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Regional Innovation Systems: Evolution, Transition, and Future Agenda

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Regional Innovation Systems: Evolution, Transition, and Future Agenda

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Abstract

The regional innovation systems (RIS) concept is mature and widely used in economic geography. However, in the face of grand societal challenges and global economic uncertainty, the traditional RIS concept has been questioned and requires further consideration and discussion, to which we want to contribute in this paper. Thus, this study explores the evolution of RIS research by analyzing RIS articles published from 1992 to April 2024 using the Latent Dirichlet Allocation (LDA) model. It identifies three phases of RIS development and summarize five classic and three upcoming topics of RIS. These topics underscore the dynamic nature of RIS research and its continued relevance in addressing contemporary challenges and opportunities in regional development. Finally, this paper points out directions for future research.

Keywords: Regional Innovation Systems, Latent Dirichlet Allocation, Innovation Policy, Regional Transformation

This is a pre-print version of a paper that has been submitted for publication to a journal.

1. Introduction

The regional innovation systems (RIS) concept has long been a crucial concept in economic geography, playing a key role both in understanding regional differences in innovation capability and in fostering innovative regional development (Asheim, 2007; Tödtling & Trippl, 2005). RIS underscores the importance of interactions among various regional actors, such as companies, research institutes, educational institutes, and government, in enhancing regional innovation capabilities and economic competitiveness (Asheim & Coenen, 2005; Leydesdorff & Fritsch, 2006; Martin et al., 2023). RIS has significantly contributed to regional policy formulation and economic strategies (Asheim et al., 2016; Asheim, et al., 2011b).

Although there have been reviews of RIS (Doloreux & Gomez, 2018; Fernandes et al., 2021), we see three reasons for an updated review. First, despite the importance of the traditional RIS concept, it is increasingly scrutinized due to significant social challenges and global economic uncertainties (Asheim et al., 2020; Hassink et al., 2022; Tödtling et al., 2022). Secondly, research on RIS has advanced in terms of multi-scale policies and global perspectives (Blažek & Steen, 2022; Frangenheim, 2023; Rohe & Mattes, 2022). Existing literature reviews may not fully address the complexities of integrating regional innovation policies with global innovation networks and cross-regional interactions. An updated literature review will help incorporate these emerging policy perspectives. Thirdly, the regional application scope of the RIS concept is expanding. It is not only used in economically developed and mature industrial regions (Deegan et al., 2022; Doloreux, 2004; Faria et al., 2020), but increasingly also in peripheral regions. These evolving perspectives highlight gaps in existing research. To understand and address these changes, it is necessary to reassess RIS to ensure its relevance and effectiveness in contemporary policy-making and regional development strategies.

Therefore, this paper aims at exploring the evolution of RIS research by analyzing RIS articles published from 1992 to April 2024 using the Latent Dirichlet Allocation (LDA) model, which is a natural language processing model (Böhmecke-Schwafert & Dörries, 2023). The remaining sections of the study are outlined as follows. Section 2 introduces Characteristics and transition of RIS. Section 3 outlines the research methodology. Section 4 describes the results obtained from the analysis. Finally, section 5 presents the conclusions and outlook of this study.

2. Characteristics and transition of RIS

The concept of RIS emerged in the 1990s, with its origins tracing back to industrial districts and the notions of innovation environments and clusters (Asheim et al., 2016; Cooke, 2008). RIS synthesizes insights from literature on innovation systems and territorial innovation models, extending the framework of the national innovation system (NIS) (Asheim et al., 2016; Fromhold-Eisebith, 2007). The primary aim of RIS is to understand and suggest innovation activities within regions, thereby enhancing their innovation capacity and competitiveness (Asheim et al., 2011a). It highlights the dynamic interactions between local and global knowledge networks and the strategic role of regional innovation policies in fostering innovation (Asheim et al., 2020; Cooke, 2008).

The RIS essentially comprises two subsystems: the knowledge generation subsystem and the knowledge exploitation subsystem (Asheim & Coenen, 2005; Asheim et al., 2016; Tödtling & Trippl, 2005). Knowledge generation subsystems include universities, public and private research organizations, technology mediating organizations, workforce mediating organizations and educational organizations (Asheim et al., 2016). These institutions ideally generate and disseminate new knowledge through research activities, laying the foundation for regional innovation capacity (van den Broek et al., 2019; Zhuang et al., 2021). The knowledge exploitation subsystem primarily

comprises enterprises, which engage with other enterprises and market entities through various networks (Asheim & Coenen, 2005). The role of enterprises within this subsystem is to commercialize knowledge, develop products, and provide services, thereby driving local technological development and employment (Asheim & Coenen, 2005; Liu & Chen, 2012). In an optimal situation, the two subsystems are interwoven in an regional socio-economic and cultural environment that facilitates knowledge exchange, resource sharing, and human capital renewal through interaction, thereby enhancing regional competitiveness (Asheim et al., 2016; Tödtling & Trippl, 2005). Governments and regional policy actors possess the potential to significantly influence the advancement of regional innovation (Tödtling & Trippl, 2005).

The RIS represents an interactive process with constant feedbacks that transcends traditional linear innovation models (Asheim et al., 2016; Tödtling & Trippl, 2005). In the RIS, innovation emerges as a result of complex interactions and cumulative knowledge processes involving multiple actors (Asheim et al., 2016). The key function of RIS lies in fostering interaction among various actors, thereby facilitating the innovation process from basic research to successful market application (Asheim et al., 2016; Asheim et al., 2011a). Furthermore, social capital reduces transaction costs for these interactions, enhancing cooperation and learning among actors (González-Martinez et al., 2023). The RIS functions as an open system, leveraging its structure and mechanisms to not only introducing external knowledge but also enhancing its internal innovation capacity through the absorption and integration of this knowledge (Cooke, 2005; Li et al., 2022). The enhancement of this capacity partly relies on synergistic effects between the RIS and the NIS, as well as the involvement of RIS in global knowledge networks (Asheim et al., 2016; Fromhold-Eisebith, 2007) and global innovation systems (Binz & Truffer, 2017).

RISs play an important role in regional transition by fostering innovation, learning, policy support, industrial upgrading, and network building (Gancarczy et al., 2023; Gasparin & Quinn, 2021; Mattes et al., 2015). In this way, they help regions to adapt to changes, to enhance competitiveness, and to achieve sustainable development. Regional transitions are needed in response to constantly changing internal and external regional environments (Gancarczyk et al., 2023; Rohe & Mattes, 2022; Trippl et al., 2023) and involve the overcoming of regional lock-ins (Coenen et al., 2018). According to Tödtling & Trippl (2013), the transformation of RIS involves not just changes within the industry itself but also the reconfiguration of the RIS, encompassing various aspects such as knowledge creation, policy support, and network building. However, RIS may face various challenges in promoting these transitions, including institutional inertia or institutional void, path dependence, and a lack of coordination and cooperation (Coenen et al., 2018; Hassink et al., 2022; Sandulli et al., 2021; Tödtling & Trippl, 2013). Tödtling et al. (2022) recently introduced the challenge-oriented regional innovation system (CoRIS) to conceptualize the role of RIS in facilitating regional transitions in a reaction to grand societal challenges, such as climate change.

3. Methodology

Compared to existing reviews in RIS, this study expands the dataset of statistical articles to cover relevant literature published between 1992 and 2024. Systematic literature reviews and bibliometric approaches are usually complemented by diverse bibliometric analysis tools to analyze and visualize the data. This study uses the LDA model, which is a natural language processing model (Böhmecke-Schwafert & Dörries, 2023). LDA models can directly preprocess text to reduce noise in the data, thus improving the accuracy of the modeling (Yogish et al., 2019). In addition, the LDA model can effectively handle large-scale datasets, which is suitable for large-scale text analysis tasks (Stvilia & Gibradze, 2022).

The LDA model is based on Bayesian algorithms to generate topic distributions, providing more objective insights into document content (Blei et al., 2003). The LDA model can identify patterns and structures hidden in the data, offering insights into the topics and concepts present in the literature (Blei et al., 2003; Böhmecke-Schwafert & Dörries, 2023). LDA has been widely applied in various types of text analysis, such as articles, reports, social media posts, etc. (Böhmecke-Schwafert & Dörries, 2023; Lee et al., 2023; Wahid et al., 2022).

This study also integrates bibliometric and statistical analysis as supplementary methods. The steps of the methodology are shown in Figure 1.

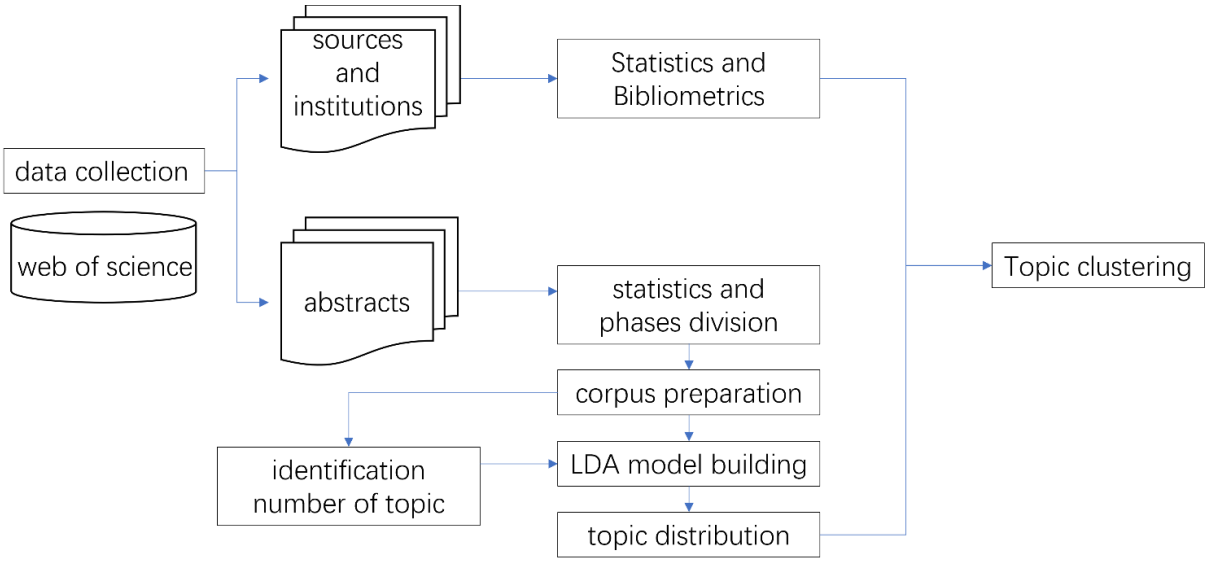

Figure 1. Overview of the research methodology

Source: own compilation

This study screens for RIS-related articles directly in the Web of Science database. The search is limited to articles where the title or abstract contains 'regional innovation system*' and only those written in English. 718 results are obtained (the last search was done on 14-08-2024). The data processing regarding the LDA model in this study is supported by Python programming. The corpus preparation, model building and training processes are described in detail in Appendix 1.

4. Results

4.1 Phase identification and classification

Considering the number of articles published over the years (as shown by the blue line in Figure 2), academic discussions on RIS overall show an upward trend. Particularly after 2009, there was a significant increase in the number of related studies. Although there was a slight decrease in publications in 2020, by 2021, the publication rate had rebounded and exceeded the level of 2019.

This study employs the Citespace bibliometric tool, using author keywords and titles as data sources, with keywords as nodes, to analyze the basic development trends of RIS (see Figure 2). Based on annual publication trends, we identify three distinct phases in the evolution of RIS research. Since the concept of RIS was introduced in 1992, related studies have gradually increased. In the early phase, keywords like “research and development”, “innovation policies” and “regional innovation system” reflect the initial exploration and establishment of the RIS theoretical framework. This phase is

characterized by relatively few publications concentrating on just a few research themes and hence by a low keyword diversity. From 2010 to 2018, a significant rise in publications indicated growing recognition of RIS. Keywords during this period became more diverse, covering practical applications and regional analyses, such as “technology transfer” and “smart specialization”. In the third phase, the “digital economy” and “energy policy” gained prominence as topics and keywords, signaling a deeper exploration of more complex interaction.

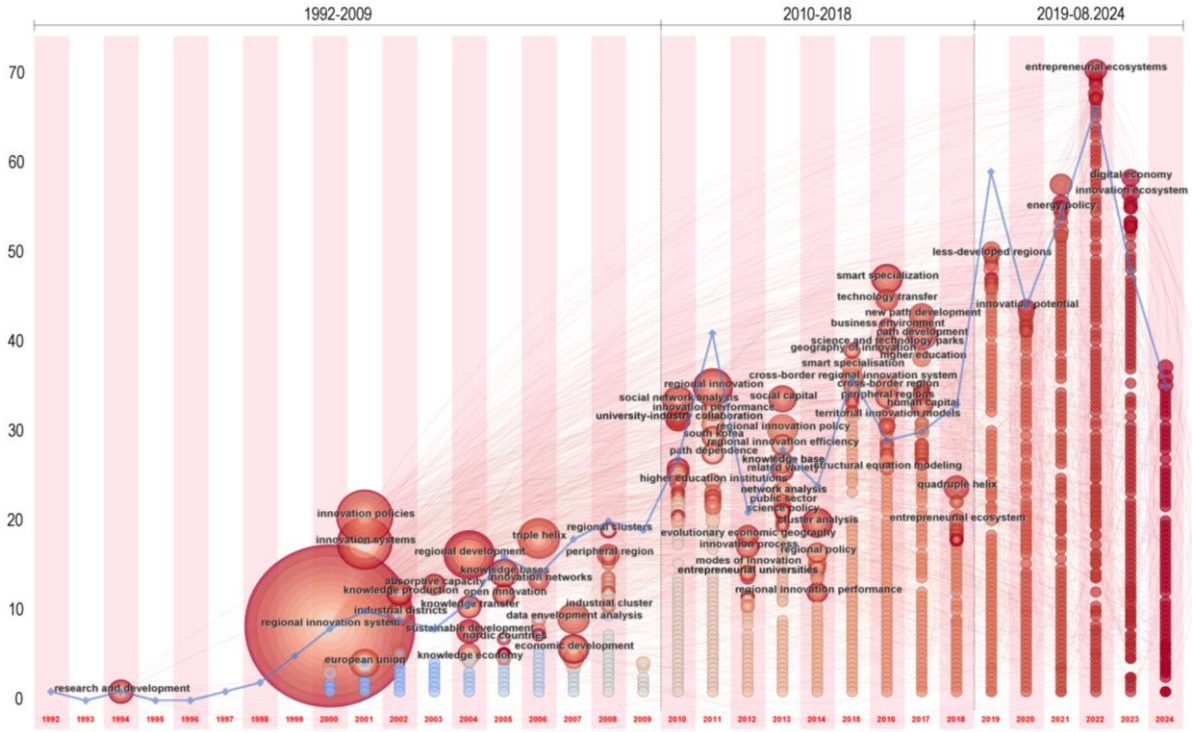

Figure 2. The different phases of RIS

Source: own compilation

4.2 Topics of RIS

In some cases, LDA analysis categorizes irrelevant or niche keywords (AlSumait et al., 2009; Xu et al., 2021). To address this, we compare and filter keyword clusters based on the number of topics initially generated by the LDA model ('initial number of topics') to determine the final number of topics ('selected number of topics'), as shown in Table 1. Detailed information on topic number determination can be found in Appendix 2.

phase	initial number of topics	selected number of topics
Phase 1: Emerging Phase (1992-2009)	7	6
Phase 2: Advancement Phase (2010-2018)	12	9
Phase 3: Transition Phase (2019-08.2024)	10	8

Table 1. phases division of RIS

Source: own compilation

The first phase can be seen as the emerging phase of research on RIS. Surprisingly against the background of advancing globalization, this phase of the RIS concept emphasizes the development of regionally specific resources and local cooperative networks, and how these elements enhance innovation activities and regional competitiveness (Asheim & Isaksen, 2002; Niosi & Bas, 2003; Tödtling & Trippl, 2005). Geographical proximity is considered a crucial factor for knowledge exchange and interactive learning (Asheim & Isaksen, 2002; Boschma, 2005). Empirical research during this phase mainly concentrated on knowledge-intensive industries characterized by frequent innovation and rapid technological advancements, such as electronics industry and biotechnology (Asheim & Isaksen, 2002; Niosi & Bas, 2003).

The second phase represents the advancement phase. This phase emphasizes the critical role of actors in the innovation process, particularly those beyond the traditional triple helix model (Höglund & Linton, 2018; Mattes et al., 2015), making RIS a more open system. Some studies actively explore the application and development of RIS influenced by non-traditional factors, such as non-local, non-metropolitan, and non-high-tech industry elements (Frykfors & Jönsson, 2010; Tödtling et al., 2011; Trippl et al., 2018). Additionally, during this phase, some studies began to explore new topics like sustainability and regional transformation (Coenen et al., 2018; Mattes et al., 2015; Tödtling & Trippl, 2018).

The third phase represents a transition for RIS. Research in this phase increasingly shifts the focus of innovation from merely promoting regional economic growth to achieving sustainable development, addressing grand societal challenges such as climate change, resource depletion, and environmental degradation (Asheim et al., 2020; Martin, 2020; Trippl et al., 2023). To address grand societal challenges, RIS must address deep transformation and reconfiguration through multi-scalar governance and policy cooperation (Asheim et al., 2020; Hassink et al., 2022; Trippl et al., 2023). This involves not only technological innovation but also changes in socio-technical systems and institutions (Martin, 2020; Sovacool et al., 2024; Terstriep et al., 2020).

4.3 Clusters and Topics

In order to comprehensively understand the evolution of RIS during these three phases, it is essential to delve into several classic clusters and upcoming topics (Table 2) that have shaped and defined the field through these phases. Table 2 shows the evolution of RIS concerning both classic clusters and upcoming topics. Classic clusters represent the core framework of RIS, while upcoming topics highlight current and future research priorities. We have identified five classic clusters, namely actor networks in RIS, typology of RIS, regional innovativeness and competitiveness, knowledge bases,

regional innovation policy. and three upcoming topics, namely asset modification in regional restructuring, multi-scalar perspective beyond regions, emerging industries in a region.

Classic cluster 1: Actor networks in RIS

Since its launch, the RIS literature has been focusing on diverse actors as key drivers of innovation network in RIS. In some early work RIS have also been combined with the triple helix model, to emphasize universities, companies, and government as primary participants in the RIS (Leydesdorff & Fritsch, 2006; Zhuang et al., 2021). Actors in the RIS must not only possess knowledge and skills but also be capable of interacting with existing social rules and economic structures to foster the creation of new industries and growth paths (Cooke, 2005; Kauffeld-Monz & Fritsch, 2013; Kim & Lee, 2022). More recently, a distinction between firm-level agency, which can stimulate innovation and entrepreneurship, and system-level agency, which provide the necessary support and environment for these activities, has been made in the RIS literature (Asheim et al., 2020). In the latest phase, there is also increasing attention paid to new actors, such as in González-Martinez et al. (2023), who argue that involving civil society actors can help companies to better understand and address social issues, as they are attuned to the needs and expectations of the community. Overall, different actors and their innovation networks has been a classic topic in RIS literature, with recently an increasing attention paid to different kind of agencies and to a broader group of actors.

Classic cluster 2 Typological study of RIS

Due to variations in types of regions and the diversity of place-specific factors, RIS can take different forms depending on the specific conditions and needs of each region (Doloreux, 2002; Isaksen & Trippl, 2017). Early typology of RIS research focused on understanding the internal and external knowledge flow mechanisms in different types of regions and their impact on innovation (Asheim & Gertler, 2006; Asheim & Isaksen, 2002; Cooke, 1998; Tödtling & Trippl, 2005). Isaksen & Trippl (2016) emphasized the concept of path dependence in RISs, closely linking RIS classification with the actual process of regional transformation. Moreover, in this phase of research the complexity and diversity of regional innovation models has been highlighted (Isaksen & Trippl, 2017). In the third phase, the perspective is expending from regional economic to include global and grand societal challenges. This shift is evident in the hierarchical regional innovation system model proposed by Tartaruga et al. (2024), which emphasizes addressing economic inequalities and hierarchical social structures to promote social inclusion, and achieve sustainable development goals. Overall, RIS typology research has consistently focused on place-specific factors, with recently a broader perspective emerging.

Classic cluster 3: Regional innovativeness and competitiveness

RIS underscores the interaction between universities, research institutions, and enterprises, which is vital for regional competitiveness and innovation (Cooke, 1992; Huggins & Johnston, 2009; Muller & Zenker, 2001; Tödtling & Kaufmann, 2001). Regional competitiveness is closely linked to the ability to create and commercialize knowledge (Asheim et al., 2016; Zhuang et al., 2021). Early research emphasized technology-driven innovation that relied on regional resources, with a particular focus on the roles of SMEs and universities (Benneworth & Hospers, 2007; Huggins & Johnston, 2009; Tödtling & Kaufmann, 2001). Over time, the significance of global connections and open innovation gained prominence (Belussi et al., 2010; De Marchi & Grandinetti, 2017), stimulating discussions on how KIBS influence regional competitiveness (Corrocher & Cusmano, 2014; Hsieh et al., 2015). Recent studies have broadened the innovation concept to include processes, management, and business model innovation (Tagliazucchi et al., 2021; Yun et al., 2023). Overall, RIS research consistently highlights the critical role of innovation in driving regional competitiveness.

Phase 1 (1992-2009)	Phase 2 (2010-2018)	Phase 3 (2019-08.2024)
Classic Cluster 1 Actor networks in RIS		
1. Innovation networks (e.g. Cooke & Morgan, 1994) 2. Triple helix (e.g. Cooke, 2005)	1. Triple helix (e.g. Frykfors & Jönsson, 2010) 2. Multi-actor interaction (e.g. Höglund & Linton, 2018)	1. Innovation networks (e.g. Plechero et al., 2021)
Classic Cluster 2 Typology of RIS		
3. Typology of RIS (e.g. Cooke, 1998)	3. Typology of RIS	2. Typology of RIS (Tartaruga et al., 2024)
Classic cluster 3 Regional innovativeness and competitiveness		
4. Small and medium-sized enterprises (SMEs) (e.g. Tödtling & Kaufmann, 2001)	4. Knowledge- intensive business services (KIBS) (e.g. Corrocher & Cusmano, 2014) 5. Innovation openness (e.g. De Marchi & Grandinetti, 2017)	3. Regional innovativeness and entrepreneurship (e.g. Tagliazucchi et al., 2021)
Classic cluster 4 Knowledge bases		
5. Knowledge bases (e.g. Asheim & Isaksen, 2002)	6. Knowledge bases (e.g. Tödtling et al., 2011)	4. Knowledge bases (e.g. Benneworth et al., 2019)
Classic cluster 5 Regional innovation policy		
6. Regional innovation policy and governance (e.g. Koschatzky & Sternberg, 2000)	7. Smart specialisation strategies (e.g. Muller et al., 2017) 8. Regional innovation policy (e.g. Sotarauta & Kosonen, 2013)	5. Sustainability in regional innovation policy (e.g. Fromhold-Eisebith, 2024)
	Upcoming Topic 1 9. Regional restructuring (e.g. Isaksen et al., 2018)	Upcoming Topic 1 6. Asset modification of region (e.g. Trippl et al., 2020)
		Upcoming Topic 2 7. Multi-scalar innovation policy (e.g. Hassink et al., 2022)
		Upcoming Topic 3 8. Emerging industry (e.g. Forrer et al., 2022)

Table 2. Topics of RIS

Note: For detailed information on the keyword analysis, see Appendix 3

Source: own compilation

Classic cluster 4: Knowledge bases

As the global knowledge economy develops, the process of knowledge production and dissemination becomes increasingly complex, which has hence been researched in the RIS literature from the beginning. Asheim et al. (2007) in particular have criticized the traditional dichotomy of knowledge as codified and tacit as being no longer sufficient to accommodate this complexity in the RIS literature. They proposed different types of knowledge bases, including analytical, synthetic, and symbolic knowledge bases, which have been intensively studied in a RIS context and have become hence a classic cluster. Research in this cluster helped to identify and understand the importance of different types of knowledge for innovation in RIS, which served to design and implement more effective and tailor-made regional innovation policies (Martin & Trippl, 2014). Different industries may namely rely on different types of knowledge bases for innovation. In later phases, combinations between different knowledge bases and the resulting complementarities and synergy effects have been emphasized in the RIS literature (Asheim et al., 2019). Overall, in this classic cluster differences and combinations of different kinds of knowledge have been discussed and researched in order to understand innovation processes and better tailor regional innovation policies to the needs of regional economies.

Classic cluster 5: Regional innovation policy

The relationship between RIS and regional policies is both close and complex, characterized by mutual influence and interaction. Regional innovation policies offer resources and support to RIS, which in turn informs and shapes these policies. Early studies highlighted the role of regional innovation policies in supporting local innovation systems. Chaminade & Vang(2008) and Gebauer et al. (2005) underscored the critical role of regional policies in local innovation systems, from global and local perspectives, respectively. Later research underscored the importance of targeted regional policies. With globalization, RIS research has increasingly focused on cross-regional networks and multi-level governance (Asheim et al., 2011b; Moodysson et al., 2016; Muller et al., 2017). Recent studies explore how regional policies can support sustainability and the impact of digital technologies on RIS (Isaksen et al., 2021; Schot & Steinmueller, 2018). Innovation policies now extend beyond mere economic growth to include addressing societal challenges such as climate change, resource management, social inclusion, digital infrastructure development, and the formation of digital industry clusters, which reflected in policy designs that prioritize support for green technologies, circular economies, digital transformation, and social innovation initiatives (Borrás & Edler, 2020; Fromhold-Eisebith, 2024; Isaksen & Rypestøl, 2022; Kamath et al., 2023; Labiak Jr & Favorito, 2023; Mazzucato, 2016). Overall, RIS research has evolved from focusing solely on increasing regional innovativeness and competitiveness and reducing regional disparities to promoting sustainable development and global competitiveness through innovation.

After 2019, research has moved beyond classic topics to focus on transformative changes and sustainable development in the third phase (Table 2). These emerging themes encompass not only technological progress and economic growth but also social structures, institutional changes, and responses to global challenges. From this, we identify three upcoming topics that represent the new frontiers and future directions of RIS research.

Upcoming topic 1: Asset modification in regional restructuring

Recently, RIS research started to focus on the conditions and support for asset modification in RIS. Technological advancements and social challenges prompt regional industrial restructuring (Kamath et al., 2023; Rypestøl et al., 2023). Asset modification has become a crucial strategy for regions to

adapt to this change and achieve sustainability. According to Isaksen et al. (2020), during the digital transformation of enterprises, innovative activities rely on the alignment and modification of assets within both the enterprises and the RIS. This process can lead to system-level restructuring. Simultaneously, the evolutionary paths of clusters are deeply integrated into the RIS structure. Different types of RIS support various innovation pathways, which in turn impact cluster development in different ways (Kamath et al., 2023). This influence is also evident in the process of regional green transformation. Trippl et al. (2020) highlight that green transformation depends not only on the structural conditions of the existing RIS but also on how assets are modified, that is reused, created/transplanted, and deconstructed. These modifications help to explain the variations in innovation and transformation across different regions (Isaksen et al., 2020; Rypestøl et al., 2023; Trippl et al., 2020).

Moreover, Isaksen et al. (2018) suggest that developing new pathways requires agency at both the enterprise and system levels, particularly when dealing with more radical economic restructuring, where system-level agency is crucial. However, the ability to achieve regional restructuring depends on additional factors, including regional imaginaries, power relationships, and directionality. These factors collectively shape system selectivity and influence the strategies and actions of regional actors during the RIS restructuring process (Miörner, 2020).

Upcoming topic 2: Multi-scalar perspective beyond regions

RIS often confines itself to specific geographic or administrative regions, overlooking the perspective of global innovation networks, global innovation systems and cross-regional interactions. Based on preliminary research carried out in classic cluster 5: Regional innovation policy, recent research in this phase advocates that regional innovation policies should integrate with different levels. Some studies suggest that through this multi-level policy implementation, it is possible to integrate resources and actions at different levels, promoting regional sustainability transition (Hassink et al., 2022; Jeannerat & Crevoisier, 2022; Tartaruga et al., 2024). However, multi-level policy faces challenges, including the complexity of policy coordination, difficulties in setting resources, as well as communication barriers (Frangenheim, 2023; Irshaid et al., 2021).

The multi-scalar perspective also involves mutual learning from concepts at other scales. Rohe and Mattes (2022) propose the interaction and complementarity between RIS and technological innovation systems (TIS). Blažek & Steen (2022) compare the concepts of RIS and GVC/GPN, suggesting that although GVC/GPN and RIS theories differ in scale (global vs. regional) and focus, they provide important and largely complementary understandings of changes in the global economy and regional development. Kim and Lee (2022) discuss that successful catch-up strategies require regions to effectively interact through the local-global interface, gradually enhancing the creation and diffusion of local knowledge, reducing dependence on external knowledge, and enhancing local ownership of innovation. Bugge et al. (2022) emphasize the importance of RIS in Norway's mission-oriented innovation policy, highlighting how it created new regional economic opportunities that drove the electrification of the maritime industry in the western region. This initiative not only promoted domestic transformation but also aligned with global emission reduction and innovation trends.

Upcoming topic 3: Emerging industries in a region

Emerging industries typically exhibit innovation novelty and relatively rapid growth rates but often require substantial investment and face high levels of uncertainty (Li et al., 2022). The development of emerging industries is influenced not only by technological breakthroughs but also by market/application relatedness, institutional relatedness, strategic agency, and serendipity (Gong et

al., 2022). The institutional structure of RIS significantly influences the emergence and development of emerging industries. The policy environment, regulations, cultural norms, and other factors collectively shape the dynamics of regional innovation and the legitimacy of emerging industries (Forrer et al., 2022; Gong et al., 2022). Governments and other institutions can promote the growth of emerging industries and the transformation of regional economies by providing funding, establishing partnerships, and formulating policy frameworks (Fløysand et al., 2022; Li et al., 2022). In this phase of RIS research, emerging industries are increasingly viewed as catalysts for achieving more regional sustainable development trajectories while driving economy (Plechero et al., 2021; Rong et al., 2021).

According to published research in this phase of RIS research, green industries are particularly highlighted. Green innovation is gaining more attention as green industries can bring both economic and ecological benefits. Corradini and Karoglou (2023) have used technology patents as indicators of innovation to assess local green innovation capabilities. While in general the green industry garners more attention and support than traditional industries, this does not happen everywhere to the same extent. Steinböck and Trippl (2023) analyze the case of the failure of the bioplastics industry in lower Austria, and argue that powerful actors representing traditional incumbent industry, maintain the current situation through different strategies and behaviors, thus hindering the development of new industries and the restructuring of the innovation system.

5. Conclusions and agenda

This paper explores the concept of RIS, outlining its development across three phases. In the first phase, known as the emerging phase, RIS research focuses on establishing and strengthening knowledge and innovation networks within regions, encompassing interactions among enterprises, universities, and government. The goal is to enhance regional innovation capacity and competitiveness, driving economic growth through the spillover effects of technological knowledge and innovation outcomes. In the second phase, the concept and practice of RIS are expanded and deepened on a global scale, encompassing both developed and developing countries. This phase emphasizes tailoring and implementing innovation policies based on the unique characteristics and needs of different regions. The third phase marks a shift in RIS towards addressing grand societal challenges and promoting related regional transformation. This phase emphasizes a multi-scalar perspective, highlighting the role of RIS in sociotechnical change and the integration of resources across different scales to promote regional sustainability and inclusive development.

This study summarizes the main topics discussed in the evolution of RIS and identifies recent research topics. RIS has been discussed around five classic clusters and three recently upcoming topics. These clusters and topics underscore the dynamic nature of RIS research and its ongoing relevance in addressing contemporary challenges and opportunities in regional development.

Based on and deepening the above-described upcoming topics, we propose the following research agenda. Firstly, most empirical studies assume that restructuring improves the regional industrial structure. However, the process of industrial upgrading or restructuring can create new frictions or obstacles. When a region attempts to transition to a more environmentally friendly economic model, conflicts often arise between traditional, incumbent industries with vested interests and emerging green industries (Kivimaa & Kern, 2016). Traditional industries, with their stable markets and profits, may be reluctant to change their existing operations. In contrast, emerging green industries require substantial resources and support, such as policy incentives and investment funds, to develop. This situation leads to a competition for limited resources and support between old and new industries. Additionally, the roles of actors in the process of asset modification and their impact need to further

explored. These roles can be either proactive or reactive, depending on the objectives, resources, and capacities of actors.

Secondly, through a multi-scalar perspective, more research is needed on how RIS can identify and leverage opportunities at various levels, such as national policies, global market trends, or technological advancements, which can act as catalysts for regional transformation (Morisson & Gong, 2024; Rohe & Mattes, 2022). In terms of policy, future research should explore how to coordinate innovation policies within a multi-scalar perspective to ensure policy consistency and synergy. Furthermore, since policy tools are diverse, understanding how their interactions can be combined to promote regional innovation and sustainable development is another important area for future research (Binz & Truffer, 2017; Tödtling & Trippl, 2021). For example, comparing policy practices across various regions could provide insights into the actual effects and interactions of these tools.

Thirdly, within RIS, different types of enterprises and organizations play crucial roles. Beyond high-tech firms, SMEs, community organizations, and other grassroots innovators are also key contributors. While their technological capabilities may be lower, their localized innovation practices effectively address the needs of local communities (Sheikh et al., 2024). Future RIS research should place greater emphasis on the innovation efforts of these grassroots actors, exploring how they leverage local resources and engage with networks both regionally and beyond to drive the growth and evolution of RIS. Furthermore, exploring their collaborative models with high-tech companies or other innovation actors can provide deeper insights into the specific mechanisms through which these grassroots innovators contribute to regional innovation.

Finally, this paper may have certain limitations in methodology. Although LDA has specific statistical methods and a specific judgment index, naming topics still unavoidably involves subjectivity. Future studies could enhance data statistical methods to address this.

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Appendix 1

Corpus preparation

Before conducting unsupervised analysis, the LDA model needs to preprocess the collected text. First, punctuation marks should be removed from the text, and a stopwords list should be loaded to filter out noise words, which are words that frequently appear in the text but contribute little to identifying topics, such as 'a', 'and', 'so', etc. Therefore, additional words like 'study', 'concepts', 'article', etc., should be manually added to the corresponding stopwords list to enhance the reliability of the analysis. Finally, lemmatization should be applied to some words, converting them into their base forms, such as different tenses or plural forms, to facilitate text data analysis and enhance interpretability.

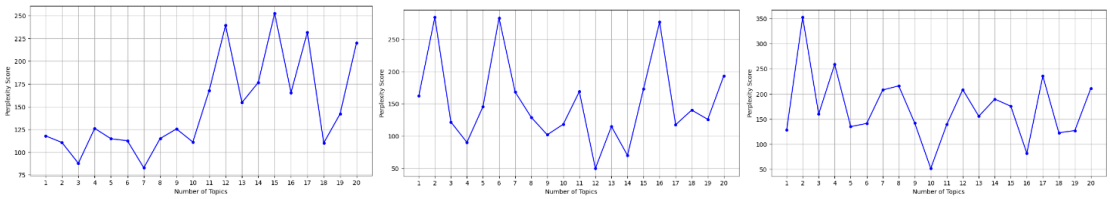
Building and training model

Before training the LDA model, it is necessary to pre-set an appropriate number of topics, which is typically determined by perplexity (Blei et al., 2003). Perplexity is a commonly used metric in natural language processing to measure the quality of a model (Savin et al., 2022).

In order to extract keywords from the text, it is necessary to build a model. The id2word function in the Gensim package allows users to categorize words by creating a vectorized 'bag-of-words'. This step utilizes the LDA model to perform topic modeling on the text and assess model performance under different numbers of topics by plotting perplexity charts. This study employs the Dictionary class from the Gensim library to create a dictionary, uses the id2word function with the dictionary to convert tokenized text into bag-of-words representation, and constructs a corpus. Perplexity is calculated directly in the code using the log_perplexity() method of the LDA model to obtain perplexity values for different numbers of topics. Finally, the Matplotlib library is used to plot a line graph of the number of topics against perplexity scores, to determine the appropriate number of topics.

Appendix 2

Based on classifying the development phases of RIS, this study further employs the LDA model to conduct text mining on article abstracts to find important topics. It uses the pyLDAvis package to visualize the values of perplexity and the distribution of topics. If the number of topics is too small, it may not provide a comprehensive explanation of the subject, while excessive classification lacks practical significance (Lee et al., 2023), thus the maximum number of topics is limited to 20. Figure 3 displays the topic distribution plot generated using the pyLDAvis package. The lower the value of perplexity, the more reasonable the corresponding number of topics (Blei et al., 2003). Therefore, the number of topics is determined to be 7, 12, and 10, respectively.



Phase 1 Phase 2 Phase 3

Figure 3. Distribution of topics and perplexity score

Source: own compilation

Appendix 3

The above topics are summarized from the keyword analysis conducted at λ = 0.61. λ is a weight parameter in the pyLDAvis system used to balance two factors when calculating the relevance of a term to a topic (Sievert & Shirley, 2014). λ has a value ranging from 0 to 1, which determines the value given to the relative importance of the two factors. According to Blei et al. (2003), the "optimal" value of λ was found to be approximately 0.6. This means that frequency and salience are given roughly equal weight when calculating relevance, enhancing the interpretability of the topic.

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