	WASTEGEN	COOLING
Correlation Coefficient	0.4162655	0.7825878	-0.1283997	0.3618056	0.3716083	0.6668699	0.4090069	0.07141354
t-Test Statistic	7.0924	19.475	-1.9932	5.9747	5.3851	12.172	4.9507	1.0858
Degrees of Freedom	240	240	237	237	181	185	122	230
p-value	1.47E-11	< 2.2e-16	4.74E-02	8.39E-09	2.23E-07	< 2.2E-16	2.40E-06	2.79E-01
Confidence Interval (95%)	[0.3062361, 0.5153195]	[0.6283639, 0.8270705]	[-0.251201853, -0.001529623]	[0.2462146, 0.4672486]	[0.2394596, 0.4902390]	[0.5787589, 0.7395908]	[0.2507749, 0.5459523]	[-0.05791786, 0.19838746]

Data Source: Eurostat (2023a 2023b; 2023c; 2023d; 2023e; 2023f; 2023g; 2023h)

Considering that smart specialisation is promoted as a tool to support regional structural change and sustainable transition, the question arises whether the empirical results of certain regions being strongly involved in interregional projects on environmental sustainability match the smart specialisation strategies (S3) formulated by the regions. To test this assumption, the Eye@RIS3 database, containing information about priorities in S3 of European NUTS 2 regions, which is the level S3 are implemented at, was filtered for those regions listing domains related to environmental sustainability in their strategy (Smart Specialisation Platform, 2022b). Regarding the domains, only the scientific domains were analysed since cooperation data relate to Horizon 2020 representing a framework of research and innovation projects (for the filter criteria, see Annex 4. The list of regions is accessible in Annex 3). Of 371 NUTS 2 regions, 232 did list a scientific specialisation in sustainability while 139 did not. Regarding the involvement in interregional projects, the analysed NUTS 2 regions on average were involved in 101 projects. Of the 100 regions that scored above average in interregional cooperation projects on environmental sustainability, 23 did not list sustainability as a scientific focus. On the other hand, seven of the 55 regions not involved in any project listed environmental sustainability as a scientific priority in their S3. Assuming that smart specialisation (1) aims to promote economic specialisations such as environmental sustainability, and (2) aims to promote interregional cooperation, it seems remarkable that the lists of regions involved in interregional sustainability projects and regions that have fixed outward-orientation and sustainability in their S3 are not congruent.

Regarding the constructed network of Northern German NUTS 2 regions, the social network is shown in Figure 3. Those regions that Northern Germany frequently cooperates with are shown in the middle of the network with coloured edges as an additional weight indicating the intensity of cooperation. The NUTS codes reveal that cooperation in interregional projects on environmental sustainability focus primarily on other regions in Germany as well as Austria, Belgium, Denmark, Finland, France, Italy, the Netherlands, Poland, Spain, Sweden, Switzerland, and the United Kingdom. It appears to be no coincidence that, apart from Luxemburg, all neighbouring countries to Germany are among the most important cooperation partners. The full cooperation network is provided in Annex 5. An additional perspective is provided in Figure 4 which illustrates the intensity of cooperation between Northern Germany and European regions. Here, it is revealed that neighbouring regions tend to cooperate with Northern German regions. This supports the assumption of (geographical and cultural) proximity as a facilitating factor for cooperation. However, geographical proximity is not a limiting factor for cooperation, as strong cooperative ties are observable with regions in all parts of Europe including non-EU countries such as Turkey or the UK. This picture can partly be explained by the nature to receive funding. Nevertheless, Figure 4 allows to state that environmental cooperation is not geographically limited in Europe and the Horizon funding scheme appears to have succeeded in connecting researchers from regions which would not have cooperated assuming the traditional proximity hypothesis.

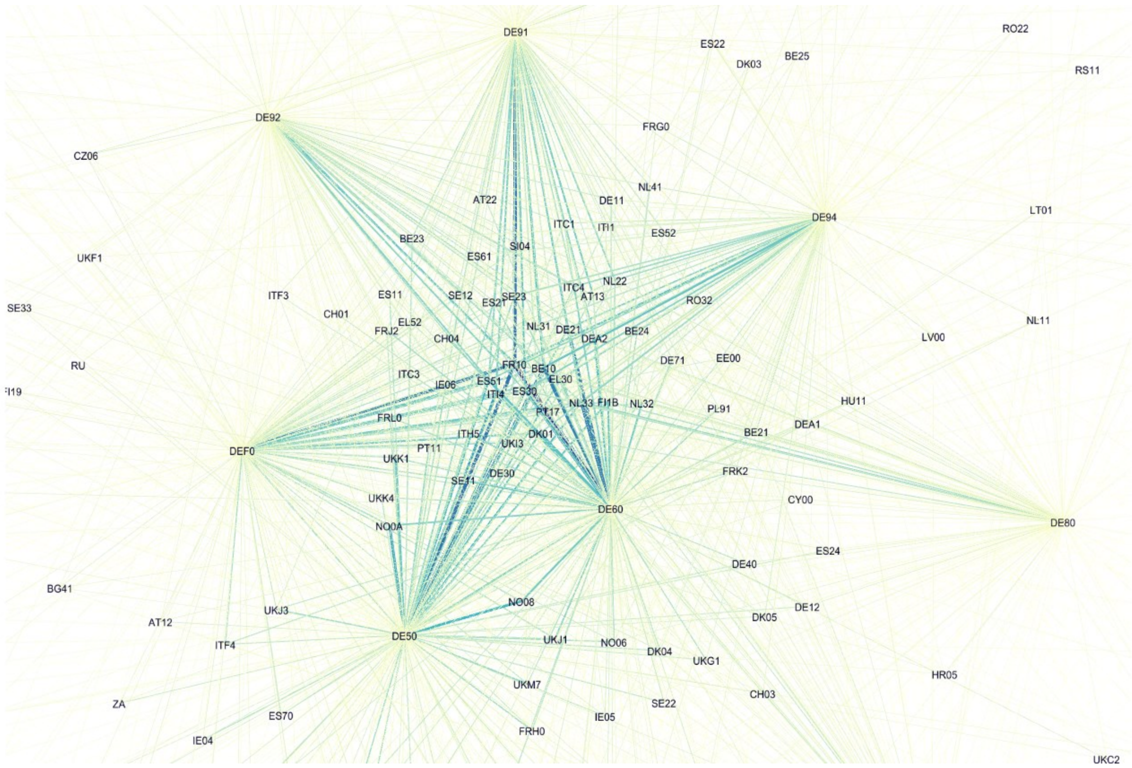


Figure 3: Weighted networks of Northern-German NUTS 2 regions in H2020 sustainability projects, 2022

Data source: CORDIS (2022)

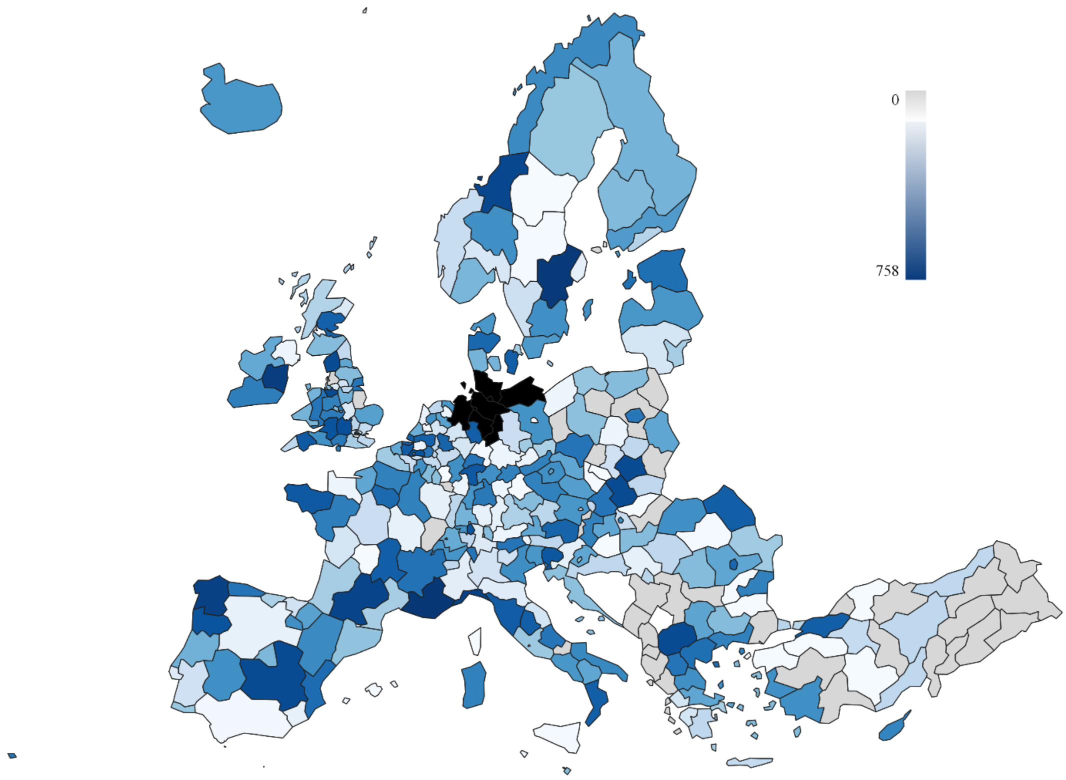


Figure 3: Interregional cooperation of Northern German NUTS 2 regions in H2020 sustainability projects, 2022

Data source: CORDIS (2022)

An additional empirical analysis of the network has been conducted by measuring different kinds of centrality, namely closeness, betweenness, degree and eigenvector centrality. These measures give an indication on the overall position of a node and the theoretical time it would take to reach other nodes (closeness centrality), the extent at which a node lies between other nodes in the network and the percentage of shortest paths passing through the node (betweenness centrality), the number of links incident upon a node (degree centrality), and the relative score of each node measuring how well a well-connected node is connected to other well-connected nodes (Tabassum et al., 2018). Table 2 lists the Top-20 regions for each measure of centrality and the respective value. Not surprisingly, the Northern German regions score the highest which is due to the design of the network putting said regions in the centre of it. However, the regions beyond Northern Germany, which play an important role within the cooperation network, are similar to those in the centre of Figure 3.

Table 2: Centrality measures of the network of Northern-German NUTS 2 regions in H2020 sustainability projects

Rank	Closeness Centrality		Betweenness Centrality		Degree Centrality		Eigenvector Centrality	
1	DE60	0.002283	DE60	16985.7835	DE60	1982	DE60	1.0000
2	DE50	0.002262	DE50	15367.3087	DE50	1927	DE50	0.9490
3	DE91	0.002183	DEF0	9211.3129	DEF0	1320	DEF0	0.6742
4	DEF0	0.002141	DE91	9000.5362	DE91	1206	FR10	0.5932
5	DE94	0.002066	DE94	6180.0952	DE94	1018	DE91	0.5809
6	DE92	0.002024	DE92	4329.4028	DE92	869	DE94	0.5076
7	DE80	0.001942	DE80	3311.3653	DE80	574	BE10	0.4247
8	DE93	0.001842	DE93	1646.5477	DE93	425	DE92	0.4124
9	CH02	0.001420	FR10	1.5533	FR10	306	ES30	0.3990
10	CH04	0.001420	ES51	1.0067	BE10	222	NL33	0.3864
11	DE21	0.001420	NL33	0.9708	ES30	209	ITI4	0.3433
12	DEA2	0.001420	BE10	0.9097	NL33	206	DE21	0.3340
13	ES51	0.001420	DK01	0.8054	ITI4	176	ES51	0.3246
14	FR10	0.001420	ES30	0.7047	ES51	174	DK01	0.2982
15	NO08	0.001420	ITI4	0.5825	DE21	171	DE80	0.2750
16	UKJ1	0.001420	EL30	0.3955	DK01	153	EL30	0.2596
17	EL30	0.001420	FI1B	0.3883	EL30	137	FI1B	0.2497
18	ITI4	0.001420	UKI3	0.3416	FI1B	132	DEA2	0.2461
19	NL31	0.001420	DE21	0.3236	DEA2	129	UKI3	0.2294
20	PT17	0.001420	NO08	0.2876	UKI3	115	NO08	0.2208

Data Source: CORDIS (2022)

3.3.3 Discussion and Limitations

The descriptive findings show differentiated geographical patterns when it comes to the involvement of European regions in interregional research projects dealing with environmental sustainability. At NUTS 2 level, a light distinction between Western and Eastern Europe becomes visible (see Figure 1). Thereby, Eastern European NUTS 2 regions in their majority are in fact involved in interregional projects rather than being not involved at all, but to a considerably smaller degree than other regions. The picture becomes clearer when looking at the NUTS 3 regions (see Figure 2). Here, it can be seen that interregional activity is highly concentrated in particular regions which are also to be found in Eastern or Southern Europe which often are regarded as less-developed areas in regional studies. Hoekman et al. (2008) describe these patterns as “elite structures”. These regions with particularly strong interregionality scores are particularly urban and most NUTS 3 concentration patterns refer to capital or major city agglomerations. The conducted correlation analysis confirms that a connection between regional factors such as GDP or economic structure and interregional orientation can be assumed (see Table 1). More rural areas, for instance in Eastern Europe but also in large parts of Germany, are not active in interregional cooperation. This finding partly contradicts Santoalha (2018) identifying regions in Benelux, Germany, Central and Eastern Europe to be relatively strong in interregional collaboration. However, this contradiction might be due to the focus of the particular dataset in this paper on environmental sustainability as Horizon projects are research-oriented and high-tech research tends to be spatially concentrated to a high degree. Moreover, the dataset cannot provide an answer to the question whether certain groups of regions do not deal with environmental sustainability at all or whether they simply do not engage in high-level research and interregional collaboration. This is further amplified by the fact that organisations rather than regions themselves were analysed. As sustainability is hardly measurable using individual indicators, the findings need to be complemented by additional research applying different datasets to paint a more complete picture.

Thereby, the observed concentration patterns align with related literature on regional innovation. Spatial clusters of knowledge-intensive regions are regularly identified and attributed to urban advantages, density, and clusters of innovation actors from the triple helix (Van den Heiligenberg et al., 2017). Particularly complex economic activities and scientific research tend to concentrate in larger cities and metropolitan areas (Acosta et al., 2011; Balland et al., 2018; Tödtling and Trippl, 2005). From a cohesion perspective, these findings are alarming: smart specialisation and innovation policy in Europe focus on bridging existing regional disparities by empowering less developed regions. The evidence that particularly those regions that would benefit most from interregional knowledge exchange are the least involved was expectable but is not desirable from a policy perspective (Camagni and Capello, 2013; McCann and Ortega-Argilés, 2015; Corradini, 2019). Moreover, the future topic of a sustainable transition, which is also particularly relevant for less-developed regions as they tend to be more vulnerable due to an old-industrial economic structure and fewer green specialisations, again reveals structures to the disadvantage of less-developed regions. Existing policy instruments apparently have not managed to overcome the persistent dichotomy which is likely to reproduce since research generally also translates into economic hard facts in the long run. However, the picture might become more differentiated when other, less competitive, collaborative programmes such as Interreg, as opposed to Horizon 2020 data in this paper, are considered, as suggested by Woolford et al. (2021).

Regarding the fit between scientific specialisation mentioned in official S3 and actual performance as measured by involvement in research projects, both spheres do not fully match. The analysis has shown that a group of regions which are quite active in interregional projects on environmental sustainability do not mention this as a strength in their S3 while, on the other hand, some regions officially announce a specialisation which is not backed by statistical analysis. Here, it needs to be remarked that organisations rarely address policies or strategies such as smart specialisation strives to do. As organisations are used as a proxy for interregional cooperation, they must not necessarily have an impact on smart specialisation strategies. In this context, a different methodological approach was chosen by D'Adda et al. (2018) asking the same question for technological domains in Italian regions. Also here, the findings imply that S3 and real-life performance are characterised by a certain level of divergence. The same finding is mentioned by Sörvik and Kleibrink (2015) as well as Deegan et al. (2021) implying that European smart specialisation and European science policy need to be better aligned and the preparation of S3 requires a stronger statistical foundation.

The second analytical step of this paper, the construction of a cooperation network of Northern German regions, also confirms previous studies. It is generally assumed that knowledge spillovers tend to focus on close regions whereby different measures of proximity such as geography, similar languages, culture, and policies are relevant (Greunz, 2005; Basile et al., 2012; Dosso and Lebert, 2020). Our analysis shows that Northern German regions cooperate with all parts of Europe and also several countries beyond Europe (see Annex 5). Although strong cooperative ties are observed with regions in direct proximity, the Horizon programme has successfully contributed to the establishment of scientific cooperation with regions which would otherwise not have cooperated following the proximity hypothesis. This can be interpreted as a step towards the establishment of a European research area as HORIZON allows to bridge some of the major obstacles, namely that researchers cooperate based on geographical proximity and tend to cooperate with similar organisations in similar regions (Frenken et al., 2007). Moreover, in light of grand challenges, such as the fight against climate change, external cooperation is strongly advised (Uyarra et al., 2014). Northern Germany matches this suggestion, and the analysis blends in with other papers assigning the region an important role for a sustainable transition (e.g., Hassink et al., 2021; Kruse and Wedemeier, 2022).

3.4 Conclusion

Innovation has been identified as one of the key levers for regional prosperity and sectoral renewal. Accordingly, innovation in Europe is not only discussed in terms of cohesion and bridging interregional disparity but also as a means to contribute to a sustainable transition facilitated by the EU Green Deal. In this context, cooperation and knowledge exchange have led to the recognition that innovation is to be studied from a network perspective, institutionalised in systematic theories such as regional innovation systems (RIS). These also form the theoretic foundation of smart specialisation, the European policy approach to support innovation and regional positioning. Cooperation, mutual learning, and knowledge exchange are thereby evidently important factors for regional economic prosperity, new path development and diversification (Mariussen et al., 2016). Despite smart specialisation highlighting the relevance of interregional cooperation since the time the concept was developed about a decade ago, practical implementation and empirical research in this regard have remained limited. The paper at hand addresses this issue by discussing how smart specialisation might contribute to the grand challenge of a sustainable transition in Europe and which role interregional cooperation can play in this regard. Moreover, the current state of research on interregional cooperation in Europe is presented showing that the previous studies predominantly rely on patent data for empirical analyses. To broaden the picture and overcome the limitations of patent data, such as a technological and regional bias, data on Horizon 2020 (H2020) research projects in Europe were analysed and a database of interregional activity related to environmental sustainability was constructed.

The findings reveal that organisational involvement in interregional European projects is highly concentrated in urban and capital regions. A correlation analysis confirms that regional characteristics such as GDP or population density positively influence a region's involvement in interregional research projects on environmental sustainability. This aspect is alarming from a policy perspective as existing divergency patterns are reproduced this way instead of being bridged. Particularly an urban-rural separation is likely to keep manifesting when today's research translates into economic strength in the future. Moreover, this development contradicts the aspiration of smart specialisation to use innovation policy for the achievement of regional convergence. Also, it was shown that smart specialisation strategies (S3) do not adequately match practical specialisations when it comes to interregional activity. Since other studies suggest the same implication of S3 not reflecting economic reality, this raises questions for an update of smart specialisation which should pay more attention to statistical analyses prior to the strategy formulation process. To receive further insights into the internal network structure of the database, a social network analysis (SNA) was conducted, placing the Northern German NUTS 2 regions in the centre. This analysis proved that cooperation appears to be positively influenced by geographical and cultural proximity, but cooperation is also observable with regions that are neither geographically nor culturally proximate. It can be assumed that the aspiration of Horizon 2020, to promote interregional cooperation and facilitate knowledge flows between regions, has been successful to the point where cooperation networks are established that would not have emerged without European research funding. This is particularly relevant in the field of environmental sustainability research considering the increasing need to adapt to the UN SDGs and to overcome previous limitations of a fragmented European research area (Kattel and Mazzucato, 2018; Mazzucato and Penna, 2020). Generally, the analyses in this paper confirm that innovation cooperation on environmental sustainability in Europe are established but further measures are required to address certain shortcomings such as regional convergence.

Annex

Annex 1: Potential additional indicators for CE benchmarking on NUTS 1 level

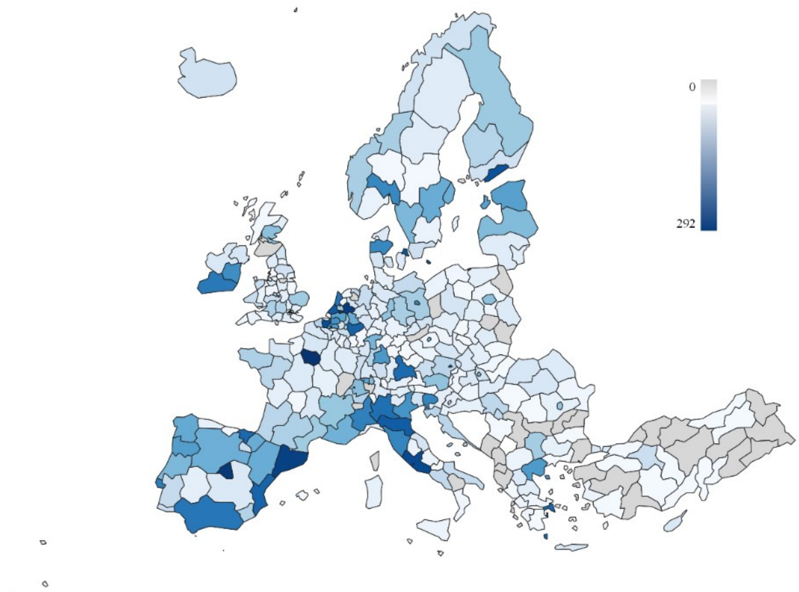
Section	Work Programme	Time	Call	Topic
Excellent Science				
	Future and Emerging Technologies	2018-20	*FET Proactive topics in the EIC Enhanced Pilot (2019-2020)*	
				FETPROACT-EIC-08-2020
Industrial Leadership				
	Leadership in enabling and industrial technologies	2014-20	*Factories of the Future*	
				FoF 3 - 2014
			Energy-efficient Buildings	
				EeB 5 - 2015
				EeB 6 - 2015
				EeB 7 - 2015
				EE 2 - 2015
			Sustainable Process Industries	
				SPIRE 2-2014
				SPIRE 4-2014
				SPIRE 6-2015
				SPIRE 7-2015
				LCE 2-2014/2015
				LCE 3-2014/2015
				EE 18-2014/2015
				Waste 1-2014
Societal Challenges				
	Food Security, Sustainable Agriculture and Forestry, Marine, Maritime and Inland Water Research and the Bioeconomy	2014-15	*Call for Sustainable Food Security*	
				SFS-x-20xx
			Call for Blue Growth: Unlocking the potential of Seas and Oceans	
				BG-x-20xx
			Call for an Innovative, Sustainable and Inclusive Bioeconomy	
				ISIB-x-20xx
		2016-17	*Call Sustainable Food Security - Resilient and resource-efficient value chains*	
				SFS-xx-20xx
			Call Blue Growth - Demonstrating an ocean of opportunities	
				BG-xx-20xx
			Call Rural Renaissance - Fostering innovation and business opportunities	
				RUR-07-2016
			Call Bio-based innovation for sustainable goods and services - Supporting the development of a European Bioeconomy	
				BB-xx-20xx
		2018-20	*Call Sustainable Food Security*	
				SFS-xx-20xx
				LC-SFS-19 bis 25 - 20xx
			Call Blue Growth	
				BG-xx-20xx

			Call Food and Natural Resources	
				FNR-xx-20xx
	Secure, Clean and Efficient Energy	2014-15	*Call Energy Efficiency*	
				EE x - 20xx
			Call Competitive low-carbon Energy	
				LCE - x - 20xx
			Call Smart Cities and Communities	
				SSC - x - 20xx
			Call SMEs and Fast Track to Innovation for Energy	
				SIE x - 20xx
		2016-17	*Energy Efficiency Call 2016-2017*	
				EE-xx-20xx
			Call Competitive Low-Carbon Energy	
				LCE - x - 20xx
	Smart, Green and Integrated Transport	2014-15	*Call Mobility for Growth*	
				MG.x.x-20xx
			Call Green Vehicles	
				GV.x.20xx
		2016-17	*Call 2016-2017 Mobility for Growth*	
				MG-x.x-20xx
			Call 2016-2017 Green Vehicles	
				GV-xx-20xx
		2018-20	*Call 2018-2020 Mobility for Growth*	
				LC-MG-x-x-20xx
				MG-BG-xx-20xx
			Call building a low-carbon, climate resilient future: Green Vehicles	
				LC-GV-xx-20xx
	Climate Action, Environment, Resource Efficiency and Raw Materials	2014-15	*Call Waste: A Resource to Recycle, Reuse and Recover Raw Materials*	
				WASTE-x-20xx
			Call Water Innovation: Boosting its value for Europe	
				WATER-x-20xx
			Call Growing a Low Carbon, Resource Efficient Economy with a Sustainable Supply of Raw Materials	
				SC5-x-20xx
		2016-17	*Call Greening the Economy*	
				SC5-xx-20xx
		2018-20	*Call Building a low-carbon, climate resilient future: climate action in support of the Paris Agreement*	
				LC-CLA-xx-20xx
			Call Greening the economy in line with the Sustainable Development Goals (SDGs)	
				CE-SC5-xx-20xx
	Secure societies - Protecting freedom and security of Europe and its citizens	2014-15	*Call Disaster-resilience: safeguarding and securing society, including adapting to climate change*	
				DRS-9 bis 11 - 20xx
Europe in a changing world				

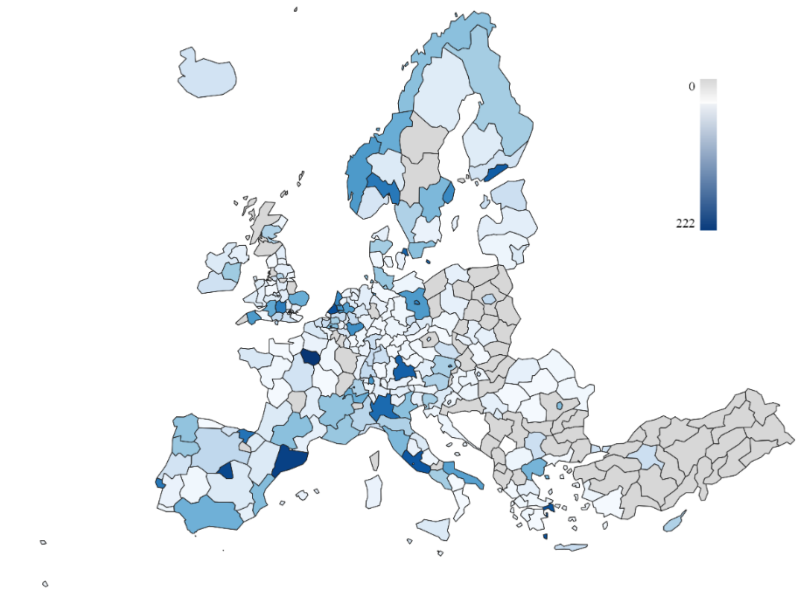
	2018-20		TRANSFORMATIONS-03-2018-2019
			TRANSFORMATIONS-06-2018
Focus Areas			
	2018-20	*Societal Challenge 3 Secure, clean and efficient energy*	
			SC3 - x - 20xx
		Societal Challenge 4 Smart, green and integrated transport	
			SC4 - x - 20xx
		Societal Challenge 2 Food security, sustainable agriculture and forestry, marine, maritime and inland water research and the bioeconomy	
			SC2 - x - 20xx
			LEIT - NMBP

Data Source: CORDIS (2022)

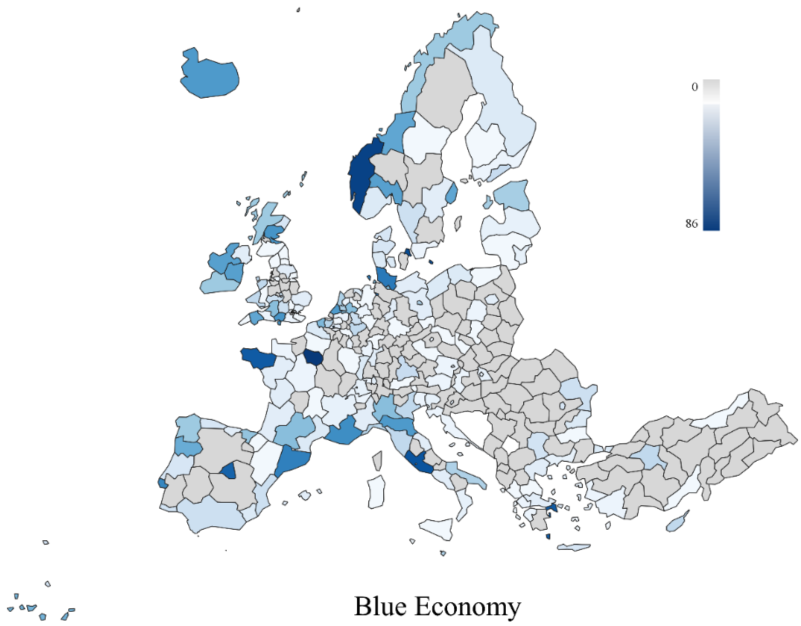
Annex 2: Thematic priorities in H2020 sustainability projects, NUTS 2 level, 2022



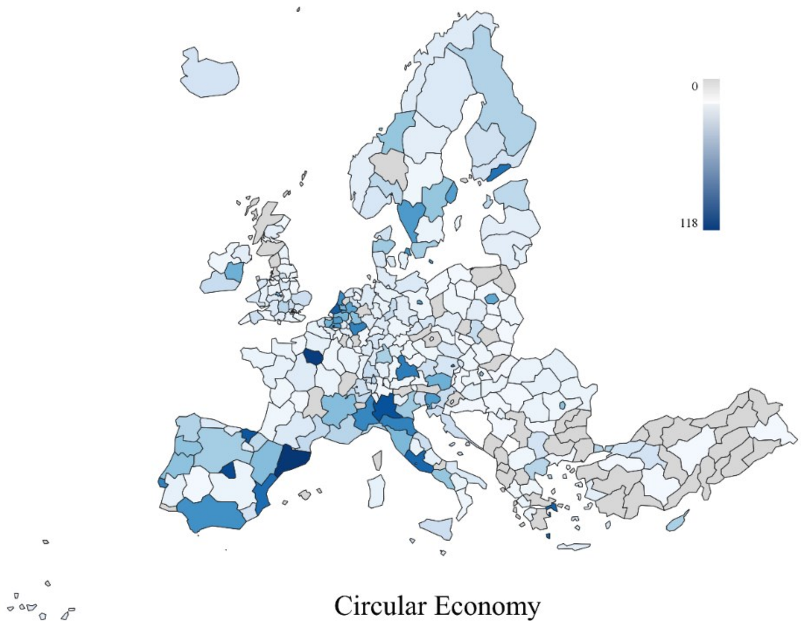
Bioeconomy



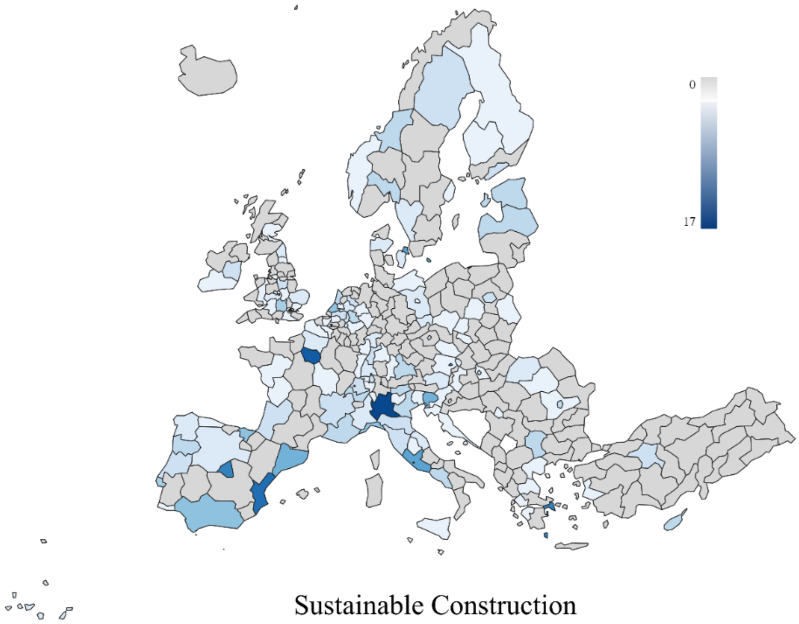
Climate Research



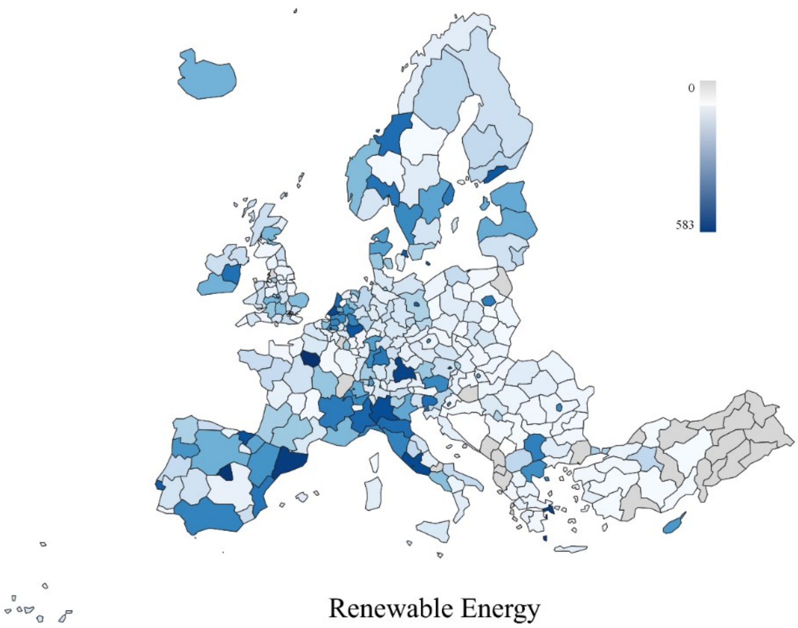
Blue Economy



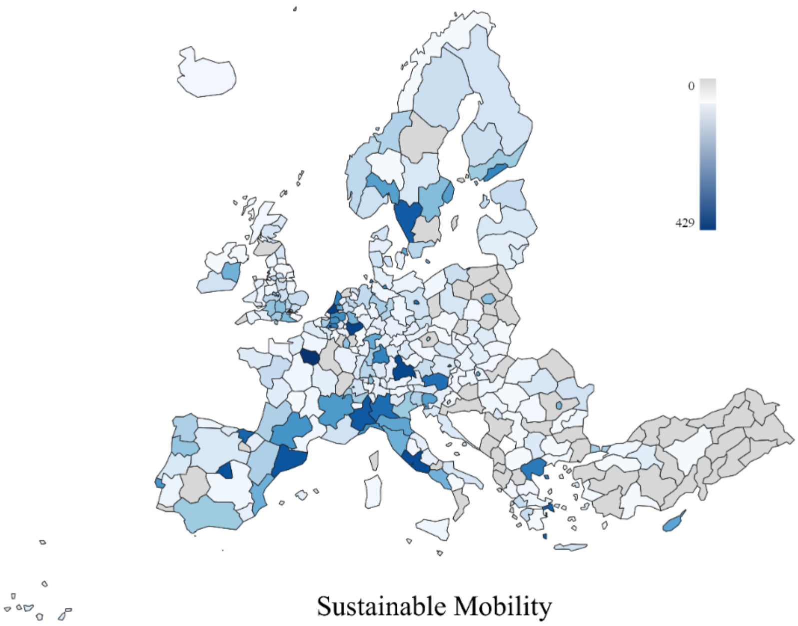
Circular Economy



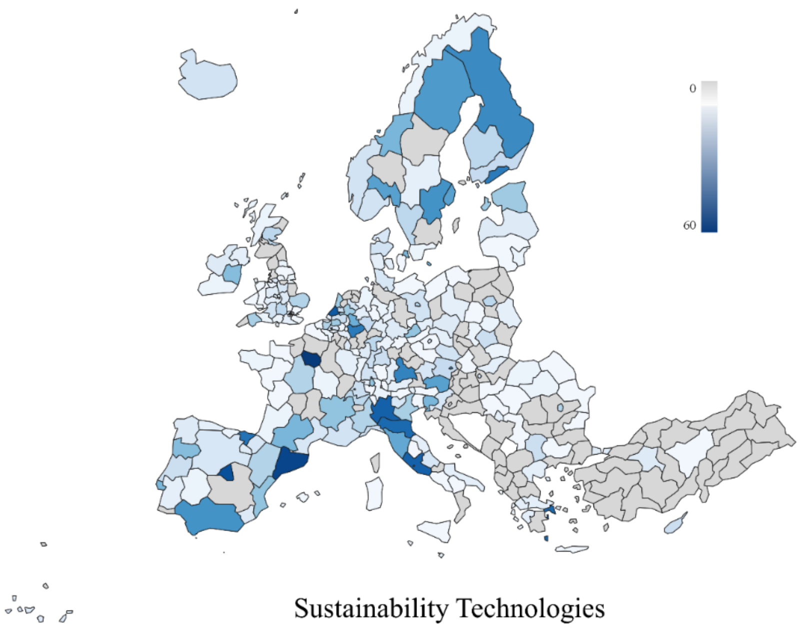
Sustainable Construction



Renewable Energy



Sustainable Mobility



Sustainability Technologies

Annex 3: Number of organisations involved in H2020 sustainability projects and associated scientific priorities, NUTS 2 level, 2022

NUTS 2	Region	Interregional Projects	Scientific Priorities	
			NUTS 1	NUTS 2
BE10	Région de Bruxelles-Capitale/Brussels Hoofdstedelijk Gewest	1246	0	1
BE21	Prov. Antwerpen	290	0	1
BE22	Prov. Limburg (BE)	50	0	1
BE23	Prov. Oost-Vlaanderen	270	0	1
BE24	Prov. Vlaams-Brabant	300	0	1
BE25	Prov. West-Vlaanderen	72	0	1
BE31	Prov. Brabant wallon	47	0	0
BE32	Prov. Hainaut	44	0	0
BE33	Prov. Liège	56	0	0
BE34	Prov. Luxembourg (BE)	4	0	0
BE35	Prov. Namur	20	0	0
BG31	Severozapaden	2	0	0
BG32	Severen tsentralen	4	0	0
BG33	Severoiztochen	16	0	0
BG34	Yugoiztochen	7	0	0
BG41	Yugozapaden	191	0	0
BG42	Yuzhen tsentralen	21	0	0
CZ01	Praha	180	1	0
CZ02	Strední Cechy	10	1	0
CZ03	Jihozápad	24	1	0
CZ04	Severozápad	16	1	0
CZ05	Severovýchod	16	1	0
CZ06	Jihovýchod	72	1	0
CZ07	Strední Morava	16	1	1
CZ08	Moravskoslezsko	13	1	0
DK01	Hovedstaden	527	1	1
DK02	Sjælland	35	1	1
DK03	Syddanmark	98	1	1
DK04	Midtjylland	202	1	1
DK05	Nordjylland	128	1	1
DE11	Stuttgart	279	1	1
DE12	Karlsruhe	179	1	1
DE13	Freiburg	121	1	1
DE14	Tübingen	48	1	1
DE21	Oberbayern	717	1	1
DE22	Niederbayern	18	1	1
DE23	Oberpfalz	23	1	1
DE24	Oberfranken	18	1	1
DE25	Mittelfranken	37	1	1
DE26	Unterfranken	33	1	1
DE27	Schwaben	43	1	1
DE30	Berlin	412	1	1
DE40	Brandenburg	132	1	1
DE50	Bremen	153	1	1
DE60	Hamburg	187	1	1

DE71	Darmstadt	197	1	1
DE72	Gießen	13	1	1
DE73	Kassel	36	1	1
DE80	Mecklenburg-Vorpommern	59	1	1
DE91	Braunschweig	99	1	1
DE92	Hannover	63	1	1
DE93	Lüneburg	27	1	1
DE94	Weser-Ems	86	1	1
DEA1	Düsseldorf	239	1	1
DEA2	Köln	619	1	1
DEA3	Münster	46	1	1
DEA4	Detmold	25	1	1
DEA5	Arnsberg	73	1	1
DEB1	Koblenz	10	1	1
DEB2	Trier	5	1	1
DEB3	Rheinhessen-Pfalz	45	1	1
DEC0	Saarland	15	1	1
DED2	Dresden	87	1	0
DED4	Chemnitz	52	1	0
DED5	Leipzig	87	1	0
DEE0	Sachsen-Anhalt	55	1	1
DEF0	Schleswig-Holstein	96	1	1
DEG0	Thüringen	39	1	1
EE00	Eesti	217	1	1
IE04	Northern and Western	70	0	0
IE05	Southern	196	0	0
IE06	Eastern and Midland	311	0	0
EL30	Attiki	800	1	1
EL41	Voreio Aigaio	17	1	0
EL42	Notio Aigaio	14	1	1
EL43	Kriti	72	1	1
EL51	Anatoliki Makedonia, Thraki	13	1	1
EL52	Kentriki Makedonia	284	1	1
EL53	Dytiki Makedonia	16	1	1
EL54	Ipeiros	9	1	1
EL61	Thessalia	27	1	1
EL62	Ionia Nisia	3	1	1
EL63	Dytiki Ellada	45	1	1
EL64	Sterea Ellada	21	1	1
EL65	Peloponnisos	6	1	1
ES11	Galicia	167	0	0
ES12	Principado de Asturias	54	0	1
ES13	Cantabria	38	0	1
ES21	País Vasco	673	0	1
ES22	Comunidad Foral de Navarra	156	0	1
ES23	La Rioja	36	0	0
ES24	Aragón	195	0	1
ES30	Comunidad de Madrid	1111	0	1
ES41	Castilla y León	178	0	1

ES42	Castilla-la Mancha	35	0	1
ES43	Extremadura	35	0	1
ES51	Cataluña	1008	0	1
ES52	Comunitat Valenciana	382	0	1
ES53	Illes Balears	29	0	1
ES61	Andalucía	315	0	1
ES62	Región de Murcia	81	0	1
ES63	Ciudad de Ceuta	0	0	0
ES64	Ciudad de Melilla	0	0	0
ES70	Canarias	83	0	1
FR10	Île de France	1900	0	1
FRB0	Centre - Val de Loire	68	0	0
FRC1	Bourgogne	65	0	0
FRC2	Franche-Comté	0	0	1
FRD1	Basse-Normandie	25	0	1
FRD2	Haute-Normandie	16	0	1
FRE1	Nord-Pas-de-Calais	56	0	1
FRE2	Picardie	42	0	1
FRF1	Alsace	53	0	1
FRF2	Champagne-Ardenne	14	0	1
FRF3	Lorraine	26	0	1
FRG0	Pays-de-la-Loire	81	0	1
FRH0	Bretagne	122	0	1
FRI1	Aquitaine	106	0	1
FRI2	Limousin	8	0	1
FRI3	Poitou-Charentes	34	0	1
FRJ1	Languedoc-Roussillon	75	0	1
FRJ2	Midi-Pyrénées	201	0	0
FRK1	Auvergne	23	0	1
FRK2	Rhône-Alpes	270	0	1
FRL0	Provence-Alpes-Côte d'Azur	195	0	1
FRM0	Corse	2	0	1
FRY1	Guadeloupe	4	0	1
FRY2	Martinique	3	0	1
FRY3	Guyane	1	0	1
FRY4	La Réunion	1	0	1
FRY5	Mayotte	0	0	0
HR02	Panonska Hrvatska	8	0	0
HR03	Jadranska Hrvatska	65	1	0
HR05	Grad Zagreb	140	1	0
HR06	Sjeverna Hrvatska	18	1	0
ITC1	Piemonte	456	0	1
ITC2	Valle d'Aosta/Vallée d'Aoste	6	0	1
ITC3	Liguria	233	0	1
ITC4	Lombardia	691	0	1
ITF1	Abruzzo	29	0	1
ITF2	Molise	3	0	0
ITF3	Campania	161	0	1
ITF4	Puglia	123	0	1

ITF5	Basilicata	14	0	1
ITF6	Calabria	23	0	1
ITG1	Sicilia	47	0	1
ITG2	Sardegna	29	0	1
ITH1	Provincia Autonoma di Bolzano/Bozen	47	0	1
ITH2	Provincia Autonoma di Trento	76	0	1
ITH3	Veneto	232	0	1
ITH4	Friuli-Venezia Giulia	87	0	1
ITH5	Emilia-Romagna	403	0	1
ITI1	Toscana	297	0	0
ITI2	Umbria	43	0	0
ITI3	Marche	69	0	1
ITI4	Lazio	870	0	1
CY00	Kypros	217	1	0
LV00	Latvija	142	1	1
LT01	Sostines regionas	70	1	0
LT02	Vidurio ir vakaru Lietuvos regionas	49	1	0
LU00	Luxembourg	104	1	1
HU11	Budapest	216	0	0
HU12	Pest	35	0	0
HU21	Közép-Dunántúl	22	0	0
HU22	Nyugat-Dunántúl	18	0	0
HU23	Dél-Dunántúl	10	0	0
HU31	Észak-Magyarország	14	0	0
HU32	Észak-Alföld	6	0	0
HU33	Dél-Alföld	23	0	0
MT00	Malta	59	1	1
NL11	Groningen	102	0	1
NL12	Friesland (NL)	20	0	1
NL13	Drenthe	22	0	1
NL21	Overijssel	110	0	1
NL22	Gelderland	387	0	1
NL23	Flevoland	17	0	1
NL31	Utrecht	247	0	1
NL32	Noord-Holland	417	0	1
NL33	Zuid-Holland	879	0	1
NL34	Zeeland	13	0	1
NL41	Noord-Brabant	277	0	1
NL42	Limburg (NL)	83	0	1
AT11	Burgenland (AT)	14	1	1
AT12	Niederösterreich	110	1	1
AT13	Wien	562	1	0
AT21	Kärnten	22	1	1
AT22	Steiermark	291	1	1
AT31	Oberösterreich	95	1	0
AT32	Salzburg	20	1	0
AT33	Tirol	34	1	1
AT34	Vorarlberg	15	1	1
PL21	Malopolskie	62	1	1

PL22	Slaskie	51	1	1
PL41	Wielkopolskie	57	1	1
PL42	Zachodniopomorskie	20	1	1
PL43	Lubuskie	1	1	1
PL51	Dolnoslaskie	34	1	1
PL52	Opolskie	3	1	1
PL61	Kujawsko-Pomorskie	5	1	1
PL62	Warminsko-Mazurskie	11	1	0
PL63	Pomorskie	56	1	1
PL71	Lódzkie	38	1	1
PL72	Swietokrzyskie	4	1	1
PL81	Lubelskie	20	1	1
PL82	Podkarpackie	4	1	1
PL84	Podlaskie	0	1	1
PL91	Warszawski stoleczny	236	1	1
PL92	Mazowiecki regionalny	5	1	1
PT11	Norte	260	1	0
PT15	Algarve	30	1	1
PT16	Centro (PT)	129	1	1
PT17	Área Metropolitana de Lisboa	472	1	1
PT18	Alentejo	56	1	1
PT20	Região Autónoma dos Açores (PT)	27	1	1
PT30	Região Autónoma da Madeira (PT)	22	1	1
RO11	Nord-Vest	49	1	1
RO12	Centru	51	1	1
RO21	Nord-Est	24	1	1
RO22	Sud-Est	37	1	1
RO31	Sud - Muntenia	13	1	1
RO32	Bucuresti - Ilfov	254	1	0
RO41	Sud-Vest Oltenia	10	1	1
RO42	Vest	10	1	1
SI03	Vzhodna Slovenija	85	1	0
SI04	Zahodna Slovenija	330	1	0
SK01	Bratislavský kraj	84	0	0
SK02	Západné Slovensko	28	0	0
SK03	Stredné Slovensko	22	0	0
SK04	Východné Slovensko	12	0	0
FI19	Länsi-Suomi	103	0	1
FI1B	Helsinki-Uusimaa	564	0	1
FI1C	Etelä-Suomi	104	0	1
FI1D	Pohjois- ja Itä-Suomi	141	0	1
FI20	Åland	1	0	0
SE11	Stockholm	343	0	1
SE12	Östra Mellansverige	234	0	1
SE21	Småland med öarna	30	0	1
SE22	Sydsverige	128	0	1
SE23	Västsverige	351	0	1
SE31	Norra Mellansverige	32	0	1
SE32	Mellersta Norrland	16	0	1

SE33	Övre Norrland	103	0	1
UKC1	Tees Valley and Durham	23	0	0
UKC2	Northumberland and Tyne and Wear	65	0	0
UKD1	Cumbria	19	0	0
UKD3	Greater Manchester	92	0	1
UKD4	Lancashire	4	0	0
UKD6	Cheshire	28	0	0
UKD7	Merseyside	9	0	0
UKE1	East Yorkshire and Northern Lincolnshire	18	0	0
UKE2	North Yorkshire	34	0	0
UKE3	South Yorkshire	2	0	0
UKE4	West Yorkshire	59	0	0
UKF1	Derbyshire and Nottinghamshire	69	0	0
UKF2	Leicestershire, Rutland and Northamptonshire	57	0	1
UKF3	Lincolnshire	5	0	0
UKG1	Herefordshire, Worcestershire and Warwickshire	122	0	0
UKG2	Shropshire and Staffordshire	22	0	0
UKG3	West Midlands	148	0	0
UKH1	East Anglia	165	0	0
UKH2	Bedfordshire and Hertfordshire	69	0	0
UKH3	Essex	65	0	0
UKI3	Inner London - West	421	0	0
UKI4	Inner London - East	127	0	0
UKI5	Outer London - East and North East	66	0	0
UKI6	Outer London - South	5	0	0
UKI7	Outer London - West and North West	67	0	0
UKJ1	Berkshire, Buckinghamshire and Oxfordshire	215	0	0
UKJ2	Surrey, East and West Sussex	101	0	0
UKJ3	Hampshire and Isle of Wight	101	0	0
UKJ4	Kent	15	0	1
UKK1	Gloucestershire, Wiltshire and Bristol/Bath area	185	0	0
UKK2	Dorset and Somerset	20	0	0
UKK3	Cornwall and Isles of Scilly	8	0	1
UKK4	Devon	118	0	0
UKL1	West Wales and The Valleys	73	0	1
UKL2	East Wales	44	0	1
UKM5	North Eastern Scotland	37	0	1
UKM6	Highlands and Islands	43	0	1
UKM7	Eastern Scotland	167	0	1
UKM8	West Central Scotland	6	0	1
UKM9	Southern Scotland	4	0	1
UKN0	Northern Ireland (UK)	58	0	1
IS00	Ísland	131	0	0
LI00	Liechtenstein	0	0	0
NO02	Innlandet	14	0	0
NO06	Trøndelag	267	0	0
NO07	Nord-Norge	76	0	1
NO08	Oslo og Akershus (statistical region 2016)	356	0	1
NO09	Agder og Rogaland (statistical region 2016)	66	0	1

NO0A	Vestlandet (statistical region 2016)	222	0	1
NO0B	Jan Mayen og Svalbard	0	0	0
CH01	Région lémanique	218	0	0
CH02	Espace Mittelland	160	0	0
CH03	Nordwestschweiz	104	0	0
CH04	Zürich	230	0	0
CH05	Ostschweiz	42	0	0
CH06	Zentralschweiz	24	0	0
CH07	Ticino	31	0	0
ME00	Crna Gora	0	1	1
MK00	Severna Makedonija	42	0	0
AL01	Veri	0	1	0
AL02	Qender	0	1	0
AL03	Jug	0	1	0
RS11	Beogradski region	92	1	0
RS12	Region Vojvodine	49	1	0
RS21	Region Sumadije i Zapadne Srbije	5	1	0
RS22	Region Juzne i Istocne Srbije	4	1	0
TR10	Istanbul	125	0	0
TR21	Tekirdag, Edirne, Kirklareli	0	0	0
TR22	Balikesir, Çanakkale	3	0	0
TR31	Izmir	36	0	0
TR32	Aydin, Denizli, Mugla	5	0	0
TR33	Manisa, Afyonkarahisar, Kütahya, Usak	1	0	0
TR41	Bursa, Eskisehir, Bilecik	9	0	0
TR42	Kocaeli, Sakarya, Düzce, Bolu, Yalova	19	0	0
TR51	Ankara	103	0	0
TR52	Konya, Karaman	3	0	1
TR61	Antalya, Isparta, Burdur	4	0	0
TR62	Adana, Mersin	4	0	0
TR63	Hatay, Kahramanmaras, Osmaniye	1	0	0
TR71	Kirikkale, Aksaray, Nigde, Nevsehir, Kirsehir	1	0	0
TR72	Kayseri, Sivas, Yozgat	4	0	0
TR81	Zonguldak, Karabük, Bartin	0	0	0
TR82	Kastamonu, Çankiri, Sinop	1	0	0
TR83	Samsun, Tokat, Çorum, Amasya	0	0	0
TR90	Trabzon, Ordu, Giresun, Rize, Artvin, Gümüshane	2	0	0
TRA1	Erzurum, Erzincan, Bayburt	1	0	0
TRA2	Agri, Kars, Igdir, Ardahan	0	0	0
TRB1	Malatya, Elazig, Bingöl, Tunceli	0	0	0
TRB2	Van, Mus, Bitlis, Hakkari	1	0	0
TRC1	Gaziantep, Adiyaman, Kilis	2	0	0
TRC2	Sanliurfa, Diyarbakir	0	0	0
TRC3	Mardin, Batman, Sirnak, Siirt	0	0	0

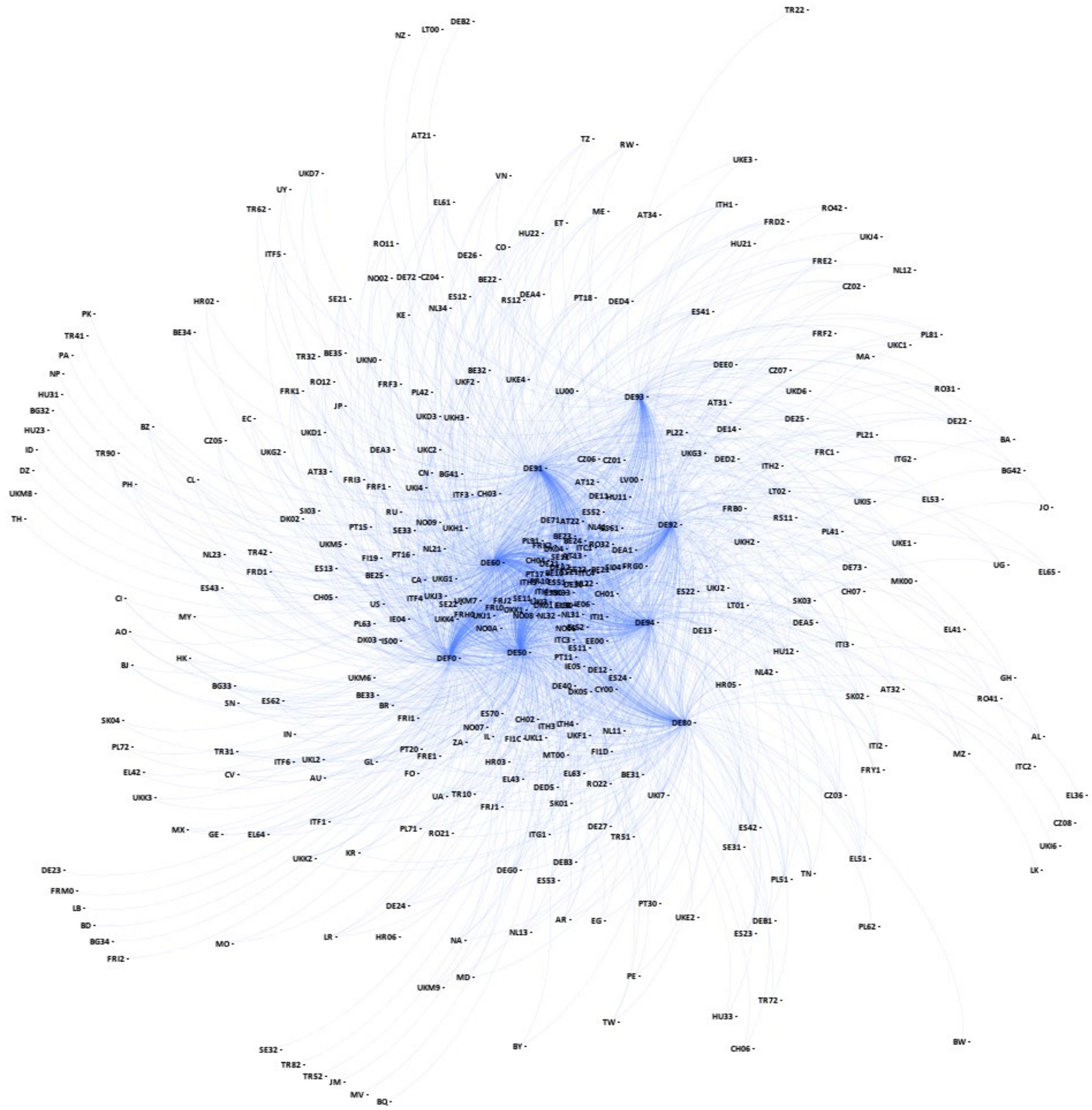
Data Source: CORDIS (2022); Smart Specialisation Platform (2022)

Annex 4: Scientific S3 domains related to environmental sustainability

Scientific Domain	**Scientific Subdomain**
01 – Exploration and Exploitation of the Earth	01.01 – Atmosphere
	01.02 – Climate and Meteorological Research
	01.07 – Sea and Oceans
02 – Environment	(All Subdomains)
04 – Transport, Telecommunication, and Other	04.26 – Protection against harmful Events in Town and
05 – Energy	(All Subdomains)
08 – Agriculture	08.72 – Agriculture Forestry Impact on the Environment

Data Source: Smart Specialisation Platform (2022)

Annex 5: Network of Northern-German NUTS 2 regions in H2020 sustainability projects, 2022



Data Source: CORDIS (2022)

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Chapter 4

Quantifying the Circular Economy (CE) in European Regions: a Bridge towards Smart Specialisation?

Authors: Mirko Kruse, Jan Wedemeier

Abstract

Circular Economy (CE) aspects are becoming increasingly relevant for a sustainable transition and regional development. Still, a methodology to assess regional performance and interregional differences is exclaimed to be missing at least in the European context. This gap makes it difficult to assess policies and evaluate development patterns. The authors present a methodology to overcome this research gap by including several dimensions of social, environmental, and economic CE aspects. The methodology consists of 29 indicators grouped in six dimensions with data obtained from various data bases. A static and a trend index are calculated to compare European NUTS 2 regions in terms of their current CE status and its development over the last years. The new insights paint a more differentiated picture of regional CE transition highlighting that a segregation is observable not so much between North and South or East and West but more between urban and rural regions. Regarding the practical CE implementation in European regions, the instrument of smart specialisation is discussed.

Keywords: circular economy; smart specialisation; transformation; assessment methodology; regional development.

JEL Classification: O18; P48; R1; R11.

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4.1 Introduction

The challenge of a sustainable transition has two sides. The first is related to the output side of production, namely the generation of greenhouse gas (GHG) emissions and their reduction. Whereby the policy focus is strongly concentrated on this aspect, the second side which is related to the material input of production, still leads a relative niche existence. However, the relevance of this neglected perspective is highlighted by facts such as the tripling of global extraction of materials between 1970 and 2017 (IPCC, 2015; 2020; Oberle et al., 2019; United Nations, 2021. At the same time, global population and global income levels tend to rise in parallel with changing consumption patterns following a Global Northern standard. This has placed additional pressure on material extraction and consumption.

As the majority of this material stream is not recycled, composted, or reused after it has served its primary objective, it is turned into waste. While raw materials become increasingly scarce and more expensive to extract, waste of unrecycled material accumulates in equal measure and leads to new problems such as the pollution of biospheres (Deus et al., 2017; Haas et al., 2020; Nikolaou and Tsagarakis, 2021). One substantial approach to reduce extraction and waste generation is the decoupling of economic growth from environmental exploitation. One of the central levers to achieve this decoupling is the transformation towards a Circular Economy (CE). The concept of a CE is based on developing circular systems of material and energy that maintain the value of resources as long as possible to realign environmental boundaries with economic activity (Muñoz and Navia, 2021). The idea of circularity is becoming increasingly popular and is promoted by national governments supranational organisations such as the EU, as well as many business organisations and business around the world (Korhonen et al., 2018a). Regarding the practical implementation of a CE, activities will not only involve the product level but also administrative levels, particularly regions. This is by reason that facilitating factors for a CE such as stakeholder cooperation or the establishment of closed cycles are positively related to proximity. Accordingly, many political strategies are implemented on a regional level (Vanhamäki et al., 2020). However, the role of regions in a CE is not covered as extensively in the scientific debate as its relevance would justify. Since the successful implementation of circular measures in regions needs to recognise regional characteristics rather than proposing a one-size-fits-all solution, the missing regional focus also constitutes a political problem. Addressing this apparent gap is even more urgent for Europe as the Green Deal sets a new development paradigm of climate-neutrality until 2050 that involves CE as a central building block for EU policy in the coming decade (European Commission, 2019; 2021; McCann and Soete, 2020; Arsova et al., 2022).

The article at hand fills a gap by addressing the topic of CE in European regions. One of the central weaknesses is the availability of a quantitative framework to measure the implementation and effects of

CE at the regional level. Such an extensive framework is missing in Europe; thus we propose a multi-dimensional methodology that combines existing approaches and introduces new aspects to overcome shortcomings of earlier models (European Commission, 2011; Elia et al., 2017; Mitrovic and Veselinov, 2018; OECD, 2020; Mazur-Wierzbicka, 2021; Arsova et al., 2022). To do so, both a static and a trend index are calculated to assess the state and the recent development of CE in European NUTS 2 regions. This analysis answers which regions can serve as an example for others, which regional policies have been successful, and highlights how to shape the process in the future. These findings are then integrated into the framework of regional innovation policy in Europe, particularly the regional innovation strategies for smart specialisation (RIS3). This instrument has been promoted as the primary policy measure for regional policy in Europe and is increasingly discussed in terms of a green transition. Accordingly, article discusses how CE and smart specialisation are related and make a claim that their mutual relevance for regional development should be further analysed (Doranova et al., 2012; Gianelle and Kleibrink, 2015; Montresor and Quatraro, 2018; Gerlitz et al., 2020). Applying such a framework of regional CE measurement (1) allows policy makers and scientists to track progress of regional CE development, (2) highlights geographical patterns, (3) identifies target regions for further analysis, and (4) helps to focus support schemes to those regions that need support.

Against this background, the article is structured as follows: section 2 provides an overview about the concept of CE and its relevance, particularly for Europe. Afterwards, the geographical dimension of CE is presented before the linkages between CE and smart specialisation are discussed. In section 3, an overview of the state-of-the-art assessment of CE in regions is presented and research gaps are identified. Section 4 addresses these gaps and reveals the development of a multi-dimensional framework of CE assessment. The results are presented in section 5 and discussed in section 6. The article closes with a conclusion and a discussion of the policy relevance (section 7).

4.2 The Concept of CE

CE as a concept has emerged from integrating different scientific disciplines from economics to natural sciences and is anchored in the broader waste and resource debate (Blomsma and Kennan, 2017). These diverse origins lead to a certain level of confusion regarding the definition of CE and its embedding in different research streams. The current discussion about CE in practice requires a solid foundation of the concept's intellectual roots which will be illustrated in the corresponding subsections.

4.2.1 Theoretical Foundations

The origins of circularity considerations trace back to the 1960s with the recognition of planet Earth as a closed system of circular relationships (Boulding, 1966; Haas et al., 2020; Nikolaou and Tsagarakis, 2021). CE as a particular topic was first introduced by Pearce and Turner (1990), but a steady shift could be recognised over the previous decades when attention transferred to a greater industrial and societal focus regarding controlling pollution and resource treatment (e.g., Meadows et al., 1972). CE then gathered further pace in the 1990s with the emergence of several environmentally related research streams developing in parallel, merging, and then separating over time. Among these research streams were fields such as industrial ecology which is based on the idea to learn from material and energy flows in nature, industrial symbiosis focusing on actor networks, cradle-to-cradle design centring on adapting societal flows to natural flows and sharing economy approaches emphasising the role of individual behaviour (Korhonen et al., 2018b; Domenech et al., 2019; Bourdin et al., 2022).

The concept which evolved from this melange of ideas and that later became known as CE has recently gained urgency in light of mitigation of climate change with a particular drive derived from policymakers such as the EU, individual countries such as China or Sweden, as well as business development bodies such as the Ellen MacArthur Foundation (Chizaryfard et al., 2021). CE as a concept was developed and led by practitioners with a scholarly position and is still emerging. This is one of the reasons of conceptual confusion about CE definitions (Korhonen et al., 2018b). The multitude of CE variants in the scientific literature in terms of concept, approach, and scope underlines the development the concept has undergone (Kirchherr et al., 2017; Wilts, 2017). The fact that CE is an evolving concept influenced by different scientific disciplines and shaped by different stakeholder groups provides an explanation why the process of developing a definition is not completed and probably never will be. Until now, there is no consensus on how to clearly define CE so that several definitions exist in parallel (Korhonen et al., 2018a; Kovacic et al., 2020; Chizaryfard et al., 2021). Even if one wanted to provide a single definition, this endeavour would be doomed to fail as it would always exclude some interests and could not recognise the dynamic and evolving discussion on CE (Korhonen et al., 2018b). Accordingly, we do not claim to present a universal definition here. However, the development of a quantitative methodology requires an understanding of what a CE is and entails.

Generally, definitions are divided based on different assumptions. Korhonen et al. (2018b) identify two lines of thought based on a business and a scientific perspective on CE. Opposing that, Hachaichi and Boudin (2023) name two streams with one focusing on a product level of restorative design and another on an economic level of creating cycles along production, distribution, and consumption processes. Methodologically, a product-level oriented CE regards material flows inspired by biological cycles. This is done so that each cycle of material use is complemented by another cycle, rather than seeing the materials being disposed after use (Kiser, 2006; Braungart et al., 2007; Braungart and McDonough, 2009; Braungart, 2011). To “design out” waste, the input side of production is adapted by focusing on biological ingredients or “nutrients” which should be at least non-toxic but possibly even beneficial when returned to the biosphere. The concepts of recycling (1) and reuse (2) are complemented by the third factor of reducing (3), thereby forming the “3R principles”. These principles have recently been supplemented by recovering (4) to create the “4R principles” (Ellen MacArthur Foundation, 2013; 2015; Heshmati, 2015). A broader definition of CE, which is the one that will be applied in this article, combines the previous aspects, and embeds them into a multidimensional framework encompassing economic, environmental, and social aspects. From this perspective, CE is not only a production variant but a concept that also covers societal aspects and economy-level implications.

Accordingly, the benefits of CE can be divided into economic, social, and ecological aspects. From an economic point of view, CE promises potential net savings of material and energy costs, competitive advantages, and increased competitiveness for companies, as well as improvements in selection and product quality for consumers. Additionally, local industries, a category to which CE companies commonly belong, have proven to perform better in times of economic recession which might indicate a stronger resilience through circularity (Greenovate Europe, 2012; Ellen MacArthur Foundation, 2013; Ketels and Protsiv, 2017). Niang et al. (2023) highlight that growth in employment in CE-related sectors was higher than the growth of total employment, indicating an economic benefit of CE. Moreover, the preservation of high-quality materials can reduce the demand and therefore the dependence on the import of raw materials and intermediate consumption. Regional cycles make value chains less vulnerable to price fluctuations and to the insecurity of supply potentially arising from resource scarcity or geopolitical factors (European Commission, 2014; 2016; Ketels and Protsiv, 2017; Wilts, 2017; Bourdin and Torre, 2020).

From an environmental point of view, CE reduces the pressure on the extraction of raw materials by increasing the supply of recyclates. Moreover, negative externalities of waste production and inappropriate disposal can be addressed by recycling, designing for repair, and extending the lifecycle of products. However, the concept of CE is limited by fundamental laws of thermodynamics stating that certain quantitative and qualitative losses are unavoidable. Moreover, maintaining the high quality of virgin materials is almost impossible since all processes of recycling involve a certain amount of quality loss and downcycling. It is therefore required to notice that the promise of a CE will not solve the problem of an unsustainable economy on its own through technological innovation and new institutional frameworks. This is even more true as rebound effects are a well-known phenomenon and have in many cases, undermined the efficiency gains of CE (Georgescu et al., 2014; Gregson et al., 2015; Gonçalves Castro et al., 2022). It is this aspect that is primarily addressed in the social dimension of CE. While CE involves social benefits such as job creation, stronger societal cooperation, or lower expenditures for households, an exclusively technical or economic focus will fail to deliver behavioural changes and neglects governance and management challenges required for a successful CE implementation. Aspects of cooperation and multidimensional interactions between different stakeholders come into play. Cultural and social aspects such as stakeholder relations, institutions, and policies are inevitable building blocks for a holistic transition perspective (Korhonen et al., 2018b; Beaurain et al., 2023; Chembessi et al., 2023). While a large part of CE literature deals with product or company perspectives, the geographical perspective, particularly the regional level must not be neglected as it will play a major role in the implementation of CE policy. Social factors of CE implementation are especially related to sub-national levels such as regions as they provide the conditions for stakeholder cooperation, the set-up of innovation systems of diverse actors, administrative capacity, as well as beneficial conditions for the development, widespread use, and diffusion of environmental innovations (Van den Heiligenberg et al., 2017; Losacker et al., 2021; Chembessi et al., 2021b; Arauzo-Carod et al., 2022). Accordingly, the neglect of the regional aspect in scientific articles and practical policy of CE underestimates the role played by governance structures, and institutional requirements to design appropriate CE policies (European Commission, 2019; 2021; Vanhamäki et al., 2020; Dagilienė et al., 2021; Henrysson and Nuur, 2021; Arsova et al., 2022; Morales and Dahlström, 2022; Williams, 2022; Rezaie et al., 2022). This research gap is one of the reasons why the potential to leverage green transition is so far not exploited. Leveraging regional development potential for the run-up of CE might benefit both. Moreover, the regional perspective allows for the identification of success factors and regional requirements for a successful CE implementation.

In this context, current research indicates that CE development is geographically highly diversified. For instance, the share of adoption of CE principles in high-income EU countries tends to be larger than in less developed EU countries (Mitrovic and Veselinov, 2018). At the regional level, urban areas are particularly highlighted when it comes to CE transition. This is justified by the argument that these regions suffer more from typical urban downsides of waste generation and therefore benefit most from CE measures. These findings imply that spatial factors such as an urban structure shape the formation of CE. However, it remains unclear whether the divide between highly- and less-developed regions in terms of CE is an objective fact or a misunderstanding based on limited data availability (Bačová et al., 2016; Muñoz and Navia, 2021; Mazur-Wierzbicka, 2021). These questions will be further addressed below.

4.2.2 CE in Europe

Geographically, research on CE is strongly rooted in parts of Asia and Europe from where research has gradually spread (Hachaichi and Bourdin, 2023). In particular, China has introduced CE measures on a large scale and promoted CE to an economic development strategy to mitigate the environmental challenges associated with strong economic growth (Heshmati, 2015; Silvestri et al., 2020). The EU has also recognised the relevance of CE to align economic growth and sustainability. Stating that raw materials are *"the lifeblood of the EU economy"* (European Commission, 2016: 3) and identifying a high import dependency when it comes to certain resources, a transformation towards a more regenerative and resource-sensitive growth model is required (Ragossnig and Schneider, 2019; WEF, 2014; European Commission, 2010; 2020a; EEA, 2016; 2020). Steps towards the integration of CE in European policy have been institutionalised since 2008 with relevant directives and strategy formulations (Avdiushchenko, 2018; Mazur-Wierzbicka, 2021). The adoption of a Circular Economy Action Plan in 2020 has officially promoted CE to a main building block of the sustainability agenda of the European Commission. This Action Plan is also embedded in the larger picture of establishing a new growth strategy, framed as the EU Green Deal, as well as the aspiration to improve resource efficiency and reduce European import dependence on raw materials (Wilts, 2017; Salvatori et al., 2019; Domenech et al., 2019; Borett et al., 2020; European Commission, 2011; 2019; 2020a). However, the EU economy is still considered too linear and certain policies have taken extended time until being pursued by European and national policies (European Commission, 2019; Reike et al., 2018; Mazzanti and Zoboli, 2009). Compared to the original idea of CE, certain aspects are regularly lost in transition towards practical policy. One of these is the social aspect of changing consumption and production patterns whereby CE is often reduced to an instrument of maintaining an unsustainable model of economic growth (e.g., Dunlap and Laratte, 2022).

4.2.3 CE and Smart Specialisation

As indicated above, it is claimed that the regional aspect of CE is highly relevant for successful policy implementation (e.g. Gibbs and O'Neill, 2017; Arsova et al., 2022). In this context, Fusillo et al. (2021) underline that trajectories of regional CE innovation systems resonate with regional capabilities. Thereby, the regional level has become a focal point of European policy over the last decade as a consequence of previous strategies being too generic and too removed from regional requirements and capacities (e.g., Fedeli et al., 2020). One of the central instruments is smart specialisation. This approach has risen to be the pivotal European policy instrument for cohesion and regional policy. The strategy behind the instrument is to guide regions in their process of identifying and developing their competitive advantages by concentrating regional resources accordingly. Identifying economic growth areas via bottom-up processes under the premise of structural renewal rather than structural conservation shall help to overcome interregional gaps in terms of productivity or research and development (R&D) in Europe by supporting less-developed regions. Theoretically, the concept is embedded in the frame of innovation systems and economic geography (Foray and Goenaga, 2013; Foray et al., 2009; 2011; 2021; Isaksen and Trippl, 2014; Asheim et al., 2016; D'Adda et al., 2018; Tödtling and Trippl, 2018) By now, smart specialisation has become the central pillar for economic development and growth policy in Europe (McCann and Ortega-Argilés 2015; Lopes et al., 2019; Gómez Prieto et al., 2019).

In recent years, there is an ongoing discussion about updating smart specialisation after the instrument has existed for about a decade. One stream of discussion argues in favour of extending the original smart specialisation concept to better suit the requirements of a green transition. However, others call for a refocusing on the initial targets of smart specialisation (Foray et al., 2012; Doranova et al., 2012; Benner, 2020; Tödtling et al., 2021; Isaksen et al., 2022). In relation to the current sustainability discussion, an extension of S3 has been discussed in order to combine sustainability and innovation policy (McCann and Soete, 2020; Larosse et al., 2020; Arsova et al., 2021; Landabaso, 2021; Kruse, 2023). The latter stream of discussion is particularly interesting in terms of CE. When discussing CE at regional level, the question arises whether the existing European instruments recognise CE as a target, whether they represent appropriate delivery channels for CE implementation, or which adaptions might be required to combine both concepts.

In practice, several European regions have already combined their smart specialisation strategies (S3) with CE goals. For instance, exemplary regions from Spain and Slovenia present strategies on smart specialisation for addressing process and product innovations in the CE transition (Smart Specialisation Platform, 2020a; 2020b). Also, certain Finnish regions have identified CE as an important economic domain of activities in the priorities of industry, construction, and waste sectors (Council of Tampere Region, 2021). In this context, Figure 1 provides an overview of European regions that already refer to CE topics as a focal point in their S3. The information was extracted from the database of regional S3 (Joint Research Centre, 2022) by screening it for terms indicating the implementation or support of CE ("circular", "sustainable production", "recycling", "resource efficiency", "cradle to cradle"). The picture shows a relatively even distribution of regions that refer to CE in their S3 (blue coloured) and highlights that the instrument of smart specialisation and the purpose of CE are increasingly merged in regional political strategies.

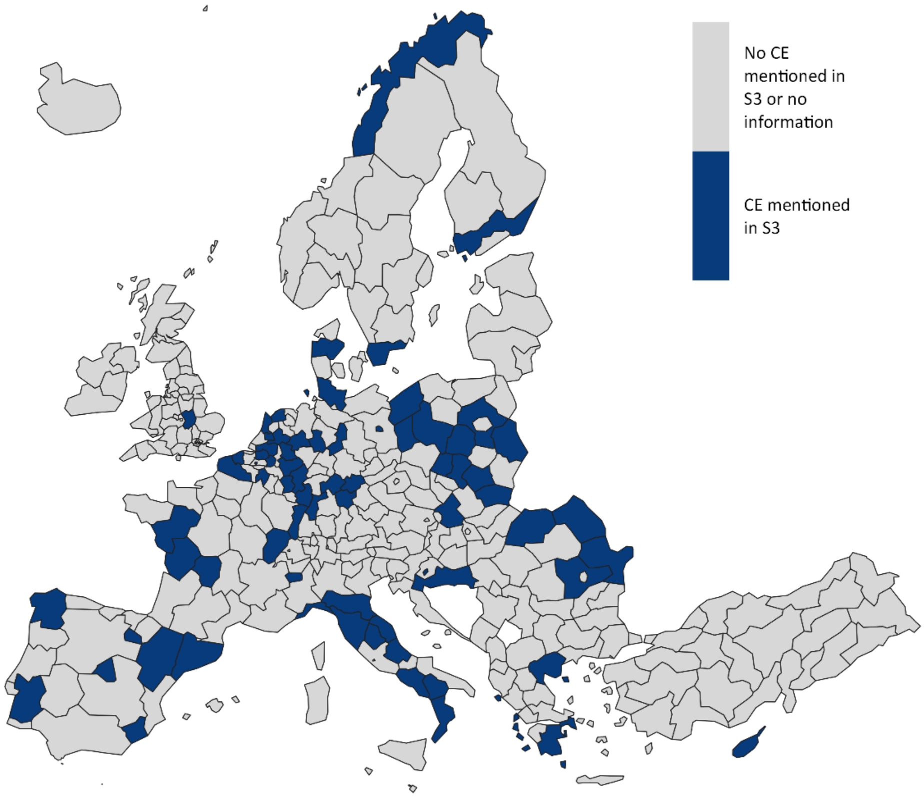

Figure 1: CE focus in smart specialisation strategies (S3), 2022
Data Source: Joint Research Centre (2022)

In current research, CE in S3 and European regional development are increasingly addressed in qualitative case studies. For instance, Harding et al. (2021) find that many European case studies on smart specialisation to foster a green transition have chosen a focus on CE. A perspective on renewable energy transition and the facilitating role of smart specialisation in this context is presented by Steen et al. (2018). Morales and Dahlström (2022) analyse smart specialisation for a green path renewal in Finnish and Swedish regions. Apart from that, it is analysed how various regions have concretised S3 thematic priority areas related to the CE priorities within the regional context (Vanhamäki et al., 2021). Tsipouri et al. (2020) claim that the transformation towards a CE can be accelerated and become beneficial when CE is a strategic focal point for regional innovation strategies. Accordingly, Stanojev and Gustaffson (2021) suggest smart specialisation to strengthen innovation for CE, a claim that is also formulated by Hristozov and Chobanov (2020). However, the combination of the two EU priority strategies and policies, namely CE and smart specialisation, represents a challenge in terms of methodology, prioritisation, and coordination. Although the topic has been raised by several researchers and policy makers, a notable research gap remains when it comes to implementation on a larger scale.

4.3 Regional CE Assessment in Europe

Studies have rated the existing monitoring and assessment tools for CE transition, particularly at the regional level, to be inadequate. While most methodologies were developed and applied in China, these remain geographically specialised and are hardly transferable to other world regions with different structural environments (Zhang et al., 2008; Quing et al., 2011; Geng et al., 2012; Su et al., 2013; Avdiushchenko and Zajac, 2019; Ye et al., 2021). Therefore, the lack of tools to monitor and evaluate CE implementation in European regions remains *"one of the clearest gaps in the CE literature"* (Silvestri et al., 2020: 3). Although the need for an assessment methodology is highlighted (e.g., Blomsma and Kennan, 2017; Virtanen et al., 2019; Borett et al., 2020), the number of publications on regional assessment has remained limited and frequently focused on single aspects of circularity rather than a broader notion. This fact hampers the transition towards a CE as crucial information is missing.

Current gaps of CE assessment involve, for instance, a lack of suitable indicators and data accessibility, particularly on sub-national levels. Thereby, the gap refers particularly to accessibility and transferability as the number of metrics and indicators is steadily increasing. Here, the absolute number of adequate metrics is not considered a weakness but rather the availability of data at the regional or local levels. For instance, the circular material use rate, an indicator measuring the share of material recovered and returned to the cycle, is available only for the national level (EASAC, 2016; Saidani et al., 2019; 2022; Avdiushchenko and Zajac, 2019; Arsova et al., 2022). Moreover, indicators on socio-institutional aspects such as consumption, governance, or political sensitivity are underrepresented compared to more technological indicators. However, the quality and variety of indicators is less of a problem than the availability of data on lower aggregated levels. These data-related gaps have also been recognised by the European Commission, which has initiated a process of reviewing the existing indicators (Vercalsteren et al., 2018; European Commission, 2018; 2020a).

Methodologies to assess CE in Europe have been developed but limitations remain. The following will provide an overview of the most relevant papers and articles focusing on CE quantification in Europe whereby their weaknesses, when it comes to the construction of a new index, are identified and addressed in the next section. Until now, several circularity indices were developed on the country level, but these cannot be transferred to the regional level. This is due to the absence of regional data or country-specific indicators. Moreover, it is a common occurrence to neglect the social dimension of CE in favour of a more economic and technical focus (e.g., Hervey, 2018; Mitrovic and Veselinov, 2018; Avdiushchenko, 2018; Mazur-Wierzbicka, 2021; Banjerdpaiboon and Limleamthong, 2023). Several other papers propose extensive methodologies without applying them practically, sometimes due to the identified data being unavailable on a larger scale (e.g., EASAC, 2016; Saidani and Kim, 2022). Work like this provides an overview of available indicators and potential calculation techniques but does not provide regional insights or raise political implications.

Other papers neglect certain aspects of CE. Among the neglected factors are those of a social, economic, or ecological nature (e.g., Ketels and Protsiv, 2017; Taelman et al., 2020). Another sort of research articles offers a limited focus on individual aspects such as job creation (Niang et al., 2023) or technological patterns (Fusillo et al., 2021), while ignoring others. This research provides an additional academic value of CE in their specific niche. However, the CE as a complex and diverse concept is not adequately represented in that the findings are hardly robust when it comes to a comparative perspective. Additionally, several papers suffer from limitations such as non-transferability of regional indicator sets (e.g., Avdiushchenko and Zajac, 2019, Virtanen et al. 2019, Heshmati and Rashidghalam, 2021), a limited numbers of indicators (e.g., Silvestri et al., 2020; Skare et al., 2023), or a limited number of regions (e.g., Bianchi et al., 2022). In addition to the problem of missing comparability when only certain regions are analysed, the weakness is not so much the indicator design but the problem of non-transferability due to specific indicators that exist exclusively in certain countries.

The development of CE measurement methodologies at sub-regional levels such as cities is discussed and applied by Papageorgiou et al. (2021), Bote Alonso et al. (2022), and Henrysson et al. (2022), revealing the same limitations for the regional level, namely a lack of suitable indicators and data availability. However, it needs to be recognised that the existence of weakness does not understate the scientific value of the described articles. They simply do not suffice on their own for our purpose, so we pursued a synopsis of the state of research with individual complements.

4.4 Data and Methods

4.4.1 Data

For this paper, the authors applied a broad definition of CE, meaning that environmental, social, and economic aspects are regarded as relevant for a CE (see section 2.1). As a foundation, we conducted an extensive literature review that led to the identification of a set of dimensions including traditional dimensions of circularity such as waste and consumption as well as employment statistics, innovation, and political indicators associated to S3 (see Table 1). These dimensions cover environmental aspects (waste statistics), economic aspects (innovation, circular employment), behavioural patterns (consumption and production), and aspects of regional policy. The final set of 29 indicators in six dimensions is the result of a pragmatic approach to select consistent, harmonised, and standardised data adhering to three requirements: (1) The data must cover all of Europe rather than only certain countries,

(2) the data must be available for a time span rather than only a point in time so that development is shown, and (3) the data must be available on a regional level.

It had to be decided whether to apply an analysis exclusively based on indicators with a broad data coverage, potentially leading to the same results as other papers, or to construct an analysis with new indicators that consist of data gaps but potentially reveal new insights. The authors decided to apply new indicators even when the data coverage was not optimal. However, certain databases and indicators were not included as they violated at least one of the three basic requirements, which mostly referred to data availability. The chosen administrative level for the analysis was NUTS 2, which refers to the regional level in Europe. This choice was motivated by data availability and relatively high coverage but does not come without disadvantages. The NUTS 2 level is responsible for the development of regional strategies for most European regions, but certain regions have allocated this responsibility to the more granular NUTS 3 level. Additionally, it needs to be remarked that an assessment on the national level (NUTS 1) would allow for the use of more detailed and targeted CE indicators that are not available on regional NUTS 2 level (see Annex 1).

Most indicators used for the analysis were obtained from the Eurostat (2022) database. Patent statistics were obtained from the PATSTAT database whereby a four-digit search strategy was applied to identify patents related to waste management and recycling (Eurostat, 2023). The year 2018 was selected as the base year by reason of being the most recent year with the highest data availability for EU regions. Rather than choosing the most recent year for each indicator, it was decided to keep a common base year to provide a coherent CE analysis for that point in time. The selected base year to calculate the trend of CE development was 2012. This base year was also chosen by Banjerdpaiboon and Limleamthong (2023) for a comparison to 2018 values. 2012 stood out as the year with a relatively high data coverage for the relevant indicators. Moreover, no major crises were observed in the time frame that could have distorted the results. Finally, the time span of six years between 2012 and 2018 exceeds the duration of legislative periods in EU regions, ensuring a certain autonomy from political trends. However, the strict focus on 2012 and 2018 had to be softened in some cases. For instance, the statistics on waste production and treatment in European regions are based on a pilot project conducted in 2011 so data is limited to this time. Moreover, data regarding the regional generation of different kinds of waste from ESPON (2022) was included due toits high data quality. However, the time frames (2006 and 2014) did not fully correspond to the standard of the methodology.

The applied policy indicators reflect the fact that monitoring schemes often neglect more qualitative indicators such as circular strategies (Reich et al., 2023). However, an exclusive focus on traditional quantitative indicators such as recycling rates ignores important social and political aspects of CE and neglects aspects such as the leverage exerted by public authorities (Wijayasundara et al., 2022). These policy indicators are qualitative in their basic form and have been transformed to become quantitatively usable by applying a binary coding system (0: does not have a strategy, 1: does have a strategy). This kind of transformation is accompanied by the danger of a selection bias resulting from a non-random selection of cases. Consequently, certain cases may be overrepresented in this case due to the binary design of 0 and 1 (Collier, 1995). This limitation also applies to the approach in this paper as it could not be overcome. This methodological limitation needs to be recognised.

Regarding the qualitative data sources, information on green procurement was obtained from the European Commission (2020b) and the status of cities as a signatory of the "Circular City Declaration" functions as an additional indicator of regional recognition of CE (Circular Cities Declaration, 2022). The existence of a regional CE strategy is based on research undertaken by Jonker and Montenegro Navarro (2018) and Salvatori et al. (2019). The indicator "smart specialisation strategies" is based on a dataset by the Joint Research Centre (2022) for the 2014-2020 programming period that was examined for words that indicate the implementation or support of CE ("circular", "sustainable production", "recycling", "resource efficiency", "cradle to cradle"). The indicator can be questioned since CE in regional strategies can be both a prerequisite and a result of a strong regional CE. Despite that ambiguity, it was decided to include the indicator as an additional measure of CE awareness in regional policy.

Table 1: Indicators for CE assessment on NUTS 2 level in Europe

Dimension	No.	Indicator	Base Year - Static	Base Year - Trend	Index	Data Source
Policy	1.1	Regional circular economy strategies	2022	2012	(+)	Jonker and Montenegro Navarro (2018)
	1.2	Circular city declaration	2022	2012	(+)	Circular Cities Declaration (2022)
	1.3	Green public procurement	2020	2012	(+)	European Commission (2020b)
	1.4	Smart specialisation strategies	2021	2012	(+)	Joint Research Centre (2022)
Innovation	2.1	GERD per capita	2017	2011	(+)	Eurostat
	2.2	Patents per employee	2018	2012	(+)	PATSTAT
	2.3	Patents in CE-related technologies	2018	2012	(+)	PATSTAT
	2.4	Gross fixed capital formation	2018	2012	(+)	Eurostat
	2.5	Employees in scientific R&D	2018	2012	(+)	Eurostat, SBS data
Circular Employment	3.1	C33 repair and installation of machinery and equipment	2018	2012	(+)	Eurostat, SBS data
	3.2	E38 waste collection, treatment and disposal activities, materials recovery	2018	2012	(+)	Eurostat, SBS data
	3.3	E39 employees in remediation activities and other waste management services	2018	2012	(+)	Eurostat, SBS data
	3.4	G45 wholesale and retail trade and repair of motor vehicles and motorcycles	2018	2012	(+)	Eurostat, SBS data
	3.5	S95 repair of computers and personal and household goods	2018	2012	(+)	Eurostat, SBS data
Consumption and Production	4.1	Total waste generated by households	2014	2006	(-)	ESPON
	4.2	Food waste generation	2014	2006	(-)	ESPON
	4.3	Electric and electronical waste colledted	2014	2006	(-)	ESPON
	4.4	Plastic waste generation	2014	2006	(-)	ESPON
	4.5	Waste generated by construction acitivties	2014	2006	(-)	ESPON
	4.6	Waste generated by manufacturing activities	2014	2006	(-)	ESPON
Waste Management	5.1	Disposal - incineration	2018	2010	(-)	Eurostat
	5.2	Recovery - energetic recovery	2018	2010	(+)	Eurostat
	5.3	Disposal - landfill and other	2011	2010	(-)	Eurostat
	5.4	Recycling - material	2011	2010	(+)	Eurostat
	5.5	Recycling - composting and digestion	2011	2010	(+)	Eurostat
Socio-Economic Development	6.1	GDP per Capita	2018	2012	(+)	Eurostat
	6.2	Tertiary education	2018	2012	(+)	Eurostat
	6.3	Unemployment rate	2018	2012	(-)	Eurostat
	6.4	Households with broadband access	2018	2012	(+)	Eurostat

4.4.2 Methods

To calculate a benchmark value that allows for a comparison of European regions in terms of CE, we set up two indexes(indices): first a "static" index based on the most recent data and second, a "trend" index covering the development in past years. The division is derived from Silvestri et al. (2020). Two steps: (1) normalisation of the original data and (2) aggregation of the normalised values to receive a composite measure were applied for the index. The first step was necessary due to different scales and dimensions. Thanks to this normalisation, each variable is expressed in an interval between 0 and 1. A value closer to 1 corresponds to a superior CE performance, whereby a value approaching 0 indicates a lower performance. Relatively better values in each indicator lead to a higher value in the overall index and indicate a more developed CE system. The normalisation function is given below, where X_{jk} represents the value of the *k-th* variable for the region j.

$$Y_{jk} = \frac{X_{jk} - \min(X_{1k},\dots,X_{jk})}{\max(X_{ik},\dots,X_{Jk}) - \min(X_{1k},\dots,X_{jk})} \qquad (1.1)$$

Variables with a negative impact on the CE performance were calculated as follows:

$$Y_{jk} = \frac{\max(X_{1k},\dots,X_{jk}) - X_{jk}}{\max(X_{ik},\dots,X_{Jk}) - \min(X_{1k},\dots,X_{jk})} \qquad (1.2)$$

In Step 2, the normalised variables were aggregated using an arithmetic average. First, the arithmetic average was calculated for the six dimensions individually, before the results were combined for the final index. This intermediate step allows for a more detailed view of how the final index is composed and acknowledges the fact that the indicators in each dimension might be correlated. This potential drawback is minimised by separating the dimensions. Also, it was decided to abstain from applying different weights to the individual variables and dimensions since an objective relevance of each indicator for circularity cannot be identified. The function is given below whereby a higher Z_j value indicates a stronger CE performance in region j.

$$Z_j = \frac{1}{k} \sum_{k=1}^{K} Y_{jk} \qquad (2)$$

For the trend index, the static index was calculated for an earlier year to measure the development in between the two points in time. The difference between the two static indices is calculated to be the trend index.

4.5 Results

To calculate the static index of CE performance, the methodology was applied to 278 European NUTS 2 regions with 2018 as the general base year. Country-specific gaps in different indicators have been observed due to data being classified as “confidential” in the Eurostat database or changes of the statistical NUTS classification between 2013 and 2018 that did not allow for a comparison of data. Significant gaps were observed in employment data in Italian regions as data was not available at all. Gaps in French, Irish, and several Polish regions are also observed in the consumption and production dimension. In terms of waste management, Finland, Sweden, Slovenia, Spain, Greece, Ireland, Czech Republic, Denmark, and some French regions had to be excluded due to a lack of data. Applying a weighted average to calculate the total index considered these gaps. The findings reveal a concentration of strong circular performance in Central European and Scandinavian regions (see Table 2). The best performing regions are predominantly regions with a strong urban character. It is worth noting that the indicator set gives too much weight to development and innovation indicators, but excluding this dimension did not significantly change the results.

Table 2: TOP 20 European regions – static index

Rank	NUTS ID	Region	Index Value
1	LU00	Luxembourg	0.6140
2	ES51	Cataluña	0.5921
3	FI1C	Etelä-Suomi	0.5858
4	ITH5	Emilia-Romagna	0.5774
5	UKI3	Inner London — West	0.5731
6	ES24	Aragón	0.5663
7	NL32	Noord-Holland	0.5662
8	CZ01	Praha	0.5661
9	BE25	Prov. West-Vlaanderen	0.5651
10	BE24	Prov. Vlaams-Brabant	0.5634
11	SE22	Sydsverige	0.5633
12	ITI1	Toscana	0.5620
13	FR10	Ile-de-France	0.5619
14	AT34	Vorarlberg	0.5590
15	ITC3	Liguria	0.5522
16	RO21	Nord-Est	0.5518
17	DK01	Hovedstaden	0.5507
18	FI1D	Pohjois- ja Itä-Suomi	0.5499
19	FI1B	Helsinki-Uusimaa	0.5435
20	ES62	Región de Murcia	0.5430

The pattern of strong CE performance in certain regions is illustrated in Figure 2. In countries such as England or France, the capital regions acquire a higher CE performance than the rest of the country while the picture in Spain is constituted by a comparable pattern but with more than one centre. The map reflects existing economic disparities, e.g., between Northern and Southern Italy or between Northern UK and the central London region. The largest concentration of CE performance can be observed in Scandinavian regions as well as large parts of Central Europe, while Eastern European regions are performing worse in terms of CE. The apparently low performance in France is primarily explained by data gaps in one dimension. Striped regions did not provide sufficient data for calculation.

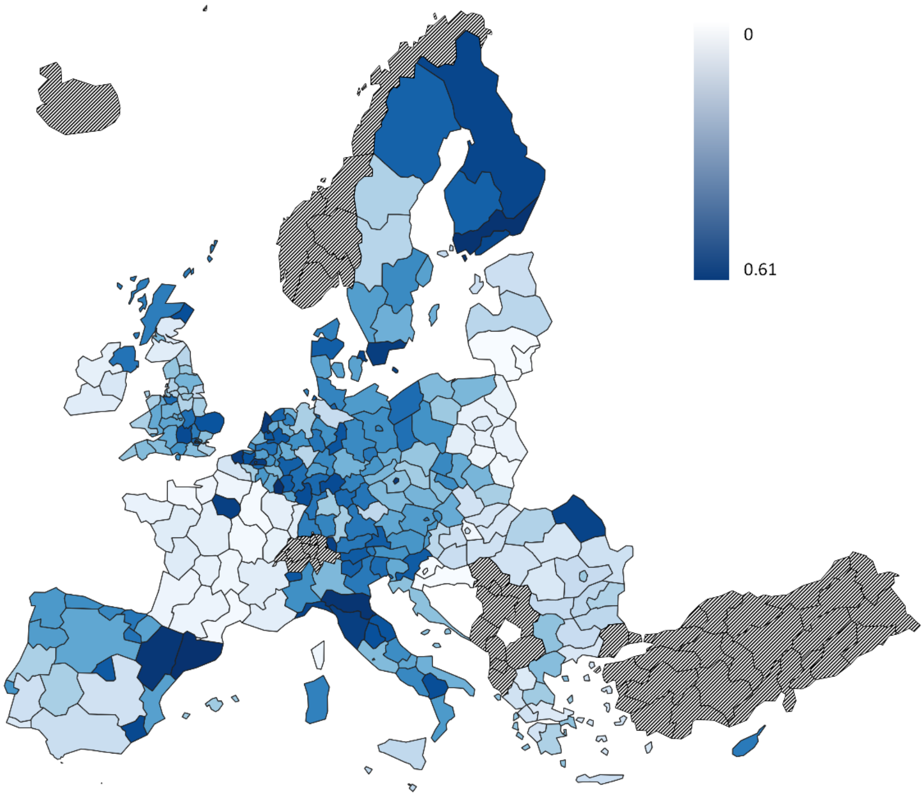

Figure 2: Map of European regions – static index
Data Source: see Table 1

The results are in line with other studies conducted on the environmental and economic performance of European regions. For instance, the strong CE performance in Central European countries such as Netherlands, Germany, Austria, or Belgium, accompanied by parts of Scandinavia as presented by Banjerdpaiboon and Limleathong (2023) is confirmed in our study. However, the low performance that the authors attributed to Finland, or Czechia is contradicted by our analysis. Apart from this, our findings can provide new insights, focuses, and differentiations to enrich the general discussion about regional CE performance in Europe. For instance, the findings of Mazur-Wierzbicka (2021) of locating the most advanced countries in terms of CE principles in Central Europe with the lowest-ranking countries in Eastern and Southern Europe are complemented by a more differentiated perspective. Our analysis reveals that certain countries such as Romania do not perform generally worse but individual Romanian regions perform above average. Therefore, the previous finding of particularly less developed EU countries continuing to focus on linear rather than CE principles cannot be confirmed (Mitrovic and Vesslinov, 2018). In comparison to Silvestri et al. (2020), who chose a similar methodological approach, the structural findings in this paper are similar. However, the larger data set and the inclusion of regions that were missing (e.g., Scandinavia or the UK), as well as the inclusion of new indicators and new dimensions with more recent data, allow this paper to paint a more complete picture of CE in European regions. Moreover, the CE performance in Eastern Europe, particularly in urban regions, is found to be stronger than what Silvestri et al. (2020) assumed. This can be attributed to the inclusion of different data bases.

Generally, the new methodology does not contradict previous findings but helps to explain them in a more reflected manner. For instance, national level analyses often assumed that countries in Eastern Europe were underdeveloped when it comes to CE whereby it could be shown that certain regions in Eastern Europe perform above average when it comes to CE. This is easily overseen when all regions of a country are accumulated. Our findings combine and refine previous approaches, which explains why no major contradictions have been identified.

4.6 Discussion

For the trend index, the static index values were compared with the values in 2012 as the general base year. The indicator set (see Table 1) was applied to 278 European NUTS 2 regions whereby those regions that revealed missing data in more than two dimensions had to be excluded. Consequently, the trend index consists of 264 European NUTS 2 regions (see Annex 2). The missing data have either occurred due to changes in the statistical NUTS classifications that did not allow for a comparison of regions over time or gaps in the data availability. In terms of waste management statistics, Bulgaria, Czechia, Denmark, Germany, Ireland, Greece, Spain, France, Italy, Finland, Sweden, as well as some Polish and British regions had to be excluded. This was done either because they did not report any data or because there were missing data in the trend index so that no comparison could be conducted. The same holds for French regions in the consumption and production dimension. The indicator “circular city declaration” in dimension 1 (Policy) was removed for the trend index since the initiative was not in place in 2012.

In terms of the trend index, a relatively even geographical distribution among Europe is observable when examining the top 20 best performing regions. Eastern European regions are reflected as well as Scandinavian, Southern, or Central European regions (see Table 3).

Table 3: TOP 20 European regions – trend index

Rank	NUTS ID	Region	Index Increase
1	FRE1	Nord-Pas de Calais	0.1998
2	FI1C	Etelä-Suomi	0.1705
3	LU00	Luxembourg	0.1551
4	FI1D	Pohjois- ja Itä-Suomi	0.1428
5	FRG0	Pays de la Loire	0.1307
6	FRI3	Poitou-Charentes	0.1292
7	FI19	Länsi-Suomi	0.1246
8	SI03	Vzhodna Slovenija	0.1199
9	BE25	Prov. West-Vlaanderen	0.1170
10	ITH5	Emilia-Romagna	0.1168
11	ES62	Región de Murcia	0.1165
12	RO41	Sud-Vest Oltenia	0.1160
13	PT11	Norte	0.1151
14	ES51	Cataluña	0.1137
15	ES24	Aragón	0.1083
16	UKF2	Leicestershire, Rutland and Northamptonshire	0.1049
17	SE22	Sydsverige	0.1047
18	UKM5	North Eastern Scotland	0.1033
19	FR10	Ile-de-France	0.0975
20	PL84	Podlaskie	0.0973

Figure 3 provides a geographical overview of the trend index in European regions. While a relatively even distribution can also be observed, the light red regions have faced negative development in terms of CE in recent years. These regions are also evenly distributed, while large parts of Germany stand out in a negative way. Generally, the figure highlights that positive developments over the period under review are also found in those regions that rank comparable low in the static index which indicates a catch-up process. Comparing the static and the trend index reveals that Finnish regions rank particularly high in both indexes. The favourable position in which Finnish regions are situated in the static index corresponds to a remarkable development in the trend index rather than a structural advantage over other regions. Starting from a worse position than others, Finland proves that catching up in terms of CE performance is possible. Structurally, countries like France tend to move towards regional convergence with a positive trend in regions that do not rank high in CE performance; while the structure in England appears to be structurally preserving with particularly positive development in already prospering regions around the capital. Striped regions did not provide sufficient data for calculation.

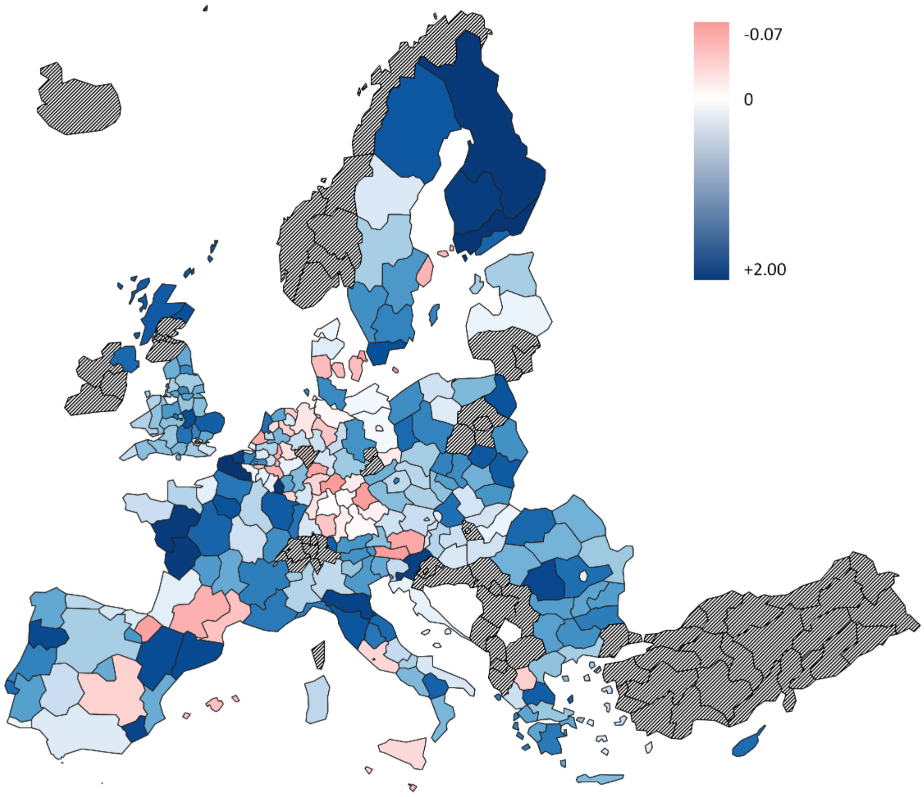

Figure 3: Map of European regions – trend index
Data Source: see Table 1

Although the CE performance tends to be positively related to agglomeration areas which combine a high level of infrastructure with a critical mass of stakeholders, the analysis shows that also sparsely populated areas such as Finnish regions can perform extraordinarily well. While the CE concentration in strong urban and industrial regions is not surprising (and has also been acknowledges by other studies) (e.g., Niang et al., 2023), it is noticeable that not all capital regions rank high in terms of their CE index. Instead, also non-capital regions with a lower centrality and more rural structure appear in the top-20. It appears that the CE performance is not fully explained by structural characteristics but qualitative factors such as regional policy and governance. While it is beyond the scope of this article to further elaborate on these factors, certain authors have started looking into institutional factors as influencers of regional CE (see e.g., Ranta et al., 2018; Budde Christensen, 2021) and the role of structural factors for CE-compliant individual behaviour (Neves and Marques, 2022). Domenech and Bahn-Walkowiak (2019) analysed national strategies on CE and identify Germany, Austria, and Finland as frontrunners. Regions from these countries also rank highly in our static index. Generally, several of the top-20 regions in the static index are also known for their regional circular strategies, for instance London, Prague, Helsinki, and Paris (Mairie de Paris, 2017; City of Helsinki, 2020; Circular Prague, 2022; ReLondon, 2023). Although we cannot concretely assume a causal correlation, our study confirms the important role that policies play for the CE transition and the role of governments in this context (see also Chembessi et al., 2021a; Hartley et al., 2023; Niang et al., 2023). Moreover, the distribution of strong CE regions among

Europe can be understood as a promising signal as CE can be successfully implemented in different socio-economic and geographical contexts. Also, it needs to be recognised that the assessment methodology does not quantify phenomena such as outsourcing of urban metabolisms, which provides an additional perspective on rural-urban interactions (Tanguy et al., 2020; Bahers and Rosado, 2023).

Another perspective to compare the static and trend indices is a scatterplot provided in Figure 4. To achieve a clearer picture in terms of geographical trends, four regional groups were distinguished: Central Europa (Austria, Belgium, France, Germany, Luxemburg, Netherlands, UK), Southern Europe (Cyprus, Greece, Italy, Malta, Portugal, Spain), Eastern Europe (Bulgaria, Czechia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia, Slovenia), and Northern Europe (Denmark, Estonia, Finland, Sweden).

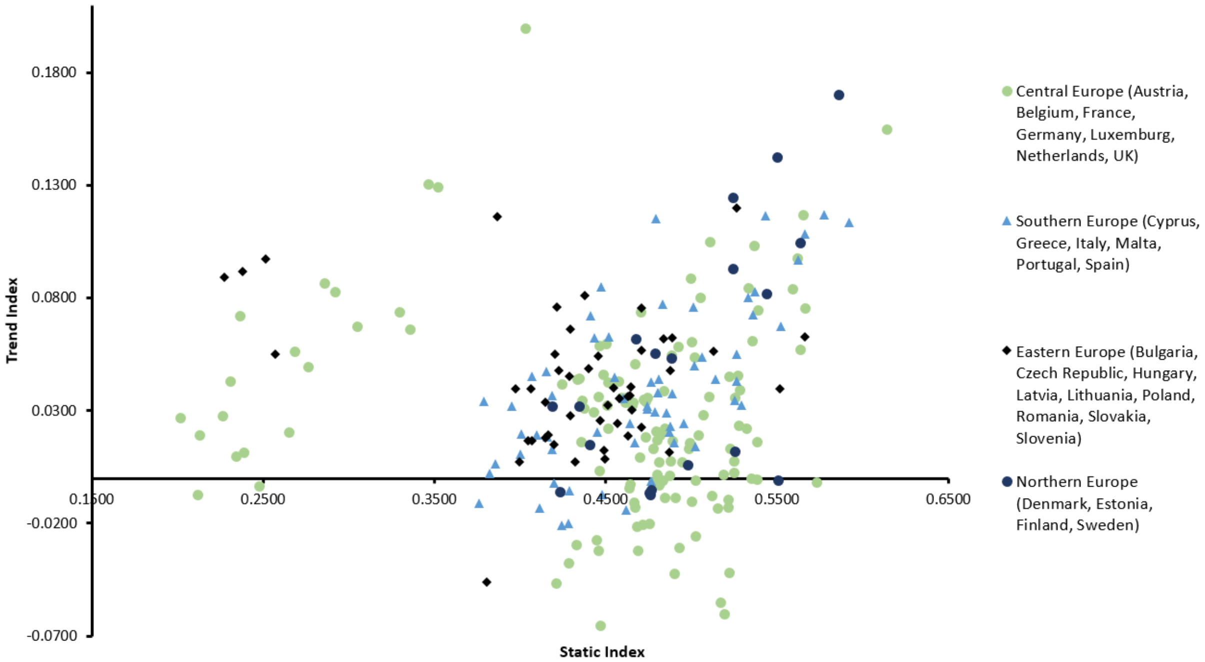

Figure 4: Static and trend index

Data Source: see Table 1

Eastern European regions (represented by black diamonds) generally find themselves in a modest position with an average performance in the static index and a slightly positive development in the trend index. Central European regions (represented by light green dots) do not present a clear picture, which can be attributed to the diversity of the group consisting of some of the worst and some of the best performing regions. In Northern European regions (represented by darker blue dots) there appears to be a trend that those regions ranking high in the static index also perform above average in the trend index. A similar development pattern is observed in Southern Europe (represented by lighter blue triangles). Geographically speaking, several regions in Central and Southern Europe appear to lose touch with the other regions in case that the negative development trend continues. These regions come under relative pressure from catching-up regions and leading regions expanding their position. Generally, Eastern or Southern European regions do not perform worse than Central or Northern European regions. However, it appears that high-performing regions with an urban character have an advantage when it comes to CE. This might be due to structural characteristics such as the availability of an established infrastructure for waste collection and the treatment or the existence of environmentally conscious social groups in urban centres that push regional governments for more CE action.

4.7 Conclusion

The benefits of a CE range from economic and environmental up to social benefits. However, when it comes to implementation, the role of regions in the transition towards CE is still under-researched even though the regional perspective is becoming increasingly important. For Europe, it is particularly striking that a thorough methodology to quantify CE on a regional level is missing. The article at hand proposes a multi-dimensional framework of 29 indicators in six dimensions to overcome previous limitations (see Table 1). While several of these dimensions have been chosen for CE measurement before, the methodology at hand is the first to combine them for a regional analysis. The data selection followed a pragmatic approach to select consistent, harmonised, and standardised data which were used to calculate a static and a trend index. Since monitoring schemes are a necessary instrument to quantify the effective implementation of policies and to identify their regional implications, the framework provides policy makers with an objective and adaptable methodology to develop CE instruments for Europe. It also highlights the current gaps in data availability on the regional level that need to be addressed to improve monitoring instruments in the future to gain deeper insights into CE development.

The results of quantifying regional CE performance in European regions partly confirm previous studies conducted on the environmental and economic performances of European regions but also draw a more differentiated picture: As some studies suggest, Eastern and Southern European countries are not utterly uncoupled from Central and Northern Europe but show a high level of interregional differentiation. Certain regions, particularly the urban capital regions, reveal a relatively high CE performance while more rural regions perform worse. The inner-country development patterns also differ among countries so that the differentiating line would not be drawn between North and South or West and Eastern Europe but rather between individual regions. The assumption of a natural correlation between urban areas and high CE performance can be rejected as a result from the findings. Instead, regional CE performance appears to be determined by regional policy rather than structural characteristics alone. Further research could involve qualitative case studies on why structurally similar regions perform that different in terms of CE. A first hint is identified by examining the instrument of smart specialisation. This European strategy for innovation and regional development has been used by some regions, particularly in Scandinavia, to facilitate regional CE development. These regions have proven to perform well in terms of CE, which might support previous claims that CE and smart specialisation might have the potential to benefit from each other. Comparing the regions focusing on CE in their S3 and the regions with high CE performance values reveals some overlaps (see Figure 1 and 2). Although it is hard to derive whether CE has been named in regional strategies as a result of strong CE performance or whether the policy has been the foundation for strong CE development, there appears to be a relation between both, that should be further analysed. It has been shown that both policy makers and researchers increasingly discuss S3 and CE together but to derive a recommendation for European policy in general, the separated case studies need to be scaled up and a more holistic approach is required (Vanhamäki et al., 2021).

Generally, the analysis at hand can help policymakers to track their regional performance and progress in terms of CE so that it can be used as a basis for the design and enhancement of regional strategies. The instrument of smart specialisation can particularly be a relevant tool in this regard as it focuses on the identification of regional capabilities and the exploitation of development potentials. The integration of CE knowledge into this process can help to improve CE visibility and create incentives for directed investments as also claimed by Fusillo et al. (2021). On a superior level, CE policy in Europe should recognise the disparate development trends particularly when urban and rural regions are compared. To avoid a further deepening of regional inequality, tailored support is required to support the worse-performing regions, so they do not lose ground in the transition towards CE and sustainability. However, the presented methodology cannot raise a claim for completeness. The identification of dimensions is based on a literature review to assess the CE performance in regions but relies on a high level of pragmatism related to the limited availability of data on regional level. Therefore, drawbacks had to be accepted when it came to regional coverage and data gaps, as well as the years analysed. Improving data quality and the development of new indicators will allow for a revision and fine tuning as well as potential complements of the methodology.

Annex

Annex 1: Potential additional indicators for CE benchmarking on NUTS 1 level

Dimension	No.	Indicator
Policy	1.1	Expenditure on environmental protection
Innovation	2.1	Private investment, jobs and gross value added related to CE sectors
	2.2	Total investment in environmental protection
	2.3	Patents related to recycling and secondary raw materials
	2.4	Energy productivity
	2.5	Water productivity
Employment	3.1	Gross value added in environmental goods and services sector
Consumption and Production	4.1	Generation of waste excluding major mineral wastes per GDP unit
	4.2	Generation of waste excluding major mineral wastes per domestic material consumption
	4.2	Generation of packaging waste per capita
	4.3	Generation of waste electrical and electronic equipment (WEEE)
	4.4	Generation of biological waste
	4.5	Material consumption
	4.6	Resource productivity
Waste Management	5.1	Recycling rate of all waste excluding major mineral waste
	5.2	Recycling rate of e-waste
	5.3	Recycling of biowaste
	5.4	Recovery rate of construction and demolition waste
	5.5	Circular material use rate
	5.6	Contribution of recycled materials to raw materials demand
	5.7	Trade of recyclable raw materials between EU member states and with the rest of the world
Regional Sustainability	6.1	Exposure to air pollution
	6.2	Air emissions accounts by NACE Rev. 2 activity
	6.3	Settlement area
	6.4	Share of busses and trains in total passenger transport
	6.5	Population living in households considering that they suffer from noise
	6.6	Share of renewable energy in gross final energy consumption
	6.7	Soil sealing index

Annex 2: CE performance in Europe, static and trend index, NUTS 2iLevel, 2018 & 2012-2018

NUTS ID	Region	Static Index	Trend index
BE10	Région de Bruxelles-Capitale/ Brussels Hoofdstedelijk Gewest	0.5345	0.0000
BE21	Prov. Antwerpen	0.4775	0.0133
BE22	Prov. Limburg (BE)	0.4817	0.0193
BE23	Prov. Oost-Vlaanderen	0.5352	0.0609
BE24	Prov. Vlaams-Brabant	0.5634	0.0573
BE25	Prov. West-Vlaanderen	0.5651	0.1170
BE31	Prov. Brabant Wallon	0.5213	-0.0095
BE32	Prov. Hainaut	0.4459	0.0033
BE33	Prov. Liège	0.4633	-0.0041
BE34	Prov. Luxembourg (BE)	0.4696	0.0095
BE35	Prov. Namur	0.4810	0.0074
BG31	Severozapaden	0.4226	0.0480
BG32	Severen tsentralen	0.4289	0.0455
BG33	Severoiztochen	0.4401	0.0487
BG34	Yugoiztochen	0.4291	0.0663
BG41	Yugozapaden	0.4560	0.0464
BG42	Yuzhen tsentralen	0.4203	0.0553
CZ01	Praha	0.5661	0.0628
CZ02	Střední Čechy	0.4568	0.0244
CZ03	Jihozápad	0.4630	0.0364
CZ04	Severozápad	0.4645	0.0405
CZ05	Severovýchod	0.4466	0.0258
CZ06	Jihovýchod	0.4651	0.0302
CZ07	Střední Morava	0.4580	0.0356
CZ08	Moravskoslezsko	0.4879	0.0479
DK01	Hovedstaden	0.5507	-0.0007
DK02	Sjælland	0.4761	-0.0070
DK03	Syddanmark	0.4754	-0.0063
DK04	Midtjylland	0.5251	0.0122
DK05	Nordjylland	0.4975	0.0062
DE11	Stuttgart	0.4467	-0.0651
DE12	Karlsruhe	0.5023	-0.0256
DE13	Freiburg	0.4988	0.0158
DE14	Tübingen	0.4903	-0.0085
DE21	Oberbayern	0.5017	-0.0549
DE22	Niederbayern	0.4283	-0.0375
DE23	Oberpfalz	0.5023	-0.0006
DE24	Oberfranken	0.4929	-0.0306
DE25	Mittelfranken	0.5188	-0.0602
DE26	Unterfranken	0.5383	-0.0003
DE27	Schwaben	0.4454	-0.0320
DE30	Berlin	0.4900	-0.0420
DE40	Brandenburg	0.4869	0.0013
DE50	Bremen	0.5214	-0.0128
DE60	Hamburg	0.5220	-0.0417

DE71	Darmstadt	0.5153	-0.0132
DE72	Gießen	0.4778	-0.0018
DE73	Kassel	0.4888	0.0165
DE80	Mecklenburg-Vorpommern	0.4795	0.0018
DE91	Braunschweig	0.5320	0.0223
DE92	Hannover	0.4842	-0.0085
DE93	Lüneburg	0.4207	-0.0463
DE94	Weser-Ems	0.4442	-0.0273
DEA1	Düsseldorf	0.4680	-0.0215
DEA2	Köln	0.5244	0.0078
DEA3	Münster	0.4845	0.0221
DEA4	Detmold	0.5040	0.0193
DEA5	Arnsberg	0.4326	-0.0293
DEB1	Koblenz	0.5098	0.0365
DEB2	Trier	0.5268	0.0459
DEB3	Rheinhessen-Pfalz	0.5380	0.0161
DEC0	Saarland	0.4751	-0.0202
DED2	Dresden	0.4686	-0.0318
DED4	Chemnitz	0.4815	:
DED5	Leipzig	0.5021	:
DEE0	Sachsen-Anhalt	0.4884	0.0546
DEF0	Schleswig-Holstein	0.4923	0.0584
DEG0	Thüringen	0.4657	0.0336
EE00	Eesti	0.4184	0.0322
IE04	Northern and Western	0.2772	:
IE05	Southern	0.3444	:
IE06	Eastern and Midland	0.3972	:
EL30	Attiki	0.4551	0.0448
EL41	Voreio Aigaio	0.4006	0.0196
EL42	Notio Aigaio	0.3999	0.0106
EL43	Kriti	0.4185	0.0367
EL51	Anatoliki Makedonia, Thraki	0.3952	0.0320
EL52	Kentriki Makedonia	0.4601	0.0354
EL53	Dytiki Makedonia	0.3760	-0.0109
EL54	Ipeiros	0.4095	0.0193
EL61	Thessalia	0.4475	0.0851
EL62	Ionia Nisia	0.4519	0.0629
EL63	Dytiki Elláda	0.4066	0.0455
EL64	Sterea Elláda	0.3788	0.0343
EL65	Peloponnisos	0.4412	0.0722
ES11	Galicia	0.4807	0.0441
ES12	Principado de Asturias	0.4872	0.0250
ES13	Cantabria	0.4896	0.0157
ES21	País Vasco	0.5020	0.0141
ES22	Comunidad Foral de Navarra	0.4762	-0.0011
ES23	La Rioja	0.5059	0.0538
ES24	Aragón	0.5663	0.1083
ES30	Comunidad de Madrid	0.5265	0.0430

ES41	Castilla y León	0.4741	0.0320
ES42	Castilla-La Mancha	0.4114	-0.0131
ES43	Extremadura	0.4448	0.0205
ES51	Cataluña	0.5921	0.1137
ES52	Comunitat Valenciana	0.4766	0.0429
ES53	Illes Balears	0.4476	-0.0071
ES61	Andalucía	0.4189	0.0128
ES62	Región de Murcia	0.5430	0.1165
ES63	Ciudad de Ceuta	0.4200	-0.0022
ES64	Ciudad de Melilla	0.4244	-0.0210
ES70	Canarias	0.4789	0.0296
FR10	Ile-de-France	0.5619	0.0975
FRB0	Centre — Val de Loire	0.2919	0.0827
FRC1	Bourgogne	0.2126	0.0192
FRC2	Franche-Comté	0.2682	0.0562
FRD1	Basse-Normandie	0.2260	0.0278
FRD2	Haute-Normandie	0.2343	0.0099
FRE1	Nord-Pas de Calais	0.4030	0.1998
FRE2	Picardie	0.2363	0.0724
FRF1	Alsace	0.3295	0.0741
FRF2	Champagne-Ardenne	0.2017	0.0268
FRF3	Lorraine	0.2857	0.0865
FRG0	Pays de la Loire	0.3465	0.1307
FRH0	Bretagne	0.2651	0.0205
FRI1	Aquitaine	0.2384	0.0115
FRI2	Limousin	0.2761	0.0494
FRI3	Poitou-Charentes	0.3516	0.1292
FRJ1	Languedoc-Roussillon	0.2119	-0.0074
FRJ2	Midi-Pyrénées	0.2477	-0.0032
FRK1	Auvergne	0.2309	0.0433
FRK2	Rhône-Alpes	0.3354	0.0661
FRL0	Provence-Alpes-Côte d’Azur	0.3049	0.0677
FRM0	Corse	0.2353	:
FRY1	Guadeloupe	0.1315	:
FRY2	Martinique	0.2635	:
FRY3	Guyane	0.1425	:
FRY4	La Réunion	0.2771	:
FRY5	Mayotte	:	:
HR02	Panonska Hrvatska	:	:
HR03	Jadranska Hrvatska	0.4574	0.0094
HR05	Grad Zagreb	:	:
HR06	Sjeverna Hrvatska	:	:
ITC1	Piemonte	0.4853	0.0291
ITC2	Valle d’Aosta/Vallée d’Aoste	0.5293	0.0326
ITC3	Liguria	0.5522	0.0674
ITC4	Lombardia	0.4638	0.0243
ITF1	Abruzzo	0.4876	0.0232
ITF2	Molise	0.4743	0.0308

ITF3	Campania	0.4888	0.0378
ITF4	Puglia	0.4670	0.0157
ITF5	Basilicata	0.5368	0.0830
ITF6	Calabria	0.4803	0.0380
ITG1	Sicilia	0.4279	-0.0198
ITG2	Sardegna	0.4953	0.0245
ITH1	Provincia Autonoma di Bolzano/Bozen	0.5263	0.0552
ITH2	Provincia Autonoma di Trento	0.5250	0.0347
ITH3	Veneto	0.5015	0.0502
ITH4	Friuli-Venezia Giulia	0.5140	0.0440
ITH5	Emilia-Romagna	0.5774	0.1168
ITI1	Toscana	0.5620	0.0969
ITI2	Umbria	0.5358	0.0725
ITI3	Marche	0.5330	0.0805
ITI4	Lazio	0.4619	-0.0142
CY00	Kýpros	0.5011	0.0762
LV00	Latvija	0.4321	0.0073
LT00	Lithuania	0.3806	-0.0461
LT01	Sostinės regionas	:	:
LT02	Vidurio ir vakarų Lietuvos regionas	:	:
LU00	Luxembourg	0.6140	0.1551
HU11	Budapest	0.4059	:
HU12	Pest	0.2296	:
HU21	Közép-Dunántúl	0.4163	0.0193
HU22	Nyugat-Dunántúl	0.4295	0.0276
HU23	Dél-Dunántúl	0.4199	0.0151
HU31	Észak-Magyarország	0.4048	0.0168
HU32	Észak-Alföld	0.3997	0.0073
HU33	Dél-Alföld	0.4147	0.0178
MT00	Malta	0.4285	-0.0055
NL11	Groningen	0.4664	-0.0106
NL12	Friesland (NL)	0.5217	0.0455
NL13	Drenthe	0.4983	0.0133
NL21	Overijssel	0.4667	-0.0128
NL22	Gelderland	0.5282	0.0393
NL23	Flevoland	0.4714	-0.0204
NL31	Utrecht	0.5276	0.0234
NL32	Noord-Holland	0.5662	0.0754
NL33	Zuid-Holland	0.4638	-0.0024
NL34	Zeeland	0.4877	0.0076
NL41	Noord-Brabant	0.5069	0.0282
NL42	Limburg (NL)	0.4809	-0.0028
AT11	Burgenland	0.4796	0.0170
AT12	Niederösterreich	0.4794	0.0208
AT13	Wien	0.5001	-0.0101
AT21	Kärnten	0.4834	-0.0006
AT22	Steiermark	0.4813	-0.0021
AT31	Oberösterreich	0.4731	0.0186

AT32	Salzburg	0.5253	0.0361
AT33	Tirol	0.5016	0.0539
AT34	Vorarlberg	0.5590	0.0840
PL21	Małopolskie	0.4647	0.0400
PL22	Śląskie	0.4710	0.0568
PL41	Wielkopolskie	0.4837	0.0618
PL42	Zachodniopomorskie	0.5127	0.0562
PL43	Lubuskie	0.5079	0.0787
PL51	Dolnośląskie	0.4509	0.0323
PL52	Opolskie	0.4885	0.0624
PL61	Kujawsko-pomorskie	0.4491	0.0124
PL62	Warmińsko-mazurskie	0.4643	0.0369
PL63	Pomorskie	0.4630	0.0187
PL71	Łódzkie	0.3056	:
PL72	Świętokrzyskie	0.2381	0.0918
PL81	Lubelskie	0.2573	0.0552
PL82	Podkarpackie	0.2276	0.0892
PL84	Podlaskie	0.2514	0.0973
PL91	Warszawski stołeczny	0.3598	:
PL92	Mazowiecki regionalny	0.2739	:
PT11	Norte	0.4791	0.1151
PT15	Algarve	0.3823	0.0021
PT16	Centro (PT)	0.4431	0.0624
PT17	Área Metropolitana de Lisboa	0.4834	0.0775
PT18	Alentejo	0.4153	0.0474
PT20	Região Autónoma dos Açores	0.3857	0.0064
PT30	Região Autónoma da Madeira	0.4157	0.0186
RO11	Nord-Vest	0.4375	0.0812
RO12	Centru	0.3973	0.0397
RO21	Nord-Est	0.5518	0.0398
RO22	Sud-Est	0.4148	0.0338
RO31	Sud-Muntenia	0.4215	0.0759
RO32	Bucureşti-Ilfov	0.4495	0.0088
RO41	Sud-Vest Oltenia	0.3868	0.1160
RO42	Vest	0.4061	0.0398
SI03	Vzhodna Slovenija	0.5261	0.1199
SI04	Zahodna Slovenija	0.4710	0.0225
SK01	Bratislavský kraj	0.4872	0.0117
SK02	Západné Slovensko	0.4706	0.0756
SK03	Stredné Slovensko	0.4071	0.0166
SK04	Východné Slovensko	0.4453	0.0542
FI19	Länsi-Suomi	0.5241	0.1246
FI1B	Helsinki-Uusimaa	0.5435	0.0818
FI1C	Etelä-Suomi	0.5858	0.1705
FI1D	Pohjois- ja Itä-Suomi	0.5499	0.1428
FI20	Åland	0.4232	-0.0060
SE11	Stockholm	0.4763	-0.0049
SE12	Östra Mellansverige	0.4882	0.0536

SE21	Småland med öarna	0.4676	0.0618
SE22	Sydsverige	0.5633	0.1047
SE23	Västsverige	0.4789	0.0556
SE31	Norra Mellansverige	0.4344	0.0322
SE32	Mellersta Norrland	0.4404	0.0149
SE33	Övre Norrland	0.5239	0.0932
UKC1	Tees Valley and Durham	0.4501	0.0598
UKC2	Northumberland and Tyne and Wear	0.4333	0.0441
UKD1	Cumbria	0.4514	0.0426
UKD3	Greater Manchester	0.4345	0.0445
UKD4	Lancashire	0.4374	0.0314
UKD6	Cheshire	0.5183	0.0019
UKD7	Merseyside	0.4507	0.0324
UKE1	East Yorkshire and Northern Lincolnshire	0.4240	0.0420
UKE2	North Yorkshire	0.4653	0.0325
UKE3	South Yorkshire	0.4482	0.0460
UKE4	West Yorkshire	0.4459	0.0589
UKF1	Derbyshire and Nottinghamshire	0.4363	0.0345
UKF2	Leicestershire, Rutland and Northamptonshire	0.5108	0.1049
UKF3	Lincolnshire	0.4455	0.0363
UKG1	Herefordshire, Worcestershire and Warwickshire	0.4744	0.0357
UKG2	Shropshire and Staffordshire	0.4667	0.0508
UKG3	West Midlands	0.4704	0.0738
UKH1	East Anglia	0.5330	0.0845
UKH2	Bedfordshire and Hertfordshire	0.4997	0.0606
UKH3	Essex	0.4575	0.0433
UKI3	Inner London — West	0.5731	-0.0016
UKI4	Inner London — East	0.5244	0.0024
UKI5	Outer London — East and North East	0.4945	0.0073
UKI6	Outer London — South	0.5117	-0.0076
UKI7	Outer London — West and North West	0.5226	0.0132
UKJ1	Berkshire, Buckinghamshire and Oxfordshire	0.5386	0.0746
UKJ2	Surrey, East and West Sussex	0.4612	0.0338
UKJ3	Hampshire and Isle of Wight	0.4837	0.0391
UKJ4	Kent	0.4355	0.0162
UKK1	Gloucestershire, Wiltshire and Bristol/Bath area	0.4728	0.0340
UKK2	Dorset and Somerset	0.4588	0.0357
UKK3	Cornwall and Isles of Scilly	0.4510	0.0222
UKK4	Devon	0.4616	0.0361
UKL1	West Wales and The Valleys	0.4426	0.0293
UKL2	East Wales	0.4718	0.0352
UKM5	North Eastern Scotland	0.5362	0.1033
UKM6	Highlands and Islands	0.4995	0.0887
UKM7	Eastern Scotland	0.3681	:
UKM8	West Central Scotland	0.4640	:
UKM9	Southern Scotland	0.3378	:
UKN0	Northern Ireland	0.5050	0.0805

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Chapter 5

What makes Regions go Green? Insights from a Spatial Model on European Patent Data

Authors: Mirko Kruse, Ivan Sergio, Jan Wedemeier

Abstract

There is an urgent imperative to address the challenges posed by climate change. Here, innovation is crucial, especially in Europe where it aligns with sustainability objectives. The article delves into the regional dynamics of innovation, focusing on the development of green patents and their role in advancing the green transition. The study applies different econometric spatial models to test the influence of various variables on green patents, green patent growth, and green specialisation. It is found that exposure to climate change and green attitude towards sustainability do not significantly influence a green transition while structural factors such as the age of the population, and an industrial economic structure appear to be highly relevant. This also has important implications for regional innovation policy to contribute to a green transition and should be recognised when updating instruments such as smart specialisation.

Keywords: regional innovation; green transition; RCA; smart specialisation; sustainability.

JEL Classification: O33; P48; Q55; R11.

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5.1 Introduction

In the face of mounting climate change challenges, the imperative for innovative solutions has become increasingly urgent, particularly in Europe, where sustainability objectives are paramount. Just after the Covid-19 crisis has been overcome and economic resilience has made its way to a top policy priority, the focus has again shifted to grand challenges such as climate change. In this regard, the battle against climate change and in favour of a green transition is closely tied to innovation and technological development. This shift reflects an evolving perspective on innovation, which now emphasises its direction towards addressing societal and environmental concerns (Freeman, 1996; Coenen et al., 2012; Markard et al., 2012; Mazzucato, 2018; Gianelle et al., 2020; Stern and Valero, 2021). Although it needs to be recognised that successful sustainability transitions must not exclusively depend on technological transitions, research and development remain crucial for moving towards an economy in line with planetary boundaries (Ménière et al., 2021).

Thereby, neither innovative activity in general nor green innovation are uniformly or randomly distributed geographically. Internal factors and dynamics within nations, regions, or cities play a crucial role for the emergence of economic specialisations. Consequently, the composition of concepts such as regional innovation systems (RIS) is increasingly moving to the centre of attention to determine how the green transition can be successfully implemented in practice. This shift marks a significant advancement in transition literature, which has historically overlooked the role of spatial factors (Yohe and Schlesinger, 2002; Coenen et al., 2012; Fagerberg et al., 2013; Isaksen et al., 2022; Eadson and van Veelen, 2023). In Europe, the practical challenge of combining economic recovery, interregional cohesion, innovativeness, and a green transition has been institutionalised in a European “Green Deal” which has already left its mark in European policies. For instance, the concept of smart specialisation, a key component of European innovation and cohesion policy, is being adapted to facilitate the green transition at regional level, with a focus on promoting sustainability as an integral dimension (Coenen and Truffer, 2012; Marsden and Farioli, 2015; European Commission, 2020; McCann and Soete, 2020; Barbieri et al., 2022; Kruse and Wedemeier, 2023). However, developing a green specialisation in regions presents a multifaceted challenge, as the emergence of new industries and the transformation of existing ones are deeply influenced by regional environments and interactions. The complexity of regional innovation rules out a “one-size-fits-all” solution and several research streams have devoted considerable effort to the identification of regional leverages to increase the environmental sustainability in regions (e.g., Shearmur et al., 2018; Cicerone et al., 2023).

This article aims to contribute to this research by analysing green specialisations in European regions and to provide implications for a green transition. To do so, section 2 presents an overview of the relevant concepts and research streams in regional innovation as well as open research questions in green innovation. To address these questions, a unique dataset and several spatial econometric models are utilised in section 3. The findings of the analysis are discussed in section 4, highlighting their implications for regional innovation policy and the green transition. Finally, section 5 summarises the key findings, and addresses potential limitations of the study, while also suggesting areas for future research.

5.2 Literature Review and Hypotheses

5.2.1 Regional Innovation and the Green Transition

Regions combine administrative competencies as well as a relevant size of agglomeration and economic diversity of different actors such as companies, research institutions, or administration and NGOs. While such networks require a certain size of similar but sufficiently different actors that allow the realisation of knowledge spillovers, the network must not become too large as trust as a foundation of cooperation correlates with a certain sense of personal acquaintance. Afterall, the sub-national and super-local level, namely regions, combine these advantages. This is why the concept of innovation systems is widely embraced at the regional level, taking the form of regional innovation systems (RIS). Here, a RIS is understood as the set of actors and networks which together define the innovation capacity in a region. What differentiates RIS from earlier innovation policy concepts is its recognition that context matters, and that each region needs to develop its own transformation path based on the regional environment (Tödtling and Trippl, 2005; Foray, 2018).

One of the major challenges of regional policy is to actively shape regional structural change to both avert unintentional developments, and to exploit the opportunities that come with the establishment of new industries. Methodologically, it needs to be distinguished between path renewal, meaning the advancement of existing industries into different but related ones, and path creation, referring to the emergence of new industries (Isaksen and Trippl, 2014). Existing economic structures and specialisations are under permanent pressure to adapt to changing environments so that the decline of old industries and the emergence of new specialisations is a regular occurrence. Successfully mediating this process is a key requirement for regional prosperity and the creation of competitive advantage represents a solid foundation for future developments. This pressure has been increasing recently because of economic crises, globalisation, and societal challenges. Here, the key instrument to sustain existing industries and develop new competitive advantages is innovation (Asheim et al., 2011; 2018; Tödtling and Trippl, 2018; Tödtling et al., 2021).

Particularly less favoured regions could benefit from innovative developments to renew their regional economic structure, while prospering regions are much better equipped to exploit these opportunities. This relationship is also upheld when it comes to climate change as economically weaker regions are relatively more vulnerable to both climate change and climate mitigation strategies due to their economic structure which is often dominated by “dirty” industries (Camagni and Capello, 2013; McCann and Soete, 2020; Rigby et al., 2022). In this regard, Rodríguez-Pose and Bartalucci (2023) investigate the regional impacts of a green transition. By assessing how different European regions are affected by the socio-economic changes associated with transitioning to a low-carbon economy they reveal significant regional disparities, with less developed regions in Southern and Eastern Europe being particularly vulnerable to the effects of a green transition. The authors also highlight the potential emergence of discontent, especially if the transition exacerbates existing disparities by further marginalising disadvantaged regions (Rodríguez-Pose and Bartalucci 2023). Regional innovation therefore is not only relevant for a green transition but also in terms of social balance.

In Europe, the primary policy instrument for regional innovation and cohesion bears the name “smart specialisation”. This concept draws on theoretical origins from regional innovation systems and was developed around 2008 with the primary main purpose to ensure a stronger focus of regional scarce resources towards strategic innovative sectors in order to achieve a larger impact of public spending (Barca, 2009; Rusu, 2013; Foray, 2013; Kruse, 2023a). Methodologically, smart specialisation rejects the idea of a “one-size-fits-all”-strategy in favour of region-specific approach tailored to regional characteristics. Through the identification and prioritisation of technological niches and development paths, the instrument promises to transform existing economic specialisations and ensure competitiveness in changing environments. After its conceptualisation, smart specialisation quickly became part of European policy and its rollout in European regions was significantly promoted when the development of a smart specialisation strategy (S3) was introduced as an ex-ante conditionality for regions to be eligible for European funding (Foray et al., 2011; Janik et al., 2020; Larosse et al., 2020). Currently, there is an ongoing discussion how to adapt the concept, which lessons to draw from experience gathered so far, and where to place the future emphasis. While cohesion dominated the first years as a motivation, it is now increasingly discussed to emphasise a green transition (Steen et al., 2018; Hassink and Gong, 2019; Foray, 2019; Landabaso, 2020; McCann and Soete, 2020; Esparza-Masana, 2021). Overall, the spatial dimension of sustainable development is increasingly addressed in regional innovation and economic geography literature as the consideration of space in transition research has long been neglected (Gibbs and O’Neill, 2017; Grillitsch and Hansen, 2019).

5.2.2 Green Innovation and Specialisation

Green economic specialisations in regions have been analysed from different angles, particularly focusing on the regional effects and the factors determining a green specialisation. Regarding the regional effects, a positive economic impact of green technologies can be assumed: Jovanović et al. (2022) found a positive relationship between green patents and national GDP, as well as Fernandes et al. (2021), and Hu et al. (2019). In addition, Horbach (2014) identified opportunities offered by green innovation particularly for less-developed regions. This question was also addressed by Liao and Li (2022), as well as by Tan et al. (2022) with similar results. At firm level, green patents apparently lead to an improved performance in firms (Zhang et al., 2019), and startups (Demirel et al., 2019). Regarding the relationship between green innovation and regional employment development, Kunapatarawong and Martínez-Ros (2016) found a positive correlation. On company level, Albitar et al. (2023) found indications that climate change commitment was positively correlated with green patents.

Apart from an economic focus, particularly environmental effects of green innovation have been studied. A positive relationship between green innovation and carbon dioxide emissions was found by Töbelmann and Wendler (2020), while also Ghisetti and Quatraro (2017), and Kirikkaleli et al. (2023) identified a correlation between the level of green technologies in a region and its environmental performance. However, Aydin et al. (2023) found indications of an environmental Kuznets curve pattern regarding green patents and the ecological footprint in EU countries. On resource level, certain green innovations can lead to a reduction on material consumption (Wendler, 2019). On company level, Carrión-Flores and Innes (2010) revealed a positive relationship between environmental innovation and the reduction of toxic air emissions.

Apart from the impacts of green innovation, particularly the question how green innovation can be effectively facilitated will need to be answered, particularly as the formulation of regional innovation strategies relies on insights how to successfully implement this transition (Van den Heiligenberg et al., 2017; Corradini, 2019; Coenen and Morgan, 2020). Although the innovativeness of regions has been extensively researched, research gaps remain regarding the desired green transition (Del Río et al., 2016; Krishnan et al., 2023). In this regard, possibly the largest research stream in analysing ecological sustainability and its driving factors in regions is connected to the concept of relatedness. This approach analyses the existing regional knowledge base to explain the evolutionary emergence of related industries. This correlation was analysed, among others, by Balland (2018) focusing on US regions, and Wang et al. (2021) focusing on Chinese prefecture level. Relatedness analyses with a specific focus on green innovation have, among others, been presented by Van den Berge and Weterings (2014), Perruchas et al. (2020), Barbieri et al. (2022), Morena and Ocampo-Corrales (2022), and Cicerone et al. (2023). Here, Tanner (2015a; 2015b) found that the technological relatedness of existing economic structures plays an important role for the structural diversification of regions. Montresor and Quatraro (2019), Santoalha and Boschma (2020), and Ocampo-Corrales et al. (2021) indicate that a pre-existing specialisation in dirty industries might hamper the development of green specialisations while existing green specialisations does not make the occurrence of new green specialisations more likely. On the other hand, Van den Berge et al. (2020) found no indication that a previous specialisation in dirty technologies might compromise the transition towards cleantech.

Apart from cooperation and relatedness analyses, patent data have been prominently applied as dependent variables. Regarding the generation of green innovation, regional features such as regulation, the economic structure, networks, and others come into play as explanatory variables (Wagner, 2007; Constantini et al., 2013; Albitar et al., 2023). Here, Fabrizi et al. (2018) found a positive impact of research network policies on environmental innovation. The positive influence of cooperation between companies for the generation of environmental innovation was confirmed by Cainelli et al. (2012), and Ocampo-Corrales et al. (2021). In addition, Olivier and Del Lo (2022) underlined the role played by proximity and spatial spillovers between regions for the emergence of renewable energy deployment, while Quatraro and Scandura (2019) confirm the role of local spillovers and academic inventors for the creation of green patents. The general interaction between environmental innovation and environmental regulation was, among others, analysed by Ghisetti and Pontoni (2015), Tamayo-Orbegozo et al. (2017), Constantiti et al. 2017), and Langinier and Ray Chaudhuri (2019), as well as by Cainelli et al. (2020), Tchorzewska et al. (2022), and Mealy and Teytelboym (2022). While all these papers found that environmental regulation can positively influence the emergence of environmental patents, Zhai et al. (2022) concluded additionally that environmental regulation might facilitate inter-regional convergence in terms of green productivity. Cicerone et al. (2023) provided a new perspective by indicating a positive relationship between artificial intelligence and regional specialisation in green technologies, while also Santoalha et al. (2021) confirm the productive role of digital applications for green specialisations.

Generally, it has been confirmed empirically that regional preconditions play a crucial role for the development of green industries. It follows from this assumption that adjusted regional policies are required to incorporate different types of regions with individual conditions (Grillitsch and Hansen, 2019). However, the analyses often resemble each other, particularly when it comes to regional factors explaining green specialisations. Therefore, the article at hand strives to complement existing research by adding new indicators and research questions. On this basis, we articulate our research agenda into three main hypotheses:

> *H1: Structural factors such as an industrial basis or a young population facilitate the emergence of green innovation.*

H2: Regional exposure to climate change impacts leads to a stronger involvement in green innovation.

H3: Green public attitude (proxied by green party votes) can facilitate green innovation.

5.3 Data and Methods

5.3.1 Data

Most papers applying patent analyses for green innovation use databases such as REGPAT or PATSTAT. Generally, patent documents contain a lot of information about new inventions and therefore allow for a variety of analyses, for instance regarding technological trends, specialisations, or cooperation networks (see 2.2). Patent statistics have advantages such as a high data quality due to considerable resources required by inventors for an application, comparability due to a standardised collection scheme, long time periods of available data, and a possibility of quantitative analysis. However, patent data also come with certain downsides: not all inventions are patented or even patentable resulting in a bias towards technological inventions. Moreover, patents do not provide an indication about the impact of an invention (e.g., Archibugi and Pianta, 1996; Grilliches, 1998; Acs et al., 2001; Arundel and Kemp, 2009; Neuhäusler and Frietsch, 2013). Nevertheless, patents have become standard for empirical analyses as their benefits prevail (e.g., Haščič and Migotto, 2015; Fabrizi et al., 2018; Natalicchio et al., 2022).

The following analysis will focus on green innovation, as measured by patent applications. For this purpose, a dataset was constructed from the PATSTAT database (autumn 2022 edition). To ensure a geographical focus on Europe, only patents filed to the European Patent Office (EPO) were included. We defined green innovation as the aggregate of technologies contributing to an environmental benefit and applied the OECD ENV-TECH search strategy which provides an overview of patent classes associated to green sectors such as renewable energy or climate change mitigation (OECD, 2016; Ghisetti and Quatraro, 2017; Montresor and Quatraro, 2019; Favot et al., 2023). However, an adaptation was introduced regarding the patent classification by choosing the Cooperative Patent Classification (CPC) instead of the International Patent Classification (IPC) due to a better coverage of new technological developments (Haščič and Migotto, 2015; EPO, 2022). Patent classifications were obtained at 5-digit-level for the period 1991-2021, covering the EU27 plus UK and the states of the European Free Trade Association (EFTA). Due to the regional focus of this paper and a good data coverage compared to lower-ranking levels, we focused on the administrative level of NUTS 2 and accordingly transformed the PATSTAT data. Thereby, also the NUTS classification is not without criticism (e.g., Shearmur et al., 2018) but without alternative when it comes to regional analyses in Europe. To quantify the respective relevance of green patents in individual regions, a Revealed Comparative Advantage (RCA) was calculated as the main dependent variable, expressing the relative specialisation of green patents in a region compared to those in the respective country (Balassa, 1965). The geographical coverage of RCA among European regions is presented in Figure 1.

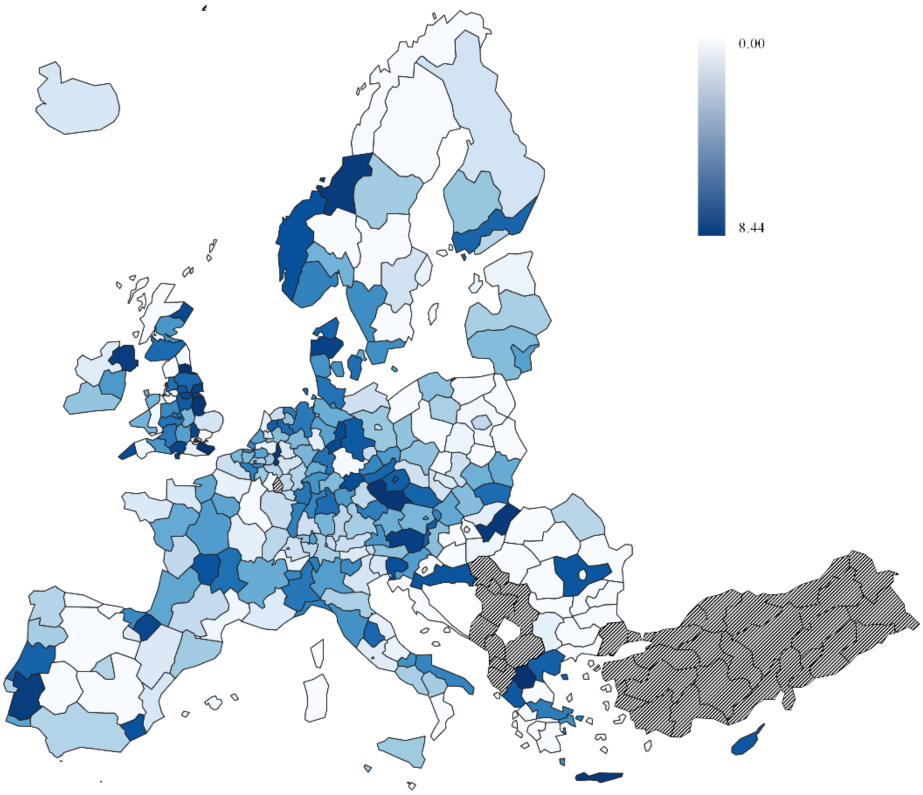

Figure 1: RCA in green innovation in European NUTS 2 regions, 2020
Data source: own depiction, based on PATSTAT data.

The central structural variables for our research are employment in industry (except construction) as a proxy for the economic structure of a region (Eurostat, 2023b), as well as the share of elderly population calculated as the share of people aged 60-79 (Eurostat, 2023c). Regarding control variables, we included GDP per capita to control for the level of economic development of regions (Eurostat, 2023d), population density to control for agglomeration effects (Eurostat, 2023e), and higher education calculated as the share of population with tertiary education (levels 5-8) (Eurostat, 2023f). These variables will be applied to test Hypothesis 1, namely that certain structural factors facilitate the emergence of green innovation.

To test Hypothesis 2, namely that regional exposure to climate change increases green innovation, we included the cooling degree days quantifying the cooling requirements of buildings, derived from meteorological observations of air temperature (Eurostat, 2023a). This variable provides a generalised information how regions are affected by climate-related heat events. Moreover, the public attitude towards green topics (as theorised in Hypothesis 3) was included by applying election results of green parties at national elections as a proxy variable. While cooling degree days have not been analysed so far, political preferences as a proxy were, among others, also applied by Horbach (2014), Grant and Tilley (2019), Santoalha and Boschma (2020), Hoffmann et al. (2022), Oliver and Del Lo (2022), and Papp (2022). In our case, election results were obtained from a European election database (Schraff et al., 2022). Thereby, green parties were identified by their membership at the European Greens and via an additional selection of environmentally oriented parties. The second step became necessary because the group is very heterogenous and memberships in the European umbrella party have been changing over time (Riveiro and Riera, 2008; Grant and Tilley, 2019; Mádr, 2021; European Greens, 2022). The list of green parties is provided in Annex 1. The full list of variables is presented in Table 1, while the descriptive statistics are depicted in Table 2.

Table 1: Descriptive variables

Variable	Description	Source	Dimension
Tot Pat	Total number of patent applications	PATSTAT	Absolute
Green Pat	Green patent applications	PATSTAT	Absolute
RCA	Revealed Technological Advantages in green technologies	Own elaboration	%
Extensive Margin	Green specialisation	Own elaboration	Binary
Intensive Margin	Growth rate of green patents	Own elaboration	%
GDP Cap	GDP per capita	Eurostat	Absolute
GDP Cap gr	Growth rate of GDP per capita	Own elaboration	%
GERD	Gross expenditure for research & development	Eurostat	Absolute
Pop Dens	Population density	Eurostat	Absolute
High edu	Share of population with higher education	Eurostat	%
Emp Ind	Share of employment in Industry	Eurostat	%
Eld Pop	Share of population between 60 and 79 years	Eurostat	%
Cool	Cooling degree days	Eurostat	Absolute
Votes Nat2	Percentage of voters who supported green parties in national elections	Election database	%
d green	Green preference > 5%	Own elaboration	Binary
d green2	Green preference > 10%	Own elaboration	Binary

Table 2: Descriptive statistics

Variable	Obs.	Mean	Std. Dev.	Min	Max
Tot Pat	1034	2800.55	4126.66	2	26618
Green Pat	1034	340.11	573.8	0	5043
RCA	1034	1.04	.75	0	8.93
Extensive Margin	1034	.41	.49	0	1
Intensive Margin	990	.07	.71	-3.34	3.04
GDP Cap	1034	32052.75	13202.46	19.8	100400
GDP Cap gr	1034	.02	.04	-.19	.16
GERD	1034	701.12	671.88	34.7	3971.9
Pop Dens	1034	458.57	1006.01	3.3	7526.7
High edu	1034	.86	.07	.37	1
Emp Ind	1024	1.11	10.85	.04	162.35
Eld Pop	1032	19.38	2.45	12.9	26.2
Cool	1021	110	155.55	0	812.18
Votes Nat2	610	7.77	4.11	.14	21.57
d green	610	.69	.46	0	1
d green2	610	.3	.46	0	1

5.3.2 Model Development

The aim of this article is to understand how green patent growth and specialisation are stimulated in European regions. To do so, our estimation strategy is based on some complementary steps that we describe in this section. Starting from the equation below, we measure the green innovation performance by using three different dependent variables: in our baseline model, we apply the measure of green agglomeration (RCA) as a dependent variable. Afterwards, calculating the growth rate of green patents over time, we develop a measure of an intensive margin. Next, by employing a dummy variable derived from *RCA* – a variable that equals 1 if region *i* has an *RCA* > 1 in *t-1* and 0 otherwise –, we derive our measure of green specialisation at the regional level (extensive margin). Hence, we employ tree different dependent variables in our model. The starting equation is the following:

$$Y_{i,t} = b_1(X_{i,t-1}) + b_2(Emp\_Ind_{i,t-1}) + b_3(Eld\_Pop_{i,t-1}) + b_4(GHG_{i,t-1}) + b_5(Cool_{i,t-1}) + b_5(d\_green_{i,t-1})\,\chi_i + \phi_t + \varepsilon \quad (1)$$

Where $Y_{i,t}$ can alternatively represent the measure of green specialisation ($RCA_{i,t}$), as well as the measure of intensive ($CAGR_{i,t}$), and the extensive ($d\_RCA_{i,t}$) margin of green innovation. To test our Hypothesis 1, the variables of main interest are represented by the share of industrial ($Emp\_Ind_{i,t-1}$) and the share of population between 60 and 79 years ($Eld\_Pop_{i,t-1}$). Then, to check Hypothesis 2, we use the measure of cooling degree days ($Cool_{i,t}$), to check climate-related impacts. Finally, we test whether the influence of green parties ($d\_green^{5\%}_{i,t-1}$ & $d\_green^{10\%}_{i,t-1}$) has a positive effect on green patenting preferences across our regions can positively influence our dependent variables. Furthermore, based on previous research, $X_{i,t-1}$ is a vector of regional controls including: $GDP\_PC_{i,t-1}$, the GDP per capita for region *i*, at time *t-1*, to control for the level of economic development of regions that could influence their innovation performance; $Pop\_Dens_{i,t-1}$, the population density variable, to control for agglomeration effects; $GERD_{i,t-1}$, the R&D investment, to control for the relevance of that investment; $High\_edu_{i,t-1}$ share of population with higher education, to control for the level of human capital of the regions. We include both region (χ_i) and year (ϕ_t) fixed effects to control for unobserved characteristics and time trends that could influence the innovation performance.

To test the hypotheses, we apply different methodologies: first, a baseline fixed effect model analysis is conducted before we adopt a GMM system as an endogeneity check for all the variables of our model. The GMM model is also useful to evaluate the persistence results ($Y_{i,t-1}$). Finally, we construct a spatial model (Dynamic Spatial Durbin Model) to test for the existence of a spatial innovation propagation phenomenon. This model should be able to appreciate both the effects of the dependent variable with spatial lag and time-spatial lag.

5.4 Results

The results of the different models are provided below. It was found that the industrial structure of a region has a significant and positive effects on the measure of green technological agglomeration ($RCA_{i,t}$) and on the intensive margin. However, the effects on the extensive margin are negative (see Table 5). Moreover, the age structure of the population seems to have a negative effect on both technological agglomerations and specialisations. No significant results emerge for $Eld\_Pop_{i,t-1}$ on our intensive margin variable. Our variable $Cool_{i,t-1}$ does not play a significant role.

Regarding the control variables, in Table 3, we find that $High\_edu_{i,t-1}$ stimulates green technological agglomerations, while R&D is weakly significant and positive on the intensive margin (see Table 4). Also, the growth rate of $GDP\_Cap_{i,t-1}$ seems to play an important role both in the emergence of green technological specialisations and in their agglomerations. However, there are no specific findings regarding the preference for green parties in national elections (see Annex 2). We conducted this analysis of green votes considering two thresholds: 5% and 10% of preferences in national elections. Additionally, we linearly imputed missing values where possible between one election and another.

Table 3: Baseline model

Variables	(1) RCA	(2) RCA	(3) RCA	(4) RCA
$GDP\_Cap_{i,t-1}$	-0.165	-0.139	-0.159	-0.105
	(0.150)	(0.147)	(0.132)	(0.122)
$GDP\_Cap\_gr_{i,t-1}$	2.809**	3.022***	3.223***	3.320***
	(1.104)	(1.120)	(1.134)	(1.194)
$GERD_{i,t-1}$	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
$Pop\_dens_{i,t-1}$	0.000	0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)
$High\_edu_{i,t-1}$	0.793**	0.745**	0.786**	0.710*
	(0.349)	(0.352)	(0.354)	(0.379)
$Emp\_ind_{i,t-1}$		0.003*	0.003**	0.003**
		(0.001)	(0.001)	(0.001)
$Eld\_Pop_{i,t-1}$			-0.128**	-0.133**
			(0.061)	(0.058)
$Cool_{i,t-1}$				0.000
				(0.001)
Constant	0.575	0.539	3.233**	3.227**
	(0.453)	(0.454)	(1.360)	(1.263)
Observations	1,034	1,024	1,024	1,013
R-squared	0.344	0.344	0.349	0.348
Country FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES

*Notes: Clustered standard errors at the regional level in parentheses. ***, **, and * indicate significance at the 1, 5, and 10 percent levels, respectively.*

Table 4: Intensive margin

Variables	(1) Intensive margin	(2) Intensive margin	(3) Intensive margin	(4) Intensive margin
$GDP\_Cap_{i,t-1}$	0.049	0.086	0.089	0.150*
	(0.094)	(0.084)	(0.085)	(0.082)
$GDP\_Cap\_gr_{i,t-1}$	0.623	1.141	1.109	1.051
	(1.046)	(0.971)	(0.969)	(1.062)
$GERD_{i,t-1}$	0.000*	0.000*	0.000*	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
$Pop\_dens_{i,t-1}$	-0.000	-0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)
$High\_edu_{i,t-1}$	0.774*	0.673	0.670	0.583
	(0.444)	(0.438)	(0.437)	(0.452)
$Emp\_ind_{i,t-1}$		0.016***	0.016***	0.016***
		(0.002)	(0.002)	(0.002)
$Eld\_Pop_{i,t-1}$			0.021	0.025
			(0.029)	(0.030)
$Cool_{i,t-1}$				0.001
				(0.001)
Constant	-0.916**	-0.959**	-1.405*	-1.713**
	(0.392)	(0.382)	(0.772)	(0.842)
Observations	986	976	976	965
R-squared	0.196	0.205	0.205	0.210
Country FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES

*Notes: Clustered standard errors at the regional level in parentheses. ***, **, and * indicate significance at the 1, 5, and 10 percent levels, respectively.*

Table 5: Extensive margin

Variables	(1) Extensive margin	(2) Extensive margin	(3) Extensive margin	(4) Extensive margin
$GDP\_Cap_{i,t-1}$	-0.070	-0.062	-0.071	-0.060
	(0.081)	(0.083)	(0.083)	(0.087)
$GDP\_Cap\_gr_{i,t-1}$	1.150*	1.322**	1.421**	1.531**
	(0.624)	(0.623)	(0.612)	(0.652)
$GERD_{i,t-1}$	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
$Pop\_dens_{i,t-1}$	-0.000	-0.000*	-0.000***	-0.000***
	(0.000)	(0.000)	(0.000)	(0.000)
$High\_edu_{i,t-1}$	0.296	0.292	0.312	0.298
	(0.201)	(0.203)	(0.201)	(0.204)
$Emp\_ind_{i,t-1}$		-0.004***	-0.004***	-0.004***
		(0.001)	(0.001)	(0.001)
$Eld\_Pop_{i,t-1}$			-0.063**	-0.066**
			(0.026)	(0.026)
$Cool_{i,t-1}$				0.000
				(0.000)
Constant	0.412	0.398	1.725***	1.752***
	(0.311)	(0.317)	(0.593)	(0.597)
Observations	1,034	1,024	1,024	1,013
R-squared	0.416	0.419	0.422	0.421
Country FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES

*Notes: Clustered standard errors at the regional level in parentheses. ***, **, and * indicate significance at the 1, 5, and 10 percent levels, respectively.*

We have focused on our FE models, which, by construction, typically do not include regressions with the lagged dependent variable. However, we believe that incorporating this type of dynamic will enhance and complement our estimations. Specifically, we can also assess the persistence of our results. Therefore, we employed a GMM (Generalised Method of Moments) model and its capability to minimise possible bias in the estimates. The GMM approach is relevant because it addresses potential endogeneity that may appear due to omitted variables or reverse causality. Specifically, the GMM estimator we implemented relies on the methodology initially proposed by Arellano and Bond (1991), renowned for its efficacy in handling arbitrary heteroscedasticity and its capacity to accommodate residual structure for generating consistent estimates. To enhance the efficiency of our estimations, we adopted the GMM System (GMM-SYS) estimator, as advocated by Arellano and Bover (1995), and Blundell and Bond (1998). This approach instruments time-varying variables with lagged first-differenced terms, resulting in superior performance compared to the conventional first difference GMM estimator.

Crucially, we treat time-varying variables as potentially endogenous and generate GMM-like instruments for them using available lags. We adhere to the heuristic proposed by Roodman (2009a; 2009b), suggesting that the number of instruments should exceed the number of endogenous variables but not surpass the number of units utilised in the analysis (Arellano and Bover, 1995; Blundell and Bond, 1998). To ensure the credibility of our findings, we conducted specification tests to examine the presence of second-order serial correlation. The outcomes indicate the absence of second-order serial correlation in our models, thereby strengthening the validity of our estimates. Furthermore, both the Hansen and Sargan tests affirm that the instruments employed are not over-identified. Our model includes the dummy year to improve stability (Roodman, 2003).

Overall, the outcomes of the GMM estimates (presented in Table 6) correspond with earlier findings, strengthening the solidity of our analysis. However, in this instance, $Cool_{i,t-1}$ also emerges as significant for the intensive margin. Additionally, we incorporate results in terms of persistence. In general, both green agglomeration and specialisation exhibit persistence in their relationship with lagged Y. The interpretation of the lagged intensive margin is more complex, as it appears significant and negative. The growth is likely not constant but rather characterised by some peaks. We re-estimated with a three-year average of the intensive margin, in which case the lagged dependent variable is positive and not significant.

Table 6: GMM-SYM system estimator

Variables	**(1)** **RCA**	**(2)** **Intensive margin**	**(3)** **Extensive margin**
$Y_{i,t-1}$	0.257***	-0.415***	0.441***
	(0.009)	(0.009)	(0.025)
$GDP\_Cap_{i,t-1}$	-0.071***	-0.028***	0.010
	(0.010)	(0.008)	(0.010)
$GDP\_Cap\_gr_{i,t-1}$	0.185	2.944***	1.152***
	(0.139)	(0.201)	(0.336)
$GERD_{i,t-1}$	0.000***	0.000***	0.000***
	(0.000)	(0.000)	(0.000)
$Pop\_dens_{i,t-1}$	0.000	-0.000***	0.000
	(0.000)	(0.000)	(0.000)
$High\_edu_{i,t-1}$	2.393***	1.519***	1.101***
	(0.156)	(0.148)	(0.166)
$Emp\_ind_{i,t-1}$	0.000	0.001***	-0.001***
	(0.000)	(0.000)	(0.000)
$Eld\_Pop_{i,t-1}$	-0.032***	-0.012***	0.003
	(0.004)	(0.003)	(0.006)
$Cool_{i,t-1}$	0.000	0.001***	-0.000
	(0.000)	(0.000)	(0.000)
Constant	-0.621***	-1.097***	-0.933***
	(0.153)	(0.125)	(0.161)
Observations	1,038	978	1,038
Number of id	154	148	154
Year FE	YES	YES	YES
j	118	118	118
ar1p	0.005	0.000	0.000
ar2p	0.112	0.202	0.063
sarganp	0.288	0.941	0.757
hansenp	0.405	0.367	0.282

*Notes: Standard errors in parentheses. ***, **, and * indicate significance at the 1, 5, and 10 percent levels, respectively.*

Moreover, we conducted a Global Moran's I analysis for our three dependent variables: $RCA_{i,t}$, $Intensive\ Margin_{i,t}$, and $Extensive\ Margin_{i,t}$ for the years 2002 to 2020. The results suggest a weak spatial relationship among the regions in our sample (see Annex 3). This finding is further confirmed by the Spatial Durbin Model (SDM), the results of which are weak and statistically insignificant (see Annex 4).

5.5 Discussion

Arguably, structural variables influence the emergence of a green specialisation (Hypothesis 1). In our results we found indications that structural factors indeed play a role for green innovation. For instance, a significant and positive influence of an industrial economic structure ($Emp\_ind_{i,t-1}$) on both green technological agglomeration (baseline model), and the growth rate of green parents (intensive margin) can be observed. Generally, an industrially structured economy appears to be a supporting factor for green innovation. Still, it needs to be remarked that industry covers a variety of sectors which are, by nature, different in terms of innovativeness so that differences among regions cannot be fully ruled out. The findings, however, are valuable for regional development in regions that have not yet completed the structural change towards a service-oriented knowledge economy. Interestingly, our results show that the effects on the existence of a green specialisation (extensive margin) are negative. This might hint towards the existence of different regional groups. The baseline model has shown that green innovation and an industrial structure can complement and mutually reinforce each other if a certain level of fit between both areas is in place. Then again, having an industrial focus might be an obstacle for regions which are just on the margin of developing a weak green specialisation. A certain level of specialisation might be required to influence the industrial sector in a way that it incorporates green ideas and moves to a green specialisation itself. These findings are particularly interesting since Ocampo-Corrales et al. (2021) found hints that an industrial structure might hamper the emergence of green technologies.

Regarding the age structure of a region, an older population ($Eld\_Pop_{i,t-1}$) seems to have a negative effect on both technological agglomeration and green specialisations. Regarding the growth rate of green patents, the existence of a predominantly older population does not yield significant results. Accordingly, an older population appears to be an obstacle for green innovation, potentially both because of a lower share of young and innovative people and a lower time preference for environmental issues. These findings resemble those by Santoalha and Boschma (2021). Apart from that, a larger share of population with higher education ($High\_edu_{i,t-1}$) appears to stimulate green technological agglomeration, while spending on R&D is weakly significant and positive regarding the growth of green patents (intensive margin). Also, the growth rate of $GDP\_Cap_{i,t-1}$ seems to play an important role both in the emergence of green technological specialisations and in their agglomerations. These findings are intuitive as the relation between innovation and patents is consequential. Generally, our findings support Hypothesis 1.

Cooling degree days (*$Cool_{i,t-1}$*), as a proxy for regional exposure to climate change are almost irrelevant for the development of a green specialisation. This result might be due to limitations in the variable due to different relevance among climate zones. On the other hand, climate change consequences such as heat events are still a relatively new occurrence in the evaluation period 1991-2021 while the emergence of a green regional specialisation takes time. Therefore, the influence of the variable might therefore consolidate in the years to come but the link between perception of climate change and green innovation appears inconclusive until now. Using the same indicator, also Kruse (2023b) did not manage to find a correlation to climate change exposure and the involvement in environmental research projects. Hypothesis 2 is rejected. Regarding the preference for green parties in national elections, our models do not reveal specific findings. The missing link between green votes and green innovation might indicate that economic transition does not so much depend on public preferences for the environment as on structural variables. Moreover, electoral decisions depend on several factors so that the indicator is not a perfect proxy for green attitudes among regional populations. However, the results are in line with Olivier and Del Lo (2022) who also received no clear-cut findings when analysing the influence of political votes on renewable energy deployment in French regions. Also, Santoalha and Boschma (2020) found little evidence of green votes influencing the development of new green specialisations. The suggestion that voting and populism is linked to industrial decline is made by Dijkstra (2020); however, there is no indication of its impact on climate in his findings. Hypothesis 3 is rejected.

Although two of three hypotheses were rejected, the findings are encouraging for regional innovation policy. In the future, green economic specialisation could play a crucial role in achieving the emission targets of the EU. This requires enhanced EU policies within the context of smart specialisation and the European Green Deal. Economically disadvantaged regions face a risk of marginalisation due to climate change impacts and mitigation efforts. Regions heavily reliant on carbon-intensive sectors are particularly vulnerable to the green transition. Additionally, vulnerability to green transition externalities is linked to GDP levels, exacerbating regional polarisation in Europe, especially for lagging-behind regions. Local consultation and negotiation are consequently considered essential for addressing these challenges effectively (Rodríguez-Pose and Bartalucci, 2023). However, the rejected hypotheses referred to variables which can hardly be influenced by policymakers. On the other hand, structural factors appear to be crucial for the emergence of green innovation and several of these indicators (education of the population, expenditure on R&D, industrial structure) can be shaped by regional policy. This key role of regional innovation also strengthens the relevance of instruments such as smart specialisation which can become important mechanisms to facilitate green regional transition in Europe.

5.6 Conclusion

The uneven distribution of green innovation across Europe poses a challenge for regional policy, considering the crucial role of innovativeness in economic renewal and future prosperity. Therefore, the innovation paradox, path dependency, and relatedness research indicate obstacles as regions which are not specialised in green innovation will have difficulties to get involved. In this context, the question becomes important which levers regions possess to develop a green specialisation. By analysing structural variables as well as a climate-related indicator and votes for green parties as a proxy for public sensitivity towards the environment, it becomes clear that certain structural conditions make the emergence of green specialisations more likely but are not necessarily required. For instance, a strong industrial basis can not only be ruled out as a barrier to green transition but can become a lever for such transition, as indicated by our study findings. Additionally, R&D efforts and a younger population make the emergence of green specialisations more likely. Climate change impact or public attitudes towards environmental topics seem to play no significant role for a green transition.

However, it is essential not to overestimate these results, as they rely on specific indicators with limitations. For instance, heat events are only one form of climate change consequences and have been a relatively new occurrence. Possibly, the indicator will increase in relevance in the years to come. Also, other climate change related indicators might reveal significant results. As Europe's exposure to climate change has remained relatively limited until now, analysing other geographical areas could lead to another interpretation of how climate change exposure influences green innovation. Limitations are also observed regarding green votes as a proxy for a green public attitude. Voting for a green party might indicate a green attitude but is no clear-cut indicator. Moreover, political decisions are influenced by a variety of local factors such as bureaucratic efficiency or singular decision-making processes. These factors are not controlled in our model. However, also other articles have struggled to find a relevant influence of green votes on green development so that the indicator either is not relevant, or another proxy variable is required. Finally, patent data also come with limitations as not all inventions are patented, and they only tell part of the story. Moreover, patents serve as an input for the innovation system, while the economic implementation of it remains unclear. These limitations also provide opportunities for further research, especially in the context of regional transitions.

Nevertheless, the econometric model revealed robust results that can be applied for regional policy. Assuming that regions will be a key area for a successfully implementing the green transition, policymakers now need to set the course for the years ahead. Focusing on the right structural environment for green innovation to flourish will not only help structural renewal but also achieving the emission reduction goals by striving towards a low-carbon economy. This focus should also be recognised when updating European instruments to address grand challenges, particularly in the context of smart specialisation.

Annex

Annex 1: Green parties in European countries

Country	Abbreviation	Full Name (English)
Austria	Grune	The Greens - The Green Alternative
Belgium	Ecolo	Confederated Ecologists for the Organisation of Original Struggles
	Groen!	Agalev - Green
Bulgaria	/	The Greens
Croatia	Zeleni Zajedno	Greens Together
Cyprus	KOP	Ecological and Environmental Movement
Czech Republic	Strana Zelenych	Green Party
Denmark	SF	Socialist People's Party
Estonia	ROH	Estonian Greens
Finland	VIHR	Green League
France	Europe Ecologie	Europe Ecology - The Greens
	Alliance Ecologiste Independante	Other Greens
Germany	Grüne	Alliance 90 / Greens
Greece	OIK.PRAS	Ecologist Greens
Hungary	LMP	Politics can be Different
Ireland	GP	Green Party
Italy	Verdi Arcobaleno	Rainbow Greens
	FED.Liste Verdi	Federation of the Greens
	FED.DEI Verdi	Federation of the Greens
	Europa Verde	/
	Sinistra e Liberta'	Left Ecology Freedom
	Verdi Europei - Green Italia	/
Latvia	ZZS	Green and Farmers' Union
Lithuania	LZP	Lithuanian Green Party
Luxembourg	GRENG	The Greens
Malta	AD	Democratic Alternative
Netherlands	GL	Greenleft
	Groen	The Greens
Poland	/	Partia Zieloni
Portugal	CDU	Unitary Democratic Coalition
Romania	PER	Ecologist Party of Romania
Slovakia	SZ	Green Party (1992)
Slovenia	Zeleni	Greens of Slovenia
Spain	Verdes	Europe of the People - The Greens
	EDP	Europe of the People - The Greens
	EDP-V	Europe of the People - The Greens
	LV-GVE	The Greens
Sweden	MP	Greens
United Kingdom	Green	Green Party of England and Wales

Annex 2: Results for green preferences in national elections

Variables	(1) $d\_green^{5\%}$	(2) $d\_green^{10\%}$	(3) $d\_green^{5\%}$	(4) $d\_green^{10\%}$	(5) $d\_green^{5\%}$	(6) $d\_green^{10\%}$
$GDP\_Cap_{i,t-1}$	-0.003	-0.007	-0.125	-0.116	-0.006	-0.009
	(0.205)	(0.200)	(0.098)	(0.096)	(0.142)	(0.138)
$GDP\_Cap\_gr_{i,t-1}$	2.769**	2.820**	0.506	0.488	1.305	1.321
	(1.112)	(1.171)	(0.993)	(1.003)	(0.905)	(0.891)
$GERD_{i,t-1}$	0.000	0.000	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$Pop\_dens_{i,t-1}$	-0.000	-0.000	-0.000**	-0.000**	-0.000**	-0.000**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$High\_edu_{i,t-1}$	0.241	0.252	0.323	0.346	0.338	0.335
	(0.340)	(0.332)	(0.516)	(0.513)	(0.321)	(0.316)
$Emp\_ind_{i,t-1}$	0.004	0.004	0.014***	0.013***	-0.003*	-0.003
	(0.003)	(0.003)	(0.003)	(0.003)	(0.002)	(0.003)
$Eld\_Pop_{i,t-1}$	-0.196**	-0.202**	-0.017	-0.014	-0.072	-0.075
	(0.092)	(0.096)	(0.069)	(0.069)	(0.055)	(0.054)
$Cool_{i,t-1}$	0.001	0.001	0.001	0.001	0.000	0.000
	(0.002)	(0.002)	(0.002)	(0.002)	(0.001)	(0.001)
$d\_green_{i,t-1}$	0.078	-0.044	0.058	0.086	0.004	-0.031
	(0.169)	(0.095)	(0.085)	(0.068)	(0.093)	(0.112)
Constant	4.463**	4.665**	0.641	0.541	1.743	1.815
	(1.922)	(2.065)	(1.638)	(1.661)	(1.237)	(1.215)
Observations	590	590	576	576	590	590
R-squared	0.541	0.540	0.287	0.287	0.494	0.495
Country FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
depvar	RCA	RCA	Intensive Margin	Intensive Margin	Extensive Margin	Extensive Margin

*Notes: Clustered standard errors at the regional level in parentheses. ***, **, and * indicate significance at the 1, 5, and 10 percent levels, respectively.*

Annex 3: Robustness check - Moran I

YEAR	RCA		INTENSIVE MARGIN		EXTENSIVE MARGIN	
	Moran's I	p-value	Moran's I	p-value	Moran's I	p-value
2002	-0.008	0.493	-0.009	0.47	-0.019	0.203
2003	0.004	0.197	-0.032	0.034**	-0.023	0.13
2004	-0.012	0.378	0.015	0.046**	0.007	0.147
2005	-0.013	0.33	0.031	0.003***	0.003	0.234
2006	0.002	0.243	0.008	0.126	0.007	0.156
2007	0.026	0.005**	0.027	0.006**	0.004	0.21
2008	0.01	0.085*	0.013	0.067*	0.002	0.238
2009	-0.001	0.305	-0.016	0.265	-0.014	0.317
2010	0.003	0.226	0.004	0.205	0.005	0.19
2011	0.01	0.105	0.013	0.062**	0.018	0.032**
2012	0.004	0.191	-0.006	0.467	-0.023	0.133
2013	0.01	0.105	0.013	0.062**	0.018	0.032**
2014	-0.013	0.332	-0.009	0.452	-0.007	0.278
2015	0.002	0.237	0.007	0.205	0.008	0.156
2016	0.004	0.201	0.011	0.126	0.017	0.04**
2017	0.003	0.001**	0.027	0.006**	0.014	0.062*
2018	-0.005	0.42	0.006	0.163	0.006	0.172
2019	-0.0001	0.295	-0.011	0.407	-0.005	0.43
2020	0.023	0.013**	0.017	0.036**	0.02	0.023**

*Notes: Standard errors in parentheses. ***, **, and * indicate significance at the 1, 5, and 10 percent levels, respectively.*

Annex 4: Spatial Durbin Model (SDM)

Variables	(1) SDM	(5) SDM	(9) SDM
Main			
$Y_{,t-1}$	0.101***	-0.411***	0.115***
	(0.035)	(0.024)	(0.028)
$GDP\_Cap_{i,t-1}$	0.069	-0.028	-0.006
	(0.118)	(0.070)	(0.069)
$GDP\_Cap\_gr_{i,t-1}$	0.939*	-0.044	0.655**
	(0.544)	(0.526)	(0.328)
$GERD_{i,t-1}$	0.000	0.000	-0.000
	(0.000)	(0.000)	(0.000)
$Pop\_dens_{i,t-1}$	-0.000	0.000	-0.000
	(0.000)	(0.000)	(0.000)
$High\_edu_{\mathrm{i,t-1}}$	0.402	-0.009	0.024
	(0.245)	(0.194)	(0.154)
$Emp\_ind_{\mathrm{i,t-1}}$	-0.005***	0.002	-0.009***
	(0.002)	(0.001)	(0.001)
$Eld\_Pop_{i,t-1}$	-0.023	-0.016	-0.004
	(0.029)	(0.016)	(0.014)
$Cool_{i,t-1}$	0.000	0.001**	-0.000
	(0.001)	(0.001)	(0.000)
W			
$L.WY_{,t-1}$	0.217	-0.385	0.431
	(0.361)	(0.362)	(0.392)
$WGDP\_Cap_{i,t-1}$	0.927	-0.248	0.444
	(0.781)	(0.383)	(0.437)
$WGDP\_Cap\_gr_{i,t-1}$	-1.051	-2.598	-0.929
	(4.442)	(4.881)	(2.876)
$WEmp\_ind_{\mathrm{i,t-1}}$	-0.534	-0.196	-0.283
	(0.432)	(0.355)	(0.261)
$WEld\_Pop_{i,t-1}$	-0.267	0.093	-0.206
	(0.269)	(0.161)	(0.205)
Spatial			
rho	0.325*	0.503**	0.368**
	(0.174)	(0.204)	(0.155)
Variance			
sigma2	0.441***	0.384***	0.162***
	(0.068)	(0.036)	(0.007)
Observations	2,412	2,412	2,412
R-squared	0.011	0.113	0.012
Number of id	134	134	134
Country FE	YES	YES	YES
Year FE	YES	YES	YES
depvar	RCA	Intensive Margin	Extensive Margin
ll	-2370	-2206	-1164
AIC	4772.96	4443.79	2360.98
BIC	4865.57	4536.40	2453.59
Test1	3.28	1.03	1.78
Test2	3.39	1.10	1.76

*Notes: Clustered standard errors at the regional level in parentheses. ***, **, and * indicate significance at the 1, 5, and 10 percent levels, respectively.*

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Appendix A: Personal contributions to the papers of the cumulative dissertation

On Sustainability in Regional Innovation Studies and Smart Specialisation (Chapter 2)
This paper was written by me as a sole author.

Inter-organisational Sustainability Cooperation among European Regions and the Role of Smart Specialisation (Chapter 3)
This paper was written by me as a sole author.

Quantifying the Circular Economy in European Regions: a Bridge towards Smart Specialisation? (Chapter 4)
This paper is a joint work with Jan Wedemeier. It is largely based on my own work, especially concerning the empirical work and analysis. The conceptualisation of the methodology and parts of the literature review have been conducted jointly while the data work and calculations were conducted by me.

What makes Regions go Green? Insights from a Spatial Model on European Patent Data (Chapter 5)
This paper is a joint work with Ivan Sergio and Jan Wedemeier. The conceptualisation and construction of the data set are my own work. The development of the methodology was mainly conducted by Ivan Sergio who also conducted the analyses. Discussion and revision have been done by Jan Wedemeier, Ivan Sergio, and me.

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Appendix B: Erklärung

Erklärung über die Anfertigung der Dissertation ohne unerlaubte Hilfsmittel

Ich erkläre hiermit, dass die Arbeit ohne unerlaubte Hilfe angefertigt worden ist und keine anderen als die angegebenen Quellen und Hilfsmittel benutzt wurden.
Ich erkläre ferner, dass die den benutzten Werken wörtlich und inhaltlich entnommenen Stellen als solche kenntlich gemacht wurden.
Eine Überprüfung der Dissertation mit qualifizierter Software im Rahmen der Untersuchung von Plagiatsvorwürfen ist gestattet.

Bremen, 19. April 2024

Mirko Kruse

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This doctoral thesis is the product of three years of studies at the University of Bremen. And like always in life, the way turned out completely different than originally planned. Changing jobs in between and leaving the research sphere certainly did not make this endeavour less challenging. However, friends, colleagues and companions managed to keep me on track. By it by motivating me, listening to my complains, or just saying the right thing at the right time. The last three years have been challenging for a number of reasons, navigating between the search for my place in the world of work, between love found and lost again, and between combing doctoral studies with a full-time job. However, it was the people along the way who allowed me to finally complete this challenge that initially and in between appeared to be impossible.

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