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THE ROLE OF INNOVATION SYSTEMS IN THE DEVELOPMENT OF A CIRCULAR AND SUSTAINABLE BIOECONOMY

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"Two years!" exclaimed Dantès; "do you really believe I can acquire all these things in so short a time?"

"Not their application, certainly, but their principles you may; to learn is not to know; there are the learners and the learned. Memory makes the one, philosophy the other."

"But cannot one learn philosophy?"

"Philosophy cannot be taught; it is the application of the sciences to truth; it is like the golden cloud in which the Messiah went up into heaven."

Alexandres Dumas, The Count of Monte Cristo, Chapter 17

Abstract

The concept of innovation is strongly interwoven with the bioeconomy. In the most known definition of this meta-sector (e.g. Global Bioeconomy Summit, European Commission), innovation is always reported as at its hearth. However, despite this importance, the bioeconomy innovation literature raised no original frameworks or concepts. This PhD thesis aims to contribute both theoretically and practically to advance the analysis of Knowledge and Innovation Systems for the Bioeconomy (KISB). The KISB framework represents the adaptation of the Innovation Systems (IS) model to the bioeconomy. In this dissertation, the KISB was developed through three main steps. First, in a systemic literature review, we explored the scope of the KISB and its main peculiarities. In the second and third steps, we tried to adapt this framework to a real context. Taking the Italian bioeconomy as a reference, we first tried to outline the shape given to the knowledge and innovation network by the EU innovation policies (i.e. research projects under the FPs). Once we found the main actors and their roles in the network, we moved to the third step, analysing the relationships and the information flow within the whole KISB. Results showed that there is scope for the KISB approach both for policy and business purposes. Furthermore, by applying this approach in the Italian context, we found that, in general, the network is structured on public research institutes and universities, while the categories private for-profit companies, public entities and other actors (e.g. associations or foundations) have more peripheric positions and less interactive roles. Only some individual entities of these latter categories are considered to be close to the others so that they can rapidly affect the network. Moreover, assessing the linkages within the Italian KISB, we found that the public bodies stand as the only dominant category, while research entities occupy a subordinate role and private for-profit and other entities act as interactive participants. Furthermore, analysing the information flow structure, no intermediaries or connectors were detected, with only two main groups emerging: the promoters, which include private for-profit entities, other entities, and public bodies; and the target group, which is represented by higher education establishments and research institutes. Conclusions provide policy suggestions to improve the system. In particular, we suggest: identifying an organism that acts as a reference point for scientific-technological policy (for example, empowering the current National Bioeconomy Coordination Group), and equipped with agile and flexible communication channels to share with and receive information from

stakeholders; foster learning and knowledge-related processes; support commercialisation grants, investments and entrepreneurship.

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Acknowledgement

It is not so easy to enclose in a few lines the many thanks that I wish to convey at the end of this three-year journey. However, as my supervisor would say, this is "*a useful exercise in style.*" So I will start by thanking him, my mentor Professor Davide Viaggi. I asked him a lot, he gave me more: Perhaps this is not in line with economic laws, but my thankfulness is significant exactly for this reason.

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I owe gratitude to all my colleagues in the Department. Often viewed as irrelevant in the perspective of society, they were and are fundamental to me. Maybe this is not much, but "*piuttosto che niente, è meglio piuttosto.*"

Lastly, my deepest gratitude goes to my family, the greatest gift this life has given me.

Chapter 1 - Introduction

1.1. Background and motivation

The definition of the concept of the bioeconomy is subject to an ongoing debate, that involves both researchers and policymakers (see Bugge et al., 2016; Hausknost et al., 2017; Hodgson et al., 2022; Viaggi et al., 2021; Wesseler and von Braun, 2017) Wesseler and Von Braun, 2017. This debate has a great impact on the scene because of its direct effects on the sectors involved and, consequently, the strategies implemented by countries (D.; Viaggi et al., 2021). However, there are some elements that are in common among all different perspectives and we can consider them as pillars of the bioeconomy (D.; Viaggi et al., 2021). One of these elements is innovation, as we can see considering the definitions provided by supranational entities. The rationale behind taking into account these entities and their definitions lies in the process that brings to defining the concept of bioeconomy: it is the synthesis of different perspectives brought and supported by the various countries, different in history, traditions and resources (Johnson et al., 2022; Lewandowski, 2018; D. Viaggi, 2018a). Therefore, these definitions have the merit of proposing a comprehensive vision that goes beyond local ones.

An example is the last definition proposed by the Global Bioeconomy Summit in 2024, which in its final communiqué states that: "*The bioeconomy is the production, utilization, conservation, and regeneration of biological resources, including related knowledge, science, technology, and innovation, to provide sustainable solutions (information, products, processes and services) within and across all economic sectors and enable a transformation to a sustainable economy. The bioeconomy is not a static notion and its meaning is continually evolving*" (GBS, 2024: 1). This definition focuses on four main points. First, it underlines the practical processes (production, utilization, conservation and regeneration) related to biological resources. Then it moves towards the creative processes and the theoretical basis behind the bioeconomy implementation (knowledge, science, technology and innovation). After that, it relates all these processes to the economic sphere, and in particular sustainable economy. Finally, it underlines the dynamic nature of the notion of bioeconomy.

Hence, based on the GBS definition, innovation is at the core of the bioeconomy. Similarly, we can consider the last definition provided in 2018 by the European Commission (EC):

"*The bioeconomy covers all sectors and systems that rely on biological resources (animals, plants, micro-organisms and derived biomass, including organic waste), their functions and principles. It includes and interlinks: land and marine ecosystems and the services they provide; all primary production sectors that use and produce biological resources (agriculture, forestry, fisheries and aquaculture); and all economic and industrial sectors that use biological resources and processes to produce food, feed, bio-based products, energy and services. To be successful, the European bioeconomy needs to have sustainability and circularity at its heart. This will drive the renewal of our industries, the modernisation of our primary production systems, the protection of the environment and will enhance biodiversity.*" (EC, 2018: 4)

Given the importance of the EU policies in this dissertation, a more detailed analysis of this definition is provided.

Even in this case, we can identify four parts, corresponding to the four sentences that compose this definition:

I) In the first sentence, the central element is "*biological resources*", placed in relation to the economic sphere, i.e. "*all sectors*", and to the socio-environmental sphere, i.e. "*systems;*"

II) The second sentence further elaborates on which sectors and systems are involved, but also defines the production purposes of the bioeconomy, i.e. food, feed, bio-based products, energy and services;

III) In the third sentence, the concepts of *sustainability* and *circularity* are recalled, delimiting the field of action of the bioeconomy and setting an objective ("*To be successful…"*);

IV) Finally, the fourth sentence represents the most ambitious part, as it outlines the mission of the EU bioeconomy.

Summarising, the EU bioeconomy focuses on the *sustainable* and *circular* management of *biological resources* by specific *sectors* and *systems*. In line with what is reported in the IV part of the definition, all these "building blocks" of the bioeconomy are seen as drivers of European sustainable innovation and growth ("This will *drive* the *renewal* […], the *modernisation* […], the *protection* […]."). Hence, according to these sentences, the bioeconomy is not a sector that tends towards innovation but is itself a form of strategic innovation for the development of pre-existing sectors. In this sense, the EC perspective deeply differs from the GBS one. Indeed, the GBS perspective considers bioeconomy as a sector in which innovation is part of the implementation process and not the means through which to innovate pre-existing sectors. In other words, the GBS regards innovation as an effect of the bioeconomy, while the EC regards it as a cause.

This vision of the EU about the bioeconomy has its roots in the concept of Knowledge-Based Bio-Economy (KBBE) developed between the 90s and the early 2000s (Aguilar et al., 2009; EC, 2002, 2005; Kircher, 2021). As stated by Patermann and Aguilar (2018), the process that led to the definition of the bioeconomy in 2018 includes some milestones: the Strategy on Life Science and Biotechnology in 2002 (EC, 2002) was the first attempt, for the biotech sector, to go beyond the simple implementation of the EU Framework Programmes, making dialogues and discussions among industry, academia and socio-economic actors more stable and structured; the mid-term review of the Biotechnology Strategy in 2007 (EC, 2007) marked the primary formal convergence between biotechnology and the current interpretation of the bioeconomy. In fact, for the very first time, in the communication on this mid-term review, appeared the concept of "*Knowledge-Based Bio-economy"* known also as KBBE; and finally, the first EU Bioeconomy Strategy in 2012 (EC, 2012), which provided the first definition of the bioeconomy – i.e., "*the production of renewable biological resources and the conversion of these resources and waste streams into value-added products, such as food, feed, bio-based products and bioenergy*" – still very production- and resource-oriented (Hausknost et al., 2017), without an explicit connection to circularity and sustainability.

In addition to this specific path of the European bioeconomy, there are also significant contextual elements – European and international – that explain the four parts of the 2018 definition. In 2000, the European Council, meeting in Lisbon, agreed on the ten-year strategy for the Union, which set as its main strategic objective "*to become the most competitive and dynamic knowledge-based economy in the world*" (Council of the European Union, 2000). Hence, the concept of a *knowledge-based economy* represented the umbrella under which the KBBE was placed. The continuation of this concept is, as mentioned, findable in the IV part of the definition.

In 2004, the OECD was a pioneer in defining the concept of a *biobased economy*, as reported in its document "Biotechnology for Sustainable Growth and Development" (OECD, 2004). Although very close to the industrial biotechnology point of view, this document introduced a vision of biotechnology that can be aimed at both economic and – here the innovative element – socio-environmental growth. This definition of a biobased economy is recognised as " the basis of most of the different bioeconomy strategies around the world and in particular the EU Bioeconomy Strategy of 2012" (Patermann and Aguilar, 2018: 22). Hence, it can be seen as the basis also for the I part of the EU Bioeconomy Strategy of 2018.

In 2015 two events marked a turning point for the world economy and development: The adoption by all United Nations (UN) Member States of "The 2030 Agenda for Sustainable Development" (UN, 2015), and the Paris Agreement on climate change during COP21 (ratified by EU on October 2016, Council Decision (EU) 2016/1841, 2016). The former introduced 17 Sustainable Development Goals (SDGs), while the latter set the framework to limit global warming to 1.5°C above pre-industrial levels. These two events, therefore, help to understand the inclusion, in 2018, of that specification on circularity and sustainability as founding elements of the EU bioeconomy (III part).

All this background mentioned so far helps to understand why, in the space of about 20 years, the European bioeconomy moved from being synthesized as KBBE to a Sustainable Bioeconomy (SBE). However, as we saw in the IV part of the 2018 definition, the innovative component is still there. In this regard, it is observed that the concept of *knowledge* has been replaced by that of *innovation*. Indeed, in the last EU documents, the latter concept is widely addressed compared to the former (see for example EC, 2022, and 2023)
Furthermore, in terms of specific policy tools, innovation policy represents one of the most important branches of bioeconomy development (Bröring et al., 2020; Egea et al., 2021; D.; Viaggi et al., 2021). Indeed, as clearly stated by the EC, "no specific EU bioeconomy legislation exists" (Knowledge Centre for Bioeconomy of the European Commission, 2022), entrusting its development to sectoral or cross-sectoral policies.

Also from a research point of view, the study of innovative processes, relationships between stakeholders and the factors that regulate the creation and diffusion of knowledge in the bioeconomy is still in its infancy (Bröring et al., 2020; D'Amato et al., 2022; Van Lancker et al., 2016). Despite the importance that innovation covers in the bioeconomy, no original and specific frameworks or concepts have been developed in this field (Bröring et al., 2020; D.; Viaggi et al., 2021). However, this type of knowledge and research may deeply contribute to indicate areas of interventions such as education and training, business development, local development, etc. Indeed, understanding the aforementioned mechanisms might allow for: a better harmonization of current policies, intervening both on overlaps between different sectors and gaps; identifying the costs that the organizations have to bear (for example, in guaranteeing constant information flow); identifying barriers to entry for startups (in terms of knowledge and information); establishing an education and training system suited to the needs of the sector. Hence, such knowledge could be of interest not only to policymakers or companies but to all stakeholders involved in the bioeconomy (academia, citizens, consumers, NGOs, etc.).

To fill these gaps, the large body of literature on innovation can strongly contribute. This branch of economics developed several frameworks to explain how innovation is produced and spread within a defined context. Starting from the seminal works of Lundvall (1985; 1992), Nelson (1988; 1993) and Dosi (Dosi et al., 1988), who pointed out the limits of interpreting innovation as a linear flow from researchers to final users, the focus moved in the 90s to the concept of diffusion of innovation (Protogerou et al., 2010b). However, in the last decade, mainstream thought, even if with different approaches, identifies innovation as a complex process within a complex system (Buchmann and Pyka, 2015). Moving from that, the concept of Systems of Innovation is nowadays well established (Rubach et al., 2017), with extensive literature on the topic (Pyka and Scharnhorst, 2009). Nevertheless, to date, the bioeconomy has little explored the possibilities that these approaches offer (Viaggi et al., 2021), with limited theoretical advancements in this area.

Awareness of these gaps, together with curiosity to deepen the complexity of the bioeconomy innovation processes and the desire to outline an overall vision of this sector, motivated us to undertake the series of studies that constitute this dissertation.

1.2. Objectives

The main objective of this thesis is to contribute to theoretical and practical advancements in the analysis of Knowledge and Innovation Systems for the Bioeconomy (KISB). This systemic approach was chosen to better describe the complexity that characterizes the bioeconomy and, at the same time, address the lack of knowledge in the mechanisms that regulate innovation, knowledge and information flows in the bioeconomy. To enhance comprehension of the possibilities and difficulties that arise in adopting the KISB approach, it was decided to divide the research work into three sub-objectives:

I) To identify what types of Innovation Systems (IS) were adapted to describe the bioeconomy, and, based on the findings, to outline a specific Knowledge and Innovation System for the Bioeconomy (KISB) and its peculiarities;

II) To investigate the role of EU Research and Innovation funds in structuring an Italian network of actors working on research and innovation in the bioeconomy;

III) To assess the linkages and the information flows within the Italian KISB.

Due to the aforementioned lack of systemic and holistic approaches to explore innovation in the bioeconomy, this research should be understood as exploratory research to apply a relatively new framework (I sub-objective) and an attempt to perform a quantitative-qualitative description of it (II and III sub-objectives).

1.3. Novelties

This dissertation introduces several novelties in the debate around innovation in the bioeconomy. To the best of our knowledge, this study represents the first attempt to introduce in the field of the bioeconomy a knowledge and innovation system approach. Indeed, after being proposed by Esposti (2012), no specific research was carried out to understand the potentiality of the KISB application. Moving from the wide literature about IS and in particular the Agricultural Knowledge and Innovation System (AKIS), we tried to outline the main characteristics of the KISB, producing an advancement in both theoretical and empirical research.

Indeed, in the first part of this study, through a systemic literature review, we analyse the state of the art of IS applied to the bioeconomy, finding a scope for a unique KISB and outlining its main peculiarities. In this vein, our contribution represents a first attempt to identify a framework that allows for the understanding of the bioeconomy in its complexity. Furthermore, with a specific focus on the contextual factors that characterise the innovation process in the bioeconomy identified by Van Lancker et al. (2016), we propose a theoretical advancement based on the literature of recent years.

In the second part, we provide an empirical example of the mapping of actors. This analysis is carried out in the Italian context and takes advantage of the CORDIS database (i.e. EU database of all financed projects) to identify the main actors and their relationships. In this case, there are two main novelties. The first one is methodological: based on the best of our knowledge, no other papers used the CORDIS database to outline a national network in the field of bioeconomy. The second one is theoretical. The study lays the foundation to outline the Italian KISB, providing a network that may be subject to further analysis by the scientific community.

In the third part, the study presented represents a first attempt to assess the linkages, evaluate the information flows, and gather feedback from key components of the Italian KISB. To do so, the Graph Theory Techniques (GTT) are introduced. To the best of our knowledge, no other studies applied this methodology in the field of the bioeconomy.

1.4. Overview

This PhD thesis is structured in three separate papers, that compose the next three chapters. The underlying theme involves studying and implementing a model that represents innovation and knowledge in the bioeconomy through a systemic approach.

In the next Chapter, we take advantage of a systematic literature review to understand the state of the art in the field of IS applied to the bioeconomy, and, at the same time, to recognize which elements characterize the innovation processes in this sector. The results show that no specific and unique KISB was adopted in the literature, with many different IS used as a lens to explore parts of the whole innovation process. However, based on the weaknesses and strengths of these approaches, it is possible to outline a common KISB that comes closer to portraying the whole picture.

In Chapter 3, through a Social Network Analysis (SNA), the study focuses on a specific national context, Italy, taking into account all the organizations that participated in EU projects about bioeconomy since the first European Bioeconomy Strategy. The paper seeks to overcome the current limitations due to the lack of databases providing aggregate data on the bioeconomy. Moreover, it represents a first step toward a better understanding of the Italian KISB and the policies that this system needs to fill the gaps and promote sustainable development. The results show that the most central actors are three public research organisations (two research institutes and one university), while private for-profit companies are the most represented in terms of the number of participants. However, no further analysis are conducted to investigate the nature of the relationships among different types of actors and the information flows.

In Chapter 4, we try to fill this gap using a Graph-Theoretical Technique (GTT) method to assess linkages and information flows between categories of actors. In particular, we grouped the organisations following the same categories of the SNA study. After that, through the submission of an online questionnaire, we collected the opinions of key actors of the Italian KISB. Processing the information recorded, several insights emerged. Among the main results, we found that medium-high intensity characterises the relationships between categories.

Furthermore, Public bodies are the only category that causes innovation, while Higher or Secondary Education Institutes, and Research Institutes are sub-ordinated categories and Private for-profit and Other (i.e. clusters, NGOs, foundations, etc.) are interactive components. Instead, in terms of information flow structure, no intermediaries have been found, with only two groups emerging from the analysis: the promoters, consisting of Private for-profit, Other, and Public bodies; and the targets, represented by Higher or Secondary Education Institutes, and Research Institutes. Furthermore, the respondents pointed out several difficulties of the system: a lack of a critical mass of actors serving as a reference point for innovation; the absence of stable and well-established reference channels; and the poor and difficult involvement of primary producers in the bioeconomy circuits. Moreover, knowledge transfer is still considered to be in its embryonic stage.

Chapter 5 discusses the results. First, in light of the approach to the thesis. Then, pointing out the limitations of the studies and outlining possible future research pathways. Finally, indicating some policy implications that can be deduced from the results.

In Chapter 6 the conclusions are drawn based on all the elements identified in the previous chapters.

Chapter 2 - Which framework for the bioeconomy innovation systems? A systematic literature review

1. Introduction

The bioeconomy represents an important segment of the economy of both high-income and low-income countries (Johnson et al., 2022; M'barek and Wesseler, 2023), gaining increasing popularity in the recent years (M'barek and Wesseler, 2023). As pointed out by the systemic literature review in Wei et al. (2022), four stages of bioeconomy research can be identified, namely: Infancy stage (1998-2002), Exploring stage (2003-2012), Blooming stage (2013-2017), and Mature stage (2018-to date). Hence, the bioeconomy research can be considered in its maturity. Moreover, even from a policy perspective, the bioeconomy is considered an established and no longer emerging sector, with more than 60 specific strategies around the world (GBS, 2024).

Despite this maturity, the concept of bioeconomy is still subject to debate, both in policy and research fields (Vogelpohl and Töller, 2021; Wei et al., 2022), with different points of view that hinder a common vision (Johnson et al., 2022; Lewandowski, 2018; Viaggi et al., 2021). The main issue is that, based on local characteristics, each country (but even each continent) pushes for a different interpretation of the bioeconomy (M'barek and Wesseler, 2023). Several papers have tried to aggregate the main visions and approaches of the bioeconomy (e.g. Bugge et al., 2016; Vivien et al., 2019; Wei et al., 2022). However, regardless of the vision taken, there are some elements that are transversal and accepted as intrinsic to the bioeconomy. One of these is innovation (Viaggi et al., 2021). Nevertheless, few studies have focused on the innovative processes that regulate the bioeconomy and, in most cases, they emphasized practical rather than theoretical implications (Bröring et al., 2020; Faulkner et al., 2024; Van Lancker et al., 2016). Among the few examples of theoretical advancement, one is given by Van Lancker et al. (2016), who identified five factors and outlined the key characteristics of the innovation process. The five factors, called by the Authors "contextual factors" and defined as factors that "impact the implementation and management of innovation development processes in the context of the bioeconomy" (Van Lancker et al., 2016: 61) are: *Radical Innovation* (RI), *Complex Knowledge Base* (CKB), *Fragmented Policy* (FP), *Challenging Commercialisation* (CC), and *Intense Cooperation* (IC). These elements are considered by the authors as the basis on which innovation development processes are established, but they do not describe the wholeness of the development processes. A methodological approach that allows to analyse, at the same time, the contextual factors and the development processes is that of Innovation Systems (IS). The IS perspective has its roots in the seminal works of Lundvall (1985; 1992), Nelson (1988; 1993) and Dosi (Dosi et al., 1988), who started to switch from a technology-based to a knowledge-based approach (Godin, 2006), replacing, in this way, the firm-centred vision of innovation with a systemic vision. The concept of IS is nowadays well-established (Rubach et al., 2017), with extensive literature on the topic (Pyka and Scharnhorst, 2009). In this framework, the socio-economic context and the relationships among organisations are considered key areas of research (Beckenbach et al., 2009; Garud et al., 2013). Consequently, with the inclusion of new economic and social variables within the innovation processes, the number of disciplines involved in the study of IS notably increased, moving the study of innovation under the domain of complexity science (Burmaoglu et al., 2019). Hence, in the last decades, following the varied backgrounds and the different research interests of the scholars, many different models to visualize innovation have been proposed.

One of the first models, widely accepted was outlined by Lundvall (1992), who introduced the concept of National Innovation Systems (NIS), shading the light on the impact of national institutions on the development of innovation processes (Russo and Rossi, 2009). Similarly, Cooke (1992) introduced the Regional Innovation Systems (RIS), underlining the local aspects of innovation and the importance of proximity may have (Boschma, 2004). Malerba (2002) focused on the Sectoral Systems of Innovation and Production. Merging the concepts of National and Sectoral Systems, Spielman and Birner (2008) developed a concept for a National Agricultural Innovation System, further developed by Klerkx et al. (2012) in the Agricultural Knowledge and Innovation System (AKIS). Instead, focusing on the typologies of actors that interact within the system, Etzkowitz and Leydesdorff (2000) identified three main categories, i.e. government, industry and academia, that establish mechanisms, more or less complex, of feedback and support for innovation. Referring to the double helix model of DNA, the Authors metaphorically called this three-actor model Triple Helix. Afterwards, the diffusion of this model in the scientific and political fields, brought scholars to consider new categories. Hence, Carayannis and Campbell, first added the media and culture, affirming the Quadruple Helix model (Carayannis and Campbell, 2009), and then, introducing the natural environment, proposed the Quintuple Helix (Carayannis and Campbell, 2010).

Despite the academic debate toward these models, these theories have been favourably received by policymakers (Aragón et al., 2012). Indeed, in the field of innovation policy, the systemic approach has found increasing success, following and proceeding in parallel with the scientific debate (Aragón et al., 2012; Enger, 2018; Protogerou et al., 2010b).

With this systematic literature review, we aim to understand what types of IS were adopted to describe the bioeconomy and, based on that, if there is scope for a unique Knowledge and Innovation System for the Bioeconomy (KISB) and which may be its peculiarities.

Indeed, despite the IS approach was somehow interpreted into the bioeconomy field, to the best of the Authors' knowledge, there are no specific literature reviews that assess the state of the art of IS framework in the bioeconomy. The originality of the present systematic literature review lies in its ability to assess, at the same time, the contextual factors of Van Lancker et al. (2016) and IS frameworks that mostly characterize the innovation literature in the bioeconomy. The final results highlight there is no unique IS for the bioeconomy – as it happens in other sectors, such as agriculture – and that the contextual factors of Van Lancker et al. seem to be deficient in describing the complexity of the current innovation context.

The paper is structured in the following way. In section 2, we present the material and methods adopted to carry out this review. In section 3, the results are reported in three main subsections, namely: general information about the papers; contextual factors identified; and categorization of the papers into four groups based on two dichotomies: collaborative-oriented vs. innovation-oriented and business-centred vs. policy-centred. These categories were then related to the contextual factors and the type of IS approach. In section 4 we discuss the results under the lens of a possible unique Knowledge and Innovation System for the Bioeconomy (KISB), similar to what happens in agriculture with the Agricultural Knowledge and Innovation System (AKIS). Finally, some conclusions are outlined in section 5.

2. Material and methods

The present paper is a systematic literature review, following the PRISMA (Preferred Reporting Items for SysteMAtic reviews) approach (Moher et al., 2009). This approach foresees several consequential steps. First, the identification of what to investigate (research question), where (sources, databases, etc.) and how to start (keywords, search strings, etc.). Second, the Authors determine specific preliminary criteria for including or excluding studies, for example, based on the typology of items (articles, reviews, book chapters, etc.) or only publications in a specific range of years. After that, a screening phase is carried out, reading titles and abstracts and identifying the match with the predetermined criteria. The final selection of the eligible articles is made by reading the full papers, rejecting the non-compliant ones that had passed the abstract-based selection. The last phase of the PRISMA approach is the qualitative review of the selected papers and the presentation of results.

Our research was conducted in July 2024. Based on the research question, we conducted our search in the Scopus database[1], using as a string: "(bioeconomy OR bio-based AND economy) AND innovation AND (system* OR network OR cluster)". This first query returned 209 documents (Fig. 1). Hence, we filtered by subject area, keeping "Social Sciences", "Business, Management and Accounting", "Economics, Econometrics and Finance", "Multidisciplinary." Based on the document type, we kept only articles and reviews. Then, we excluded Chinese as a language. Finally, according to our research question and the explained background, we selected only papers from 2017 to 2024. In this way, a subtotal of 56 documents was found.

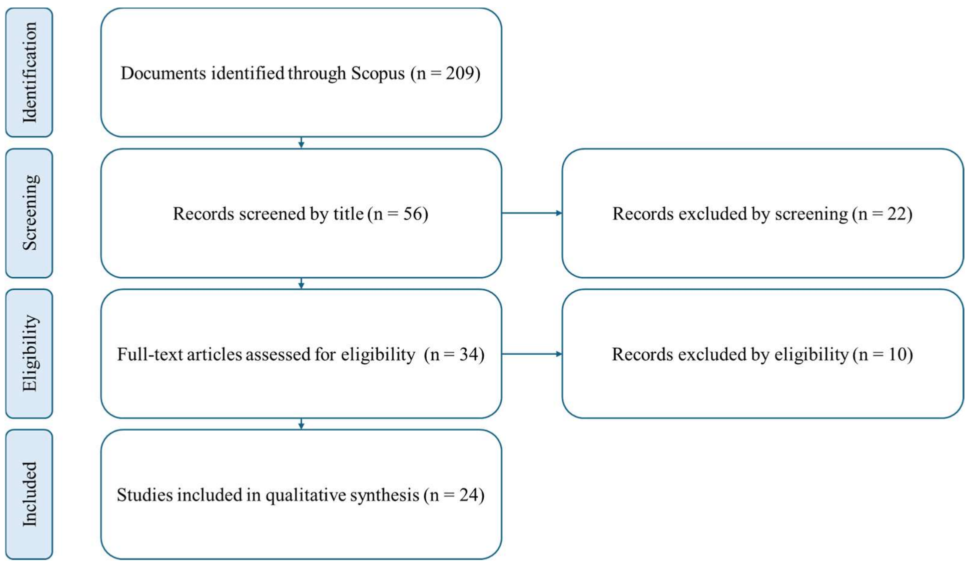


Figure 1. Overview of the process of document selection following the PRISMA method (Moher et al., 2009)

Based on the research question and the objective of this study, before starting to read titles, abstracts and, eventually, full papers, we defined some criteria:

- no papers with no focus/analysis of innovation processes;
- no papers on business opportunities/product-oriented (with no specific focuses on innovation systems);
- no papers on sustainability assessment;
- no papers on technology's impact on sustainability;
- no papers on circular economy with no reference to bioeconomy.

[1] Scopus, Elsevier B.V., https://www.scopus.com/, last seen 29/10/2024

After the exclusion of non-compliant papers based on abstracts or full-paper reading or because the document was not findable, we conducted our qualitative research on the final number of 24 papers.

The qualitative analysis was conducted through four main steps:

i. Identification of general information, namely: Nationality of the Institution(s) of the Author(s); Paper's Topic; Sector(s) or Subsector(s) of the Bioeconomy considered; Study reference Scale; Methodology applied; Innovation Systems Framework adopted; and whether Case Study or not (if yes, where);
ii. Identification of the contextual factors (see Tab. 1 for the considered criteria);
iii. Classification of the papers based on four categories, contrasting on the vertical axis the collaborative-oriented and innovation-oriented papers, while on the horizontal axis the business-centred and policy-centred ones (Fig. 2)
iv. Distribution of IS and contextual factors into the four previously identified groups.

In greater detail, the criteria listed in Tab. 1 are extrapolated by Van Lancker et al. (2016). Hence, to assign one factor to one paper, one or more than one of the criteria must be directly addressed in at least one of the sections of the paper. Thus, for example, to assign "challenging commercialisation", in at least one section there must be the identification of difficulties related to the commercialisation or adoption of bio-based products by other companies (B2B), by the final consumer (B2C) or both.

Table 1. Criteria for selecting contextual factors

Contextual factor	Criteria
Radical innovation	• Redesigned business models • Reconfigured supply chains • Setup new supply chains (new convergences of sectors)
Complex knowledge base	• Varieties of sciences and technologies
Intense cooperation	• Cooperation between different actors
Challenging commercialisation and adoption	• Challenging in B2B • Challenging in B2C

Policy schemes fragmented	• Different policy schemes • Different administrative levels • Legal limitations for biobased/biomass applications

The classification of papers based on the identified four categories represents an original framework developed by the Authors. This framework, taking up the original distinction between technology-based and knowledge-based approaches, broadens its scope and contrasts innovation-oriented papers with collaboration-oriented ones. Similarly, the contrast between the firm/business-centred research and policy-centred research was adopted to understand the main point of view of today's research on the topic of innovation in the bioeconomy. Hence, by placing these two contrasts on two axes, a name for each quadrant was identified depending on the two dimensions involved, namely: I) Network Policy (collaboration-oriented and policy-centred); II) Business Environment (collaboration-oriented and business-centred); III) Innovative Business (innovation-oriented and business-centred); and IV) Innovation Policy (innovation-oriented and policy-centred).

Through these groups, it was possible to better understand the differences in IS frameworks adoptions and, focusing on the innovation process, the factors that characterise the bioeconomy

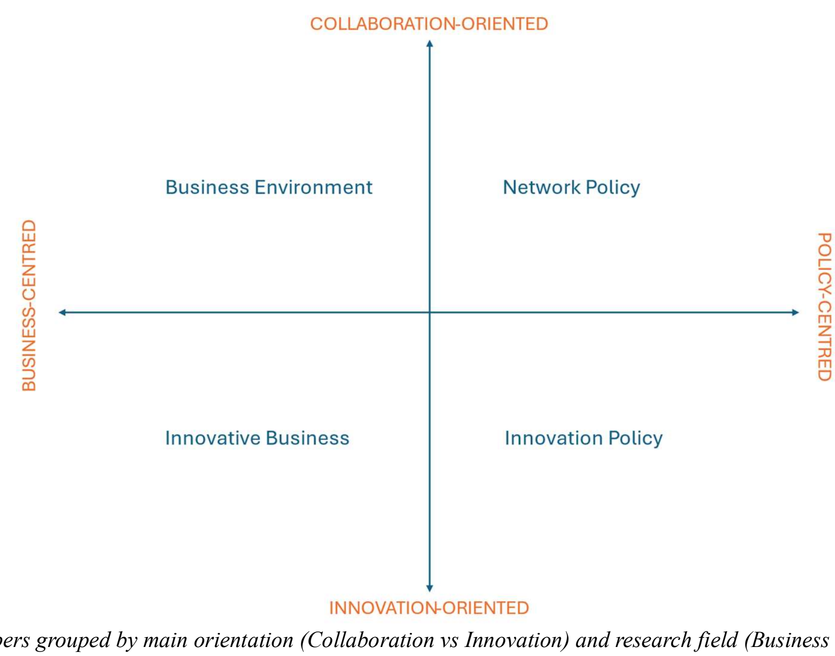


Figure 2. Papers grouped by main orientation (Collaboration vs Innovation) and research field (Business vs Policy)

context.

In the results section, after a general overview (subsection 3.1) and a description of the contextual factors identified (subsection 3.2), the four groups are used as a lens (subsection

3.3) to explore the relationship among them and IS frameworks adopted by scholars (subsubsection 3.3.1) and among them and contextual factors emerging from the papers (subsubsection 3.3.2).

3. Results

3.1. General overview

Considering the geographical location of the authors' institutes, Europe has the most prominent role, with twenty papers out of twenty-four that involve only European institutes and two papers that involve European and non-European entities (however, in both cases the first Author belongs to a European country). Only in two cases, the Authors are not European, i.e. in one case from Brazil and in the other from Brazil and Australia. At the country-level, the most represented country is Germany with 10 contributions, followed by Finland with 5 papers. In terms of approach, the large majority of papers are applied research with eighteen of them that consider a case study. Lovrić et al. (2020) and Bueno et al. (2022) stand out as the sole studies where the Authors conducted practical research without analysing a specific case. Among the remaining three, two are literature reviews (Lang et al., 2023; Salvador et al., 2021) and one is a commentary (Losacker et al., 2023). Moreover, in terms of methodology, the most used methods are qualitative ones, namely focus groups, semi-structured interviews and questionnaires. Other methods comprise analysis of research projects, social network analysis, system dynamics and innovation systems approaches.

Looking at the reference scale, the National perspective is the most addressed, with twelve papers, followed by the Global perspective with five papers. Other scales, such as Regional or Continental are addressed as well, but respectively in three and two cases. The Municipal and mixed scale (i.e. National plus Regional) are referenced in one article each.

Regarding the bioeconomy sectors or subsectors considered in the papers, the main approach is that of considering the bioeconomy in its general complexity (Bogner and Dahlke, 2022; Chmielińskii and Wieliczko, 2022; Hurtado and Berbel, 2023; Lang et al., 2023; Losacker et al., 2023; Salvador et al., 2021), followed by forestry or wood-based bioeconomy (D'Amato et al., 2022; Giurca and Metz, 2018; Laasonen, 2023; Lovrić et al., 2020) and green chemistry or biofibre (Alfano et al., 2023; Kamath et al., 2023; Korhonen et al., 2020; Loos et al., 2018). Less common is the propensity to consider various sectors at the same time (Pyka, 2017; Scheiterle et al., 2018; Torre et al., 2023).

3.2. Contextual factors identified

Identifying the contextual factors as outlined by Van Lancker et al. (2016), we found that the most common one is i*ntensive cooperation*, a concept that emerged in almost all the papers considered (Fig. 3). Even the *complex knowledge base* is a widespread factor, discussed or addressed in almost 75% of papers. *Radical innovation* is covered in just over half of the papers, while slightly less than half examines the *challenging commercialisation*. Finally, the least explored factor is that of *fragmented policy*, with less than a quarter of the articles focusing on it.

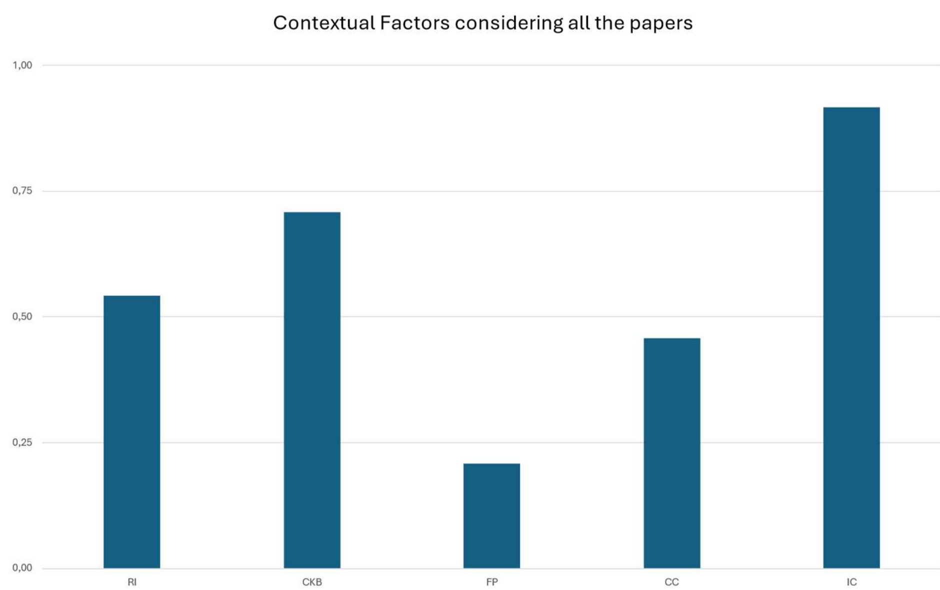


Figure 3. Contextual factors identified, in relative terms, in the papers considered. Legend: RI = Radical Innovations; CKB = Complex Knowledge Base; CC = Challenging Commercialisation; IC = Intense Cooperation

However, we also found some elements or critiques that, moving away from Van Lancker's definitions, may deepen the knowledge of the innovative context in the bioeconomy. These aspects are further discussed in the following sections.

3.2.1. Intense cooperation

This factor is the most addressed by different Authors and no changes or modifications are reported in the concept: The idea of different actors that cooperate in the bioeconomy innovation processes is widely perceived as one of the main characteristics of the sector. Furthermore, this result may suggest that, nowadays, the multi-stakeholder approach is perceived as more distinctive than the multidisciplinary approach (see next section on CKB). Bogner and Dahlke (2022) underline the importance of empowering and educating heterogeneous actors (different in age, gender, social and educational background) to stay actively engaged and participate in the innovation process with an *ex-ante* approach rather than an *ex-post* acceptance approach.

However, D'Amato et al. (2022) report the difficulty in the Finnish Wood-based Bioeconomy (WBE) to engage in cross-sectoral and cross-discipline knowledge co-production, pointing out the lack of collaborative skills, and organisational differences. Similarly, Laasonen (2023) highlights the positive effects of well-developed relational capabilities, and, on the other hand, the negative impact of their lack on the whole innovation system. A solution to these problems is pointed out by Alfano et al. (2023), which observe the role of clusters in aggregating different actors, that could act as intermediaries and help to overcome the collaboration issues.

Donner and de Vries (2023) underline the importance of small-scale initiatives in the circular bioeconomy business models and the role of geographical embeddedness and the relational proximity of actors. In this vein, the local-based innovation and the importance of local actors are pointed out also by Torre et al. (2023), in their study on rural development, and by Taffuri et al. (2021) in their paper on the urban management of bio-waste. In the former, the Authors underline the effectiveness of knowledge exchange that the multi-level coordination (from national to local) made and the importance of long-term research programs to keep local actors embedded and aware of how collaborative research works. In the latter, the Authors highlight the complex web of stakeholders involved in the CBE paradigm even at the municipality level.

However, in some cases, the difference between IC and CKB is blurred. This is the case with some emerging concepts, such as *living labs*, where, in the case of Losacker et al. (2023), they are interpreted as places of interdisciplinary interaction, while in the case of Donner and de Vries (2023), they are seen, more in general, as "joint systemic co-creation approaches" (Donner and de Vries, 2023: 13). However, in both cases, the living labs are cited in the "future research" section, underlining the absence of studies in the direction of stable and, more or less, informal collaborations in the bioeconomy.

3.2.2. Complex knowledge base

Although the complex knowledge base of the bioeconomy is widely recognised (e.g. Bogner and Dahlke, 2022; Loos et al., 2018; Scheiterle et al., 2018) and still remains one of the peculiarities of this sector, the papers considered a greater tendency to identify this concept with the terms *multi-* or *interdisciplinarity* emerges (see for example Chmielińskii and Wieliczko, 2022; Orozco and Grundmann, 2022; Torre et al., 2023). Chmielińskii and Wieliczko (2022) identify interdisciplinary as a way to catch the overall complexity of the bioeconomy and render a holistic vision. This complexity is also pointed out when addressing the issue of lacking knowledge or capacity. For example, considering the case of Loos et al. (2018), they point out the lack capacity of the national system for the implementation of a biomass-based value web that involves several professionals and different know-how. Similarly, Drejerska et al. (2020), the Authors point out the lack of managerial know-how in implementing circular biowaste management. These two examples demonstrate how, through a systemic analysis, factors emerge that are difficult to identify in a mere technology-oriented or based on a linear approach. In this vein, in recent years some connected concepts are often addressed together with knowledge base, such as skills (e.g. Alfano et al., 2023) or education (e.g. Chmielińskii and Wieliczko, 2022; Hurtado and Berbel, 2023).

3.2.3. Radical innovation

In their paper, Van Lancker et al. (2016) state that "although some existing products and processes may only need some incremental, gradual innovations, the transition [towards the bioeconomy] will mainly require diverse, radically new and disruptive innovations" (Van Lancker et al., 2016: 61). This contrast between a more radical and a more moderate approach to innovation often emerges in the papers analysed, although with varying terminology. For example, Taffuri et al. (2021) apply an "improvement" perspective, by introducing bio-waste valorisation possibilities within the current Metropolitan Solid Waste Management System of a city in northern Italy (i.e. Turin). Kamath et al. (2023) contrast the "path-modernisation" with the "path-creation." The range of different types of innovation is also part of the work of Orozco and Grundmann (2022), who outline the variation from incremental to disruptive innovations. This latter concept, in particular, gains a wide consensus. Indeed, also Lovrić et al. (2020), Bueno et al. (2022), and Losacker et al. (2023) use the term "disruptive" to identify the most radical innovations. However, it is important to underline that, although both radical and disruptive are concepts that imply a deep change, they slightly differ from each other. In fact, the concept of disruptive innovation implies a modification of market dynamics through novel business models and low-end market capture, while the concept of radical innovation is more related to groundbreaking technological advancements (completely new ideas or products) that cause significant organizational transformations within companies (Hopp et al., 2018).

Closer to the concept of "radical" is the concept of "transformative knowledge" explored by Bogner and Dahlke (2022) in their paper on the German bioeconomy policy. Indeed, also in this case the main focus is on the policy side. However, the transition from "innovation" to "knowledge" implies a broadening of the overall vision of the phenomenon, with further dimensions analysed, such as "system knowledge", "normative knowledge", "techno-economic knowledge" and "transformative knowledge." Furthermore, this approach reconnects the concept of RI with that of CKB.

In the papers analysed, radical innovation is also seen from the business side, as emerged with the concept of disruptive innovation. In this field, Giurca and Metz (2018) consider the market formation, while Lazarevic et al. (2020) consider a niche market. Lang et al. (2023) underline the important connection between transformative innovation and the involvement of consumers in bio-based business models. Hence, even from a more business-oriented perspective, the importance of a systemic vision may help (see for e.g. the business model canvas developed by Salvador et al., 2021).

3.2.4. Challenging commercialisation

The aspect of how challenging is the commercialisation of innovations both for B2B and B2C is addressed both directly and indirectly in the papers considered. For example, Bogner and Dahlke (2022) indirectly address the problem by considering the projects that took place in Germany, documenting a strong focus on the market acceptance of products and processes related to the bioeconomy.

Chmielińskii and Wieliczko (2022) underline the difficulties that findings from research encounter in commercialisation. However, in their statement, the Authors do not only imply the importance of convincing potential buyers, but they also call for engaging stakeholders across business, scientific, governmental, and consumer sectors and for better using education at all levels. In this way, they mix business and policy recommendations to systematically enhance the national bioeconomy.

Losacker (2023), more in line with van Lancker, refer to "technology legitimization." However, this concept encompasses social acceptability and broadens the discussion to a legal aspect as well. Moreover, Lang et al. (2023) discuss the active role of consumers in influencing business models, while, Korhonen et al. 2020 face the problem of the performativity of biomaterials compared to other materials and the importance of this issue in health risks for humans and the environment, stating that in some cases "it makes sense to use the most durable materials available, regardless of the material's environmental performance."

In other words, due to the large number of ethical challenges that the innovation processes have to face in the bioeconomy, it seems that the specific focus on the commercialisation side limits the capacity of this factor to describe the bioeconomy innovation context.

3.2.5. Fragmented policy

Due to the sectors convergence that characterise the bioeconomy (Lazarevic et al., 2020) still the optimisation of policies represents an issue (e.g. Korhonen et al., 2020). Anyhow, in addition to the low rate of papers that directly address this factor, we found that three policy issues are perceived as more compelling. First, a need for targeted policy interventions (Giurca and Metz, 2018), that implement the nowadays well-established and structured strategies for the bioeconomy (Bogner and Dahlke, 2022; Hurtado and Berbel, 2023). This is the case of the EU, where in addition to the strategy pointed out by the Commission (EC, 2018), almost all MS developed their own strategy (Joint Research Centre European Commission, 2022). An example of successful policy intervention is outlined by Lovrić et al. (2020) in the case of Finnish WBE. In this context, the incremental change from a forestry to a wood-based bioeconomy policy has been perceived as a success for the stakeholders involved.

The second policy issue is the lack of specific funds, considered under several aspects: D'Amato et al. (2022) indicate the limited funding opportunities for cooperating in cross-sectoral initiatives as one of the main tension factors in the Finnish WBE; in (Laasonen, 2023), the Finnish regional and business development agencies and the research and education organisations point out the need for external funding for R&D activities with other partners as one of the element to keep vital collaborations; Alfano et al. (2023) show that only a small percentage of the green investments made by Italian firms belonging to a *biocluster* is supported by public funds, with the highest percentage of investments financed by venture capital or traditional bank financing.

The third policy issue is a lack of legal frameworks for new technologies or services in the field of the bioeconomy, as emerged in the challenging commercialisation (see specific section).

Based on these findings, the fragmented policy factor does not describe the overall complexity of policy frameworks in the bioeconomy.

3.3. Papers classification

The highest number of papers belongs to the category of *Business environment*, with nine papers, followed by *Network policy* with eight (Fig. 4). The *Innovation policy* group and

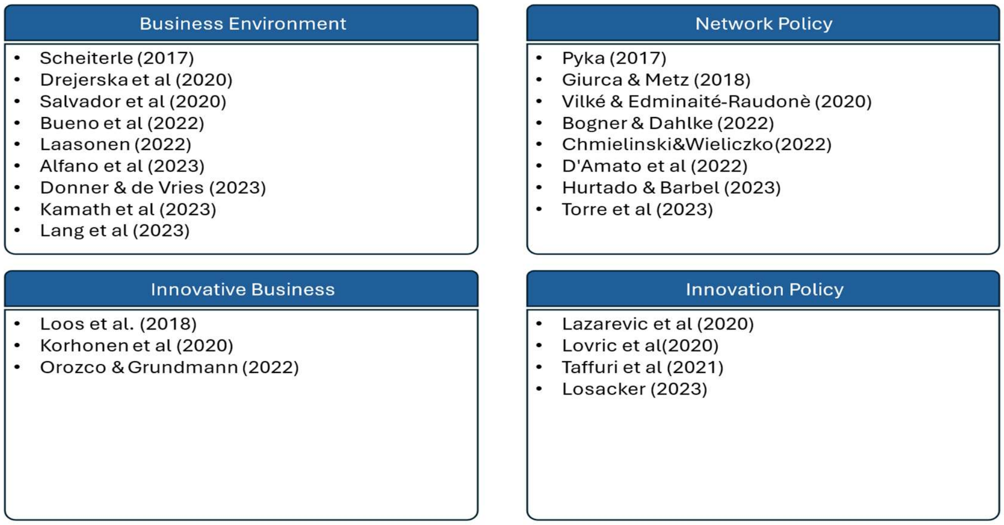


Figure 4. The selected papers classified based on the four different groups

Innovative business follow with, respectively, four and three papers. Hence, looking at the four dimensions considered, we found a higher number of papers directly focused on collaboration (seventeen papers) rather than innovation (seven articles), while between business and policy-centred papers we found a balance of twelve papers each.

3.3.1. Groups and Innovation Systems

Although the identification of the Innovation Systems (IS) Framework for each category did not yield significant results, some remarks can be made. In general, there is a wide range of frameworks adopted by different Authors. In the first period (2017-2020) we notice a greater diffusion of innovation systems most known in the literature on innovation, i.e. National Innovation Systems (NIS), Regional Innovation Systems (RIS) and Technology Innovation Systems (TIS); while in a second phase (2020-2023) we notice a decline in these systems in favour of other frameworks, such as knowledge-based systems (e.g. Bogner and Dahlke, 2022; D'Amato et al., 2022) or stakeholders analysis (Taffuri et al., 2021). More in detail, looking at the several IS frameworks, the NIS was more adopted in the business-centred (Loos et al., 2018; Scheiterle et al., 2018), TIS in policy-centred papers (Giurca and Metz, 2018; Lazarevic et al., 2020) and RIS in collaboration-oriented studies (Hurtado and Berbel, 2023; Kamath et al., 2023). No specific IS are adopted on the innovation-oriented side, but only in this field can we see a tendency to focus on the concept of stakeholders, through stakeholder (Taffuri et al., 2021) or multi-stakeholder analysis (Korhonen et al., 2020) frameworks.

Delving into the specific groups, no remarks emerge from the *Innovative Business* and *Innovation Policy*, while in the case of *Business Environment* and *Network Policy* we notice two peculiarities. In the *Business Environment* case, there is a tendency to focus with greater detail on sub-groups of the whole IS, adopting concepts like *networks* (Bueno et al, 2022) or *bioclusters* (Alfano et al., 2023; Kamath et al., 2023). Instead, the *Network Policy* group's peculiarity is the broadening of the vision towards a systemic approach of both innovation and knowledge. Indeed, only in this group, the concept of *knowledge* is used as a discriminant. For example, Bogner and Dahlke (2022) use different knowledge (i.e. transformative knowledge, system knowledge, normative knowledge and techno-economic knowledge) to identify the different types of policies, while D'Amato et al (2022) discuss the *Knowledge co-production* within the Finnish WBE. Finally, Chmielińskii and Wieliczko (2022) adopt the framework of *Innovation and Knowledge Systems,* which can be linked to the broad literature on Knowledge and Innovation Systems (KIS).

3.3.2. Groups and Contextual Factors

Apart from *Intense cooperation,* which is the most addressed factor in each category, other contextual factors are mostly in line with the IS frameworks outlined above (Fig. 5).

Figure 5. Contextual factors identified, in relative terms, in the four groups of papers considered

Indeed, *Complex Knowledge Base* is the most represented factor in collaborative-oriented research, in particular in the *Network Policy* group, where it is at the same level of *Intense Cooperation* and this confirms the aforementioned interest in the concept of knowledge in this group. Instead, in innovation-oriented studies, *Radical Innovation* has a prominent role in the *Innovation Policy* group, while in *Innovative Business,* it shares the same rate with *Complex Knowledge Base* and *Challenging Commercialisation*. In particular, this latter factor characterises innovation-oriented research more than collaborative-oriented one. Not surprisingly, the *Fragmented Policy* is addressed almost only in the policy-centred papers, given the very low representation in the business-centred side (more specifically, only in the *Business Environment* group).

4. Discussion

The variety of frameworks applied to describe the IS in the bioeconomy hinders the identification of a singular and unified framework. While this abundance of methodologies allows for the analysis of innovative systems from multiple perspectives, moving toward a unique, widely accepted IS may provide some advantages. An example might be provided by one of the most known and successful IS, the Agricultural Knowledge and Innovation System (AKIS) (Germundsson and Norrman, 2023; Ingram and Maye, 2020; Klerkx and Begemann, 2020). Rooted in the studies of Röling (Röling, 1988; Röling and Wagemakers, 1998), Arnold and Bell (2001) and Spielman and Birner (2008), the AKIS framework was supported by various supranational bodies, such as OECD (2012), World Bank (Julio and German, 2001), and EU (EU-SCAR, 2012, 2015, 2019). The latter, in particular, after a gradual introduction of this framework as a policy tool (EU-SCAR, 2012, 2015, 2019), decided to highlight the role of the AKIS introducing it in the Common Agricultural Policy (CAP) 2023-2027 (European Parliament and the Council of the European Union, 2021) and asking MS to assess how the different actors that compose the national AKIS interact and support the production and use of knowledge and innovation (EU CAP Network, 2023). Although this concept is still perceived by many political and administrative decision-makers as vague and there is difficulty in fully understanding it (Knierim and Birke, 2023), a well-functioning AKIS is seen as a way to strength the impact of funds and policy interventions, avoiding duplications and saving costs (EU-SCAR, 2019). In this sense, a unique IS for the bioeconomy, as the Knowledge and Innovation System for the Bioeconomy (KISB) proposed by Esposti (2012), might represent a way to determine coherent fund allocations and policy interventions, fulfilling the requests in this direction that we found in this review. More in general, this vision might overcome the fragmented and sectorial policy framework that persists in the current bioeconomy. Furthermore, such a tool might be useful not only for policymakers but also for all the other components of the system (Knierim and Birke, 2023). For example, extension services and firms may find interesting niche markets, while research institutes or universities may find new streams of research.

Nevertheless, it is fundamental to keep in mind that some profound differences persist between AKIS and KISB. First, due to its modernizing mission and its focus on increasing the sustainability of the rural world, AKIS core components are *practitioners*, i.e. farmers, foresters, fishers, and food processors (Knierim and Birke, 2023), seen as implementers of practices that have a direct effect on the environment (Schmidt et al., 2022). Instead, as we saw in our findings, the current bioeconomy implies a vision that even overcomes Van Lancker's *Complex Knowledge Base*, incorporating knowledge-intensive, high-tech and high organisational and implementation skills. In addition, as we found in this review, the active role of primary producers in the innovation processes of KISB is little explored and, therefore, considered marginal.

Second, the current AKIS literature and the actual policy implementation are mainly focused on extension services (Amerani et al., 2024; Knierim and Birke, 2023), especially in their role of *innovation brokers*. Based on the papers we considered, this aspect cannot be focal of KISB nowadays because of the current lack of specific research on advisory services in the bioeconomy innovation process. Indeed, to date, research is mainly based on the helix approaches (triple, quadruple and rarely quintuple), considering only the main actors (e.g. business, academia and policymakers) and not connection figures. In this sense, it is not clear whether firms are directly linked to research institutions – with no need for intermediaries –, or if the high-tech innovations in the bioeconomy sector have equipped firms' in-house R&D with the necessary skills to avoid external advisory services.

Third, AKIS can be considered part of KISB. Anyhow, the study of the interactions between these two systems is still in its infancy (Chmielińskii and Wieliczko, 2022; Vilkė and Gedminaitė-Raudonė, 2020), with several aspects to be further explored, such as the importance of the national AKIS within a national KISB or the interactions between AKIS and the other IS to form KISB.

Fourth, the different roles and importance of consumers. On this aspect, the KISB perspective gives a complexity that the contextual factors identified by Van Lancker et al. (2016) do not catch completely. Indeed, both the *Challenging Commercialisation* and *Intense Cooperation* do not focus directly on the challenging aspects that characterise the whole innovation process in the bioeconomy. For example, sustainability and circularity concepts are nowadays considered paramount for the bioeconomy (D'Amato and Korhonen, 2021; Drejerska et al., 2020; Lang et al., 2023; Salvador et al., 2021). In this vein, the use of biological resources inevitably raises ethical dilemmas (Viaggi, 2018; Viaggi et al., 2021). An example of this is the possible contrast between food production and the production of other crops (e.g. for biofibres or bioenergy), which is known as the *competing dilemma* (Asada et al., 2020). Another example is the well-known debate around genetic modifications (Hartung and Schiemann, 2014; Jacobsen et al., 2013; Weisenfeld et al., 2023), which strongly affects the biotechnological component of the bioeconomy (Wei et al., 2022). These two examples give an idea of the importance of stakeholders' engagement in the innovation development, in particular consumers, citizens and end-users. This could be also the reason why the *Intense cooperation* is the most accepted contextual factor as emerged from our results. However, still, many aspects of this cooperation are unclear. Just to cite some unanswered questions: What are, nowadays, the main drivers? What bottom-up mechanisms characterize cooperation for innovation in the bioeconomy? Is this cooperation market-pushed or policy-driven? How does consumer behaviour influence the transition towards new bio-products? What is the role and how do local actors contribute to the implementation of new bioeconomic value chains?

This latter aspect raises questions regarding the dispute that we found among researchers around the issue of *Radical innovation*. As we saw, researchers are mainly divided between a more moderate and incremental vision of how to implement the bioeconomy (e.g. Taffuri et al., 2021) and a more intense and radical one (e.g. Bogner and Dahlke, 2022). Although opposed, from a KISB perspective these two positions can be reconciled. Indeed, the path-modernisation and the path-creation (Kamath et al., 2023) are both part of the knowledge and innovation processes, with their own actors, mechanisms and characterising factors. Hence, both these two streams of research can contribute to a better understanding of the complexity of innovation in the bioeconomy.

Moreover, all the underlined aspects can benefit both from business-centred and policy-centred research. The business-centred research can largely contribute, through its attitude toward the *stakeholder* concept (Taffuri et al., 2021; Korhonen et al., 2020) and the sub-systems description (*bioclusters*, *networks,* etc.) (Alfano et al. 2023; Bueno et al., 2022; Kamath et al., 2023). Even in this case, the AKIS literature may provide a framework to explore many of the aspects underlined in the previous questions: microAKIS (Sutherland et al., 2023). This framework focuses on the innovation subset of the whole AKIS that operates at the farm's individual level or, using the description provided by Sutherland et al. Sutherland et al. (2022), "the sources of knowledge that farmers personally develop to pursue innovations and to

manage their farms” (Sutherland et al., 2022: 40). The possibility of exploring the microKISB opens the room to further analysis in the business research, such as new business models, business environment and market creation with a firm-centred systemic perspective. It also allows for considerations in the field of policy-centred research. This stream of research can benefit from the microKISB perspective to draw conclusions about the aforementioned role of local actors. Furthermore, the lack of analysis of the mechanisms of knowledge transmission in the whole system and the pressing requests to combine policy interventions and funds allocations – short and medium-term perspective – with bioeconomy strategies – long-term perspective – also calls into question the wider KISB perspective (more national-oriented). An example is provided by the emerging issue of education and training in the bioeconomy (Chmielińskii and Wieliczko, 2022; Hurtado and Berbel, 2023; Laasonen, 2023), which represents an interesting point of view for policy considerations to optimize the system's ability to absorb or generate knowledge (Buchmann and Pyka, 2015; Y Kurtsal et al., 2024). In this sense, the policy-centred research may merge *Intense cooperation* with *Fragmented policy*, showing that the system perspective can, at the same time, explain the mechanisms and propose pathways, as occurs in the study by Hurtado and Berbel (2023).
Hence, both KISB and microKISB can contribute to answering the unanswered questions, combining different levels of research (national, regional, local, etc.), and, at the same time, explaining the mechanisms that regulate all the contextual factors, taken both individually and together.

Finally, considering the least adopted contextual factors, i.e. CC and FP, we saw that in both cases they limited in their ability to describe the overall complexity of the innovation development processes in the bioeconomy. This may partly explain why they are less explored by the papers considered. Hence, our suggestion is to enlarge both the concepts. The CC should become *commercialisation dilemmas* (or e*thical and market challenges in commercialisation*), extending the concept to the ethical aspects of the commercialisation of bioproducts. Instead, the FP should become *complex policy and legal framework*, underlining the large mix of different levels of policies and norms that characterize the bioeconomy.

However, this study has some limitations. Excluding the linear approach of innovation from research criteria, part of the innovation processes are excluded. In this sense, future research may include this approach to enlarge the vision of the innovation processes. Similarly, future research may include contributions provided before 2017, the year we chose as the lower limit of our study. Indeed, earlier studies from the Infancy and Exploring stages of the bioeconomy literature may provide further insights for theoretical advancements in knowledge creation and innovation development in the field of bioeconomy.

5. Conclusions

In this study, we conducted a systematic literature review to explore the application of the IS framework in the field of the bioeconomy. In particular, the aim was to identify the scope and the characteristics for a unique KISB. We found that a unique framework is nowadays missed. Several approaches were adopted, but rarely with the aim of a theoretical advancement for the whole bioeconomy literature. Indeed, often the approach adopted was the one best fitting for the purpose of the research, with rare examples of the opposite, i.e. to seek for a holistic framework that describes innovation processes within the bioeconomy.

However, one of the main results of this study is the possibility to apply and benefit of a unique KISB. In fact, the mechanisms and dynamics examined in this study go further beyond the simple technology-oriented or linear approach to innovation, as we saw considering the complex amount of skills and professionals needed to implement bioeconomy processes (e.g. in biowaste management). Hence, based on the examined papers, some peculiarities should characterise the KISB. First, based on the result that IC and CKB are the most common factors, we outlined how multi-actor approach and multidisciplinary are fundamental in the bioeconomy innovation processes and it is not possible to avoid this in the KISB. Second, we found a more intense stream of research in the field of collaborations rather than innovations. In this sense, the efforts of made by scholars can strongly contribute to outline a KISB, for example including the analysis of knowledge development. Third, even if less represented, the innovation-oriented papers add insights in terms of challenging aspects of commercialisation in the bioeconomy and their attitude towards the concept of stakeholder. Finally, we found that there is a wide scope for KISB and the connected concept of microKISB (i.e. the innovation subset of the whole KISB that operates at the organisation's individual level) in both business-centred and policy-centred research. Therefore, KISB and microKISB must be designed in such a way that they can represent an interesting and useful tool for all the actors involved in the bioeconomy innovation process, mainly policymakers, business actors, and researchers.

Furthermore, similarly to AKIS in the current CAP, even KISB may become a policy objective transversal to all the sectors involved. This would make all the operators aware of the actors involved in the knowledge and innovation system, and, on the other hand, the bioeconomy would benefit of would benefit from a more systemic promotion and sharing of knowledge.

Moreover, looking at the contextual factors of Van Lancker et al. (2017), our suggestion is to enlarge the two less represented concepts, i.e. *challenging commercialization* (CC) and fragmented *policy* (FP). The CC should become *commercialisation dilemmas* (or e*thical and market challenges in commercialisation*), extending the concept to the ethical aspects of the commercialisation of bioproducts. Instead, the FP should become *complex policy and legal framework*, underlining the large mix of different levels of policies and norms that characterize the bioeconomy.

Chapter 3 - The role of Horizon projects for Knowledge and Innovation in the Italian bioeconomy - A Social Network Analysis

1. Introduction

In the field of innovation science, innovation processes have been understood in different ways over time. Indeed, starting in the 80s, several frameworks that explain how innovation is produced within a defined context emerged. To date, the state of the art recognizes innovation as part of a complex process within a complex system (Fugeray-Scarbel et al., 2023; Protogerou et al., 2010b), allocating research on innovation within the wide framework of complexity science (Burmaoglu et al., 2019). In this complex system, heterogeneous actors interact, cooperate, collaborate and communicate, directly and indirectly, to collect, process and produce knowledge (Russo and Rossi, 2009). Among the various actions that can be undertaken, collaborative research is seen as one of the directions for innovation policies (Protogerou et al., 2010b). Within the Framework Programmes for Research and Innovation of the European Union, the importance of collaborative research grew steadily (Balland et al., 2019), with several incentives for inter- and multidisciplinary approaches. In this context, the bioeconomy, which is intersectoral by definition (EC, 2018) and is a relatively young sector for the European economy (EC, 2012), might represent the ideal sector in which network policies are put into practice by European policymakers to foster the entire knowledge and innovation system. Moreover, the bioeconomy, as the result of the convergence of pre-existing systems of innovation (Giurca and Metz, 2018), may incur system failures (Hellsmark et al., 2016; Stöber et al., 2023) that hinder the true potential of the sector. When this occurs, the intervention of policymakers is advocated by evolutionary researchers (Aragón et al., 2012; Pyka and Prettner, 2018). Despite this critical aspect, few studies have focused on the impact of European research and innovation policies on the bioeconomy network (Novotni et al., 2022; Van Lancker et al., 2016; Weiss et al., 2023), considering mainly individual perspectives (e.g. Weiss et al., 2023, explore some innovation cases, focusing on the system around these innovators) or sectorial networks (e.g. Novotni et al., 2022, explores the wood industry projects). To the Authors' knowledge, no research has been conducted on which national network emerges considering FPs' participants.

To explore this promising perspective, this study focuses on a specific national context, Italy, taking into account all the organizations that participated in projects about bioeconomy since the first European Bioeconomy Strategy, came out more than ten years ago (EC, 2012). More in detail, the main objective of this research is to investigate the role of EU Research and Innovation funds in structuring the Italian network of actors working on research and innovation in the bioeconomy. To achieve this objective, the study was conducted through a Social Network Analysis (SNA), based on publicly available data from CORDIS, the official EU database on research projects and their participants.

In this paper, we aim to contribute to a better understanding of the Italian bioeconomy empirically, structuring an initial and preliminary map of the Italian bioeconomy system to provide valuable elements for policy considerations, especially regarding knowledge and innovation policies.

The paper is structured as follows. After an introduction to the innovation policies and the important role of innovation networks in the EU in Section 2, Section 3 explains the methodology applied in this research together with the data used. The results are shown in Section 5, followed by the discussion part in Section 6. Finally, conclusions are outlined in Section 6.

2. Innovation policies and innovation networks in EU

In the field of innovation policy, from the 80s to date, the systemic approach has found increasing success, following and proceeding in parallel with the scientific debate around Innovation Systems (IS) (Aragón et al., 2012; Çetinkaya and Erdil, 2016; Enger, 2018; Protogerou et al., 2010b). In the European Union, this approach was gradually introduced, starting from 1984, when the first Common research and innovation policy was introduced (Enger, 2018; Protogerou et al., 2010b), with the name Framework Programme (FP). Financial assistance was granted by this research program to facilitate collaborative, pre-competitive research projects among businesses, academic institutions, and research centres (Protogerou et al., 2010a). However, in the beginning, such collaborations were seen merely as "temporary response to shocks" (Saviotti, 2009: 31) and therefore, the first FPs cannot be considered network-oriented but rather supply- or technology-oriented policies (Protogerou et al., 2010b). Nevertheless, in the 90s, the theoretical affirmation of the aforementioned systemic models, pushed the European innovation policy toward an increased interest in collaborative research, seen as valuable *per se* and not as a simple means anymore (Fugeray-Scarbel et al., 2023). In this vein, the network policies became an integral part of the European innovation policy

(Balland et al., 2019; Enger, 2018). The reasons for this choice are manifold. First, network policies have positive political effects, such as helping to avoid fragmentation of research, allowing for better cost-effective research with less duplication, or facilitating inter-organisational knowledge spillovers (Balland et al., 2019). Second, they have repercussions on the feeling of European "togetherness" of the organizations that take part in the projects (Protogerou et al., 2010a). Finally, from the evolutionary perspective, network policies and government intervention find justification when system failures occur (Aragón et al., 2012).

Nevertheless, some critiques have been moved to such kind of policies. (Makkonen and Mitze, 2016) warn against the risk of *oligarchic networks*, and Enger (2018) explores this risk through the so-called "Matthew effect" (Merton, 1968), i.e. the rich get richer and the poor get poorer. Another issue concerning networks is the *lock-in* situation (Boschma, 2004): due to an excess of proximity among firms, the network as a whole may exhibit a reluctance to change (Çetinkaya and Erdil, 2016) or to follow promising areas of innovation and research (Protogerou et al., 2010a). In particular, the main critique for lock-in situations is the poor ability to interact with other networks or systems (Aragón et al., 2012).

Moreover, Bauer et al. (2018) warn against the limited degree of novelty that intra-industry collaborations may achieve. Finally, concerns were expressed regarding the effectiveness of top-down organisation of policy initiatives, such as interdisciplinary research (Buchmann and Pyka, 2015). In this sense, Rosenberg (2009) strongly criticized interdisciplinary research when it comes from the planning of policymakers or administrators, pointing out the poor success of the projects thus designed.

The recognized diffuse and intersectoral nature of the bioeconomy (Purkus et al., 2018) and the focal importance of innovation within this sector (D.; Viaggi et al., 2021) are elements that bring bioeconomy closer to the literature on innovation networks and policies. However, it is still difficult to delineate a bioeconomy innovation literature, due to the limited number of studies that focused on innovation networks and innovation policies in the bioeconomy (Van Lancker et al., 2016), as we found in the previous dedicated literature review. In particular, although the large majority of the publications on the topic are developed by European researchers or consider case studies in the EU, none of them considers the FPs to analyse their impact on the bioeconomy.

3. Methodology and Data

3.1. Social Network Analysis

A network is a way to think and understand the relationships among the entities that constitute a social system (Borgatti et al., 2018). Although the entities can be any subjects (even concepts) that are finite in number and unequivocally identifiable (Butts, 2008), in *social* networks it is expected that each entity represents an active agent, i.e. individuals or organisations (Borgatti et al., 2009). These entities are generally called actors or nodes by social network researchers (Borgatti et al., 2018). However, actors can have a multitude of different relations with each other. These relations are usually called ties or links and their definition criteria are crucial as they determine the formation of unique networks, even if they involve the same actors (Borgatti et al., 2018). The study of the interactions between network members, the role of these members within the network, the structure itself of the network and the social structures within the social context are the main objects of the Social Network Analysis (SNA) (Batura, 2012; Saqr and Montero, 2020; Sekerci and Alp, 2023). The mathematical substrate for SNA methodology is graph theory (Vicsek et al., 2016), which provides a wide range of concepts and methods for the visualisation, measurement and analysis of social networks (Butts, 2008; Scott, 2012). The main advantage of this body of theories and methods is its intrinsic flexibility which opens up the opportunity for versatility across various domains (Butts, 2008; Sekerci and Alp, 2023). Indeed, starting from psychology and sociology (Lewis, 2009), SNA was then applied in many fields, such as engineering, economics, and political science, just to cite some.

In this study, we decided to take advantage of the SNA methodology to outline and analyse the Italian knowledge and innovation network for the bioeconomy. More in detail, this methodology allows for better understanding in terms of actors characteristics, relationships among them, and dynamics within the network over time.

To examine the individual location of each actor and define which actors cover the most important positions in the graph, the centrality metric was adopted (Sekerci and Alp, 2023). This metric explores the node-related properties (López Hernández and Schanz, 2019) through a series of different sub-metrices (Sekerci and Alp, 2023). In this study, we adopted some of the most known node's centrality measures (i.e. degree, weighted degree, closeness centrality, betweenness centrality and eigenvector centrality). The *degree centrality* is widely used in SNA and indicates the number of ties that a node has (Novotni et al., 2022), while in the *weighted degree centrality* the number of ties is pondered by the weight of each edge. The *closeness centrality* measures the length of the shortest path connecting one node to another (Sekerci and

Alp, 2023), and represents a way to understand which actors may quickly affect the network. The *betweenness centrality* allows to find the so-called network brokers or gatekeepers (Giurca and Metz, 2018), pointing out the number of times a specific node lies between other nodes in the network (Enger, 2018). Instead, the *eigenvector centrality* is a measure of the connections of one node with other nodes of high importance (Sekerci and Alp, 2023).

Concerning the study of relationships among actors, the network coefficients help to describe the general structure. In this research we adopted the average degree, average weighted degree, graph density, network diameter, average clustering coefficient and average path length. *Graph density* represents a ratio between the edges present in a graph and the maximum number of edges that the graph may contain (Calignano and Trippl, 2020). The *average clustering coefficient* points out the lower tendency of the actors to create a clique, that is a group of nodes interconnected to each other, excluding outsiders who lack ties with all the members of the group (Balland et al., 2019; Batura, 2012). Finally, the *average path length* represents the average number of steps along the shortest paths for all possible pairs of network nodes (Balland et al., 2019).

3.2. Data

Applying SNA in the context of the bioeconomy, we analyse the Italian organisations that took part in EU-funded projects. This empirical analysis is based on the EU Commission's Community Research and Development Information Service (CORDIS – *link internet*) database. Using the keyword "bioeconomy"[2] in the search string, we selected all the projects active[3] from 2012 to 2023 with at least one Italian organisation. The starting year was chosen in accordance with the first EU bioeconomy strategy, released that year (EU, 2012). Once the data has been downloaded, a deep reading was carried out and any errors, duplicates or discrepancies were corrected. Hence, the first downloaded database (Tab. 2) listed a total of 907 projects, involving 828 organisations that received an EU contribution of almost 415 m EUR. Hence, on average, each actor took part to 1.09 projects, while the average fund per organisation was 501.115 EUR. In addition, in order to understand the dynamics within the network in the first ten years of the EU Bioeconomy Strategy, we decided to proceed with a two-period analysis. To do so, the projects were divided into two sub-periods, following the

[2] For completeness, even the keywords "bio-based economy", "bio-economy", and "bioecon" were used but they produced no results.

[3] It means that some projects started before 2012 and finished during or after that year. However, they were kept because of the low number (9).

first and the second EU Bioeconomy Strategy (i.e. EC, 2012 and EC, 2018): I – 2012/2017; II – 2018/2023.

In the first sub-period, 373 organisations took part in 318 projects, with an average of 0.85 projects per actor, receiving, on average, 358,277 EUR. Instead, in the second cohort 455 organisations participated in 589 projects (1.29 projects per organisation) with an average financing of 618,212 EUR.

Table 2. A synthetic overview of the Italian performance in the field of EU-funded projects on the Bioeconomy, considering three different time periods

	2012-2023	2012-2017	2018-2023
number of projects	907	318	589
number of actors	828	373	455
EU funds	414.923.947,00 €	133.637.360,00 €	281.286.587,00 €
average projects per actor	1.09	0.85	1.29
average funds per actor	501.115,88 €	358.277,10 €	618.212,28 €

However, we decided to consider only the organisations who participated in at least two projects (Tab. 3). This was made for two reasons: First, to avoid organisations that randomly have taken part in European projects; and, second, to enhance the visual representation for a more efficient understanding by both experts and non-experts of SNA. Furthermore, by doing so, the number of projects taken into account still represents the vast majority, decreasing from 907 to 812. Instead, the number of actors considerably decreases to 273 organisations for the whole period, while for the two sub-periods there were, respectively, 181 and 243 organisations. These selected organisations represent the nodes of the three networks we decided to visualise. Instead, the relations are represented by the number of shared projects by one organisation with every single other organisation. In order to identify this number, applying set theory as approach, the intersections of all possible pairs were calculated through RStudio[4]. In this phase, we employed ChatGPT[5] to determine the most suitable codes in RStudio. The

[4] Elaborations were performed with R 4.3.2, October, 2023; RStudio: Integrated Development for R. RStudio, PBC, Boston, MA URL http://www.rstudio.com/
[5] ChatGPT, OpenAI, October-November, 2023, https://chat.openai.com/chat

calculation gave the links among actors. This operation was repeated for the whole period (2012-2023) and for the two sub-periods (I – 2012/2017; II – 2018/2023).

Table 3. A synthetic overview of the Italian organisations that took part in at least two EU-funded projects on the bioeconomy, considering three different time periods

	2012-2023	2012-2017	2018-2023
number of projects	812	259	553
number of actors	273	181	243
EU funds	343.111.326,00 €	107.098.928,00 €	236.012.398,00 €
average projects per actor	2,97	1,43	2,27
average funds per actor	1.256.818,04 €	591.706,78 €	971.244,44 €

Finally, to visualise and analyse the networks, data were imported into Gephi (Bastian, 2009).

4. Results

In absolute terms, the highest share of participants belongs to the Private for-Profit (P) entities (Fig. 6). Instead, the lowest share is that of Public Bodies (PB). Furthermore, it is possible to observe that Higher or Secondary Education Establishments (H), Research Organisations (R) and Public Bodies (PB) are characterised by three peaks: the first peak between 2016 and 2018; the second peak in 2020; and the third one (the highest) in 2023. Instead, Private for-profit entities (P) and Other (O) are characterised by two peaks: One in 2018 and the second one in 2023. Hence, 2023 represents the year with the highest rate of starting projects for all the categories, and confirms a growth trend in the participation of Italian entities in bioeconomy projects.

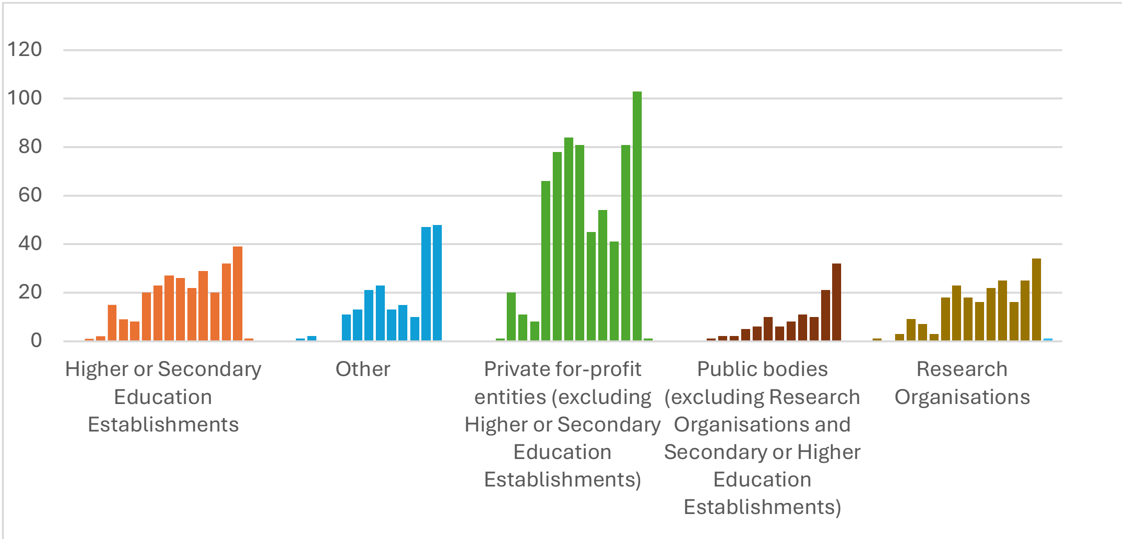
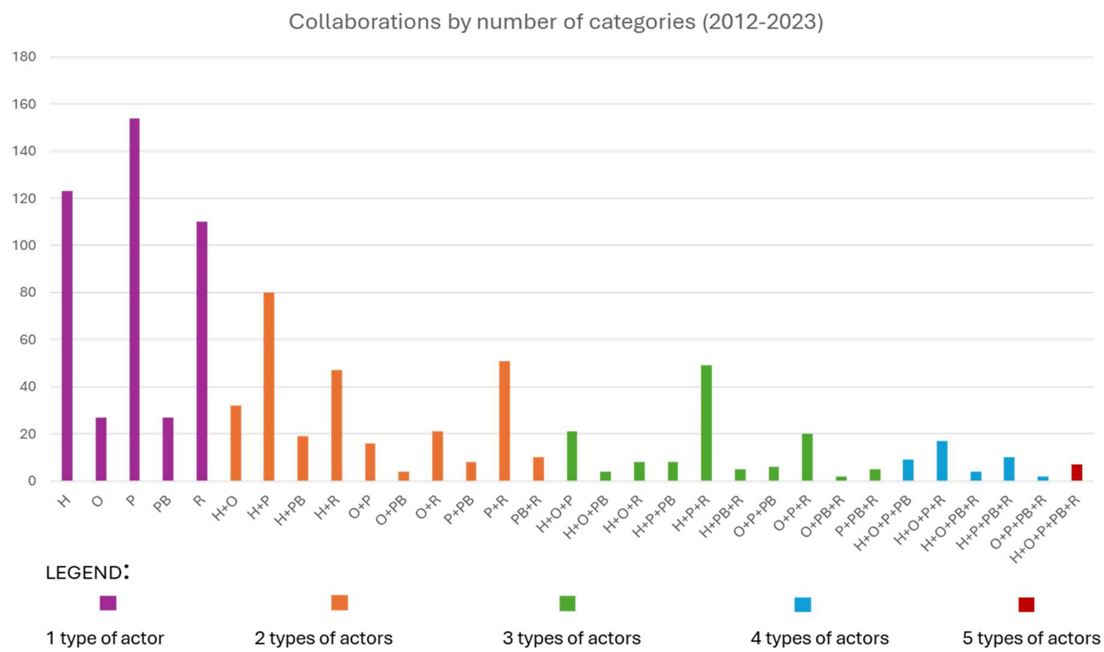


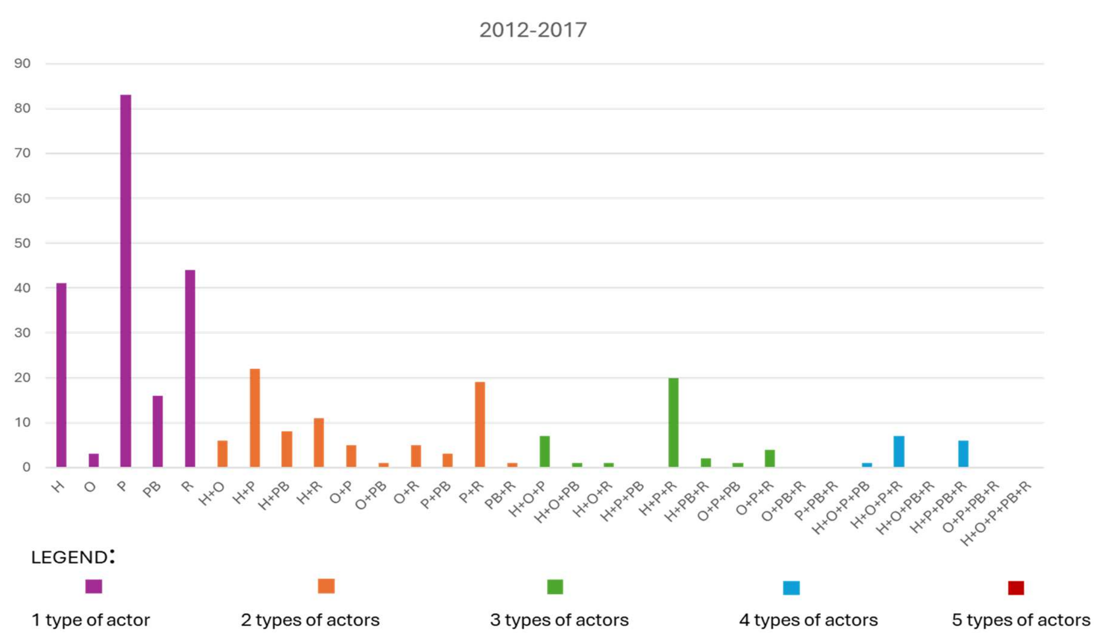
Figure 6. Number of participants to starting projects per year from 2012 to 2023, divided by type of organisation (in absolute values)

Regarding the typology of projects, more than 90% of the projects taken into account are explicitly or *de facto* (depending on the FP) collaborative research projects, confirming the importance of this typology of projects in the EU FPs.

By dividing the projects for the whole period (2012-2023) based on the number of categories that took part in them, the participation of only one category is the most predominant (48.6% – Fig. 7a). Among the cases with >1 categories involved, the most frequent is represented by two categories of actors, namely between H and P (80 projects – 8.8%), followed by P and R (51 projects – 5.6%). The collaboration among three categories reaches the top value – 49 projects, 5.4% – with H, P, and R, that is higher than the collaboration between H and R (47 projects, 5.1%). In the four actors collaboration case, the highest value is represented by the collaboration among H, O, P and R (17 projects – 1.8%). Finally, only seven projects (0.7%) saw collaboration across all categories.

Considering the two subperiods (2012-2017, and 2018-2023), it emerges that such collaborations increased in the second period (Fig. 7b and 7c): Although the one actor category shows an increase for H, R and O and a decrease for P and PB, all the other typologies of collaboration display a growth.





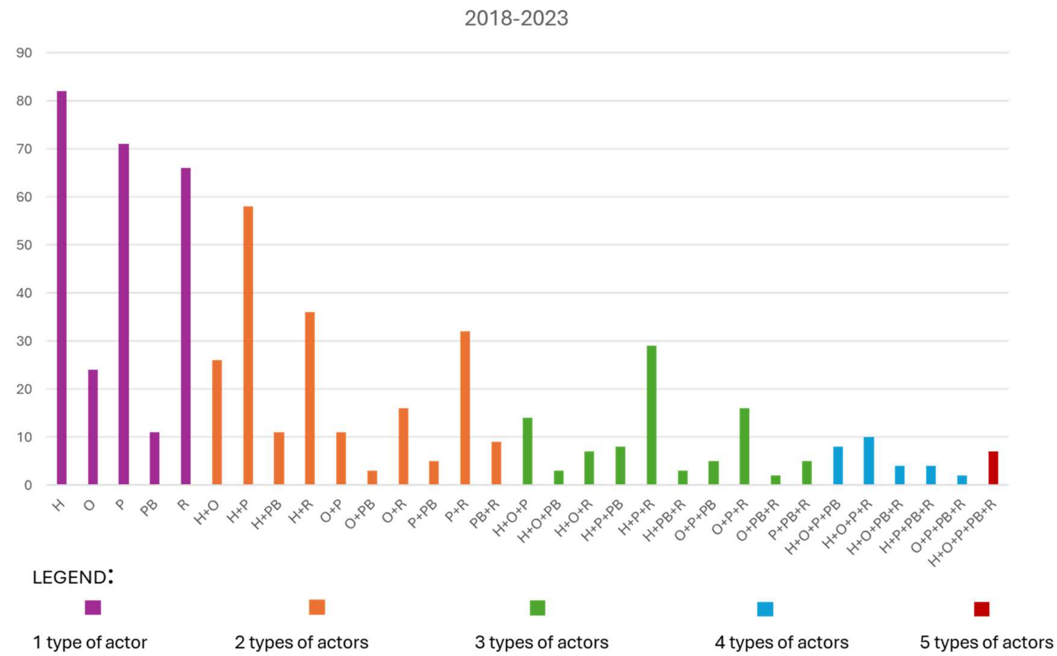


Figure 7. Projects depicted according to the types of organizations that took part in them. a. For the whole period; b. from 2012 to 2017; c. from 2018 to 2023. The graphs show the participation of individual categories (in blue) or collaborations between the various categories (the other colours)

While the results shown up to this point took into account all the 828 Italian actors involved in EU projects, moving to the results coming from the SNA, we must keep in mind that they refer to those organisations (273) that participated in at least two EU projects for the period considered.

It emerges that while P have the highest participation (43,6%), R and H play the most central roles, according to their degree centrality. This indicator shows the number of edges a node has. Therefore, R and H shared the higher number of projects with other entities. Based on that, the role of research institutions and universities is clearly predominant, also as connectors of other institutions (Fig. 8, 9 and 10).

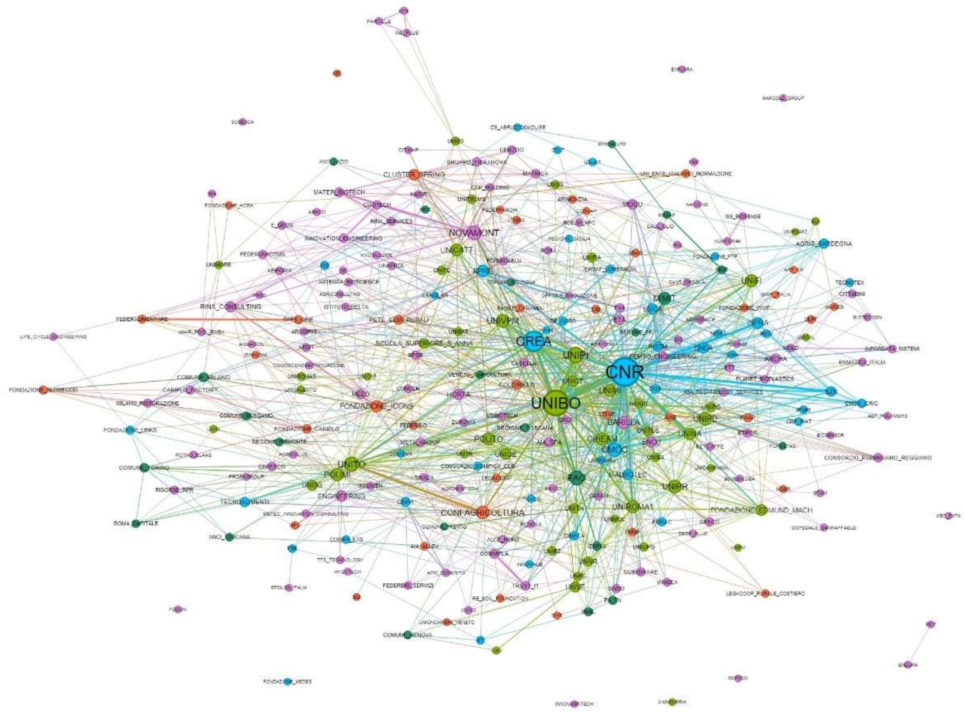


Figure 8. The Italian knowledge and innovation network (2012-2023)

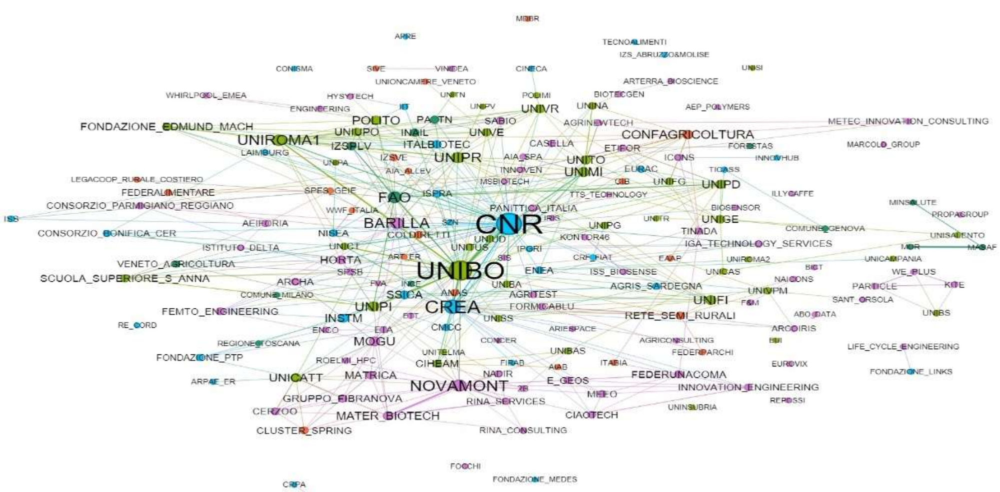


Figure 9. The Italian knowledge and innovation network (2012-2017)

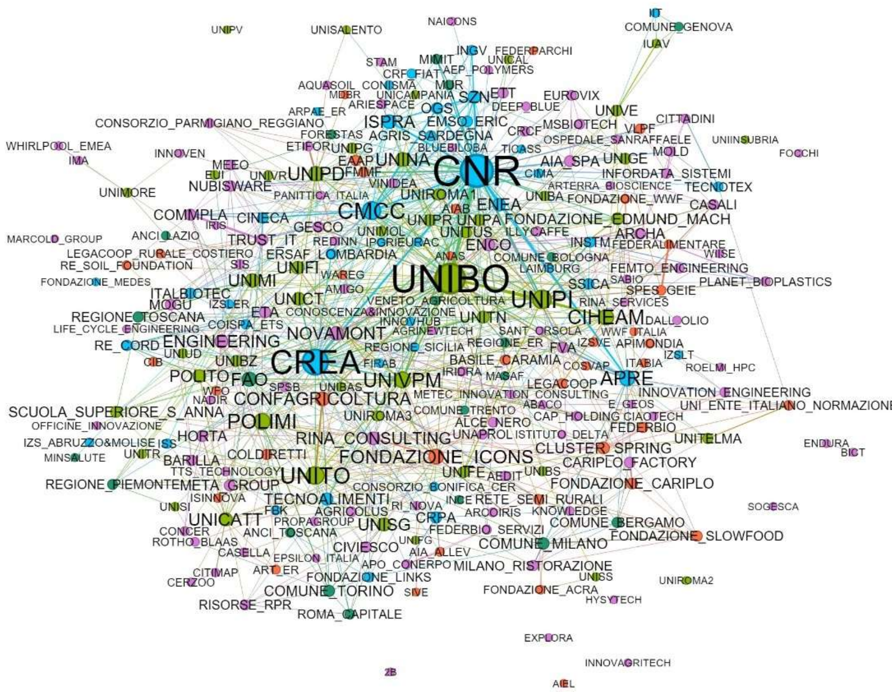


Figure 10. The Italian knowledge and innovation network (2018-2023)

The most central positions are held by two research centres (Consiglio Nazionale delle Ricerche – CNR – and Consiglio per la ricerca in agricoltura e l'analisi dell'economia agraria – CREA) and one university (University of Bologna – UNIBO) in all the periods taken into account. Furthermore, considering the whole period, even the fourth and fifth positions are held by universities (Tab. 4), namely the University of Pisa (UNIPI) and the University of Turin (UNITO). The first representative of the P category is Novamont in the seventh position, while FAO (International Public Body, considered Italian because based in Rome and kept in this study because it may influence knowledge and innovation) is in the sixth position. Furthermore, when considering the weighted degree, no significant changes were reported. In terms of eigenvector centrality, Barilla moves from the fourteenth to the seventh position, while Novamont drops to the eighteenth, meaning that the former company better performs in connecting with the most central nodes than the latter one. However, considering the first twenty positions of eigenvector centrality, only five are not research organisations or universities. This result highlights the collaborative relationships between national research centres and universities, providing a core structure for the national network.

Also in the case of closeness centrality, there is a strong predominance of research centres and universities, with only Barilla representing P (13th position), and FAO (4th) and MIMIT (Ministry of Enterprises and Made in Italy – 17th) as PB among the top twenty. Moreover among these, Confagricoltura (12th) represents the only Other. These non-research entities are from different sectors, i.e. Barilla from food industry, FAO and Confagricoltura from agriculture, and MIMIT is the ministry of entrepreneurship in general, with no specific sectors. This aspect underlines the possibility of quickly reaching different sectors through these actors that take central positions in terms of closeness centrality.

In the case of betweenness centrality, an indicator of network brokers, Novamont rises again up to 6th position, while Barilla falls to 41st position. In the list of gatekeepers, except for new entrants represented by universities or research organizations, we observe the entrance of Fondazione Icons (category Other) at the 12th position. Hence, only two non-research entities take the role of gatekeepers in the network.

Table 4. Main indexes of the first seven actors by degree centrality for the whole period (2012-2023)

	2012-2023	***2012-2017***	***2018-2023***
CNR	**1**	**1**	**1**
Degree	117	60	83
Weighted Degree	225	79	145
Eccentricity	3	3	4
Closeness Centrality	0.62954	0.589641	0.574307
Harmonic Closeness Centrality	0.71859	0.685811	0.66557
Betweenness Centrality	9,930,499,449	3,853,586,001	6,872,228,144
Eigen Centrality	1	1	1
UNIBO	**2**	**2**	**2**
Degree	99	52	74
Weighted Degree	188	75	113
Eccentricity	3	4	4
Closeness Centrality	0.600462	0.556391	0.577215
Harmonic Closeness Centrality	0.682692	0.651464	0.653143
Betweenness Centrality	6,493,369,686	2,996,735,607	6,032,993,309
Eigen Centrality	0.933632	0.867124	0.9773
CREA	**3**	**3**	**3**
Degree	72	31	60
Weighted Degree	118	39	79

Eccentricity	3	4	4
Closeness Centrality	0.562771	0.491694	0.546763
Harmonic Closeness Centrality	0.629487	0.566441	0.616594
Betweenness Centrality	4,544,093,498	1,791,090,395	4,580,516,924
Eigen Centrality	0.704686	0.492235	0.769651
UNIPI	**4**	**9**	**4**
Degree	46	16	36
Weighted Degree	79	21	58
Eccentricity	4	4	5
Closeness Centrality	0.500963	0.45122	0.474012
Harmonic Closeness Centrality	0.560256	0.503378	0.536696
Betweenness Centrality	1,477,587,012	510,877,779	1,353,800,288
Eigen Centrality	0.465627	0.324303	0.484625
UNITO	**5**	**17**	**6**
Degree	39	12	33
Weighted Degree	54	14	40
Eccentricity	4	4	4
Closeness Centrality	0.510806	0.440476	0.483051
Harmonic Closeness Centrality	0.557372	0.482545	0.537646
Betweenness Centrality	1,797,287,582	367,403,077	1,501,959,893
Eigen Centrality	0.41268	0.249209	0.492832
FAO	**6**	**6**	**13**
Degree	38	21	21
Weighted Degree	49	26	23
Eccentricity	4	4	4
Closeness Centrality	0.504854	0.459627	0.468172
Harmonic Closeness Centrality	0.552244	0.520833	0.509503
Betweenness Centrality	791,897,598	664,858,648	447,273,386
Eigen Centrality	0.483774	0.473916	0.402474
NOVAMONT	**7**	**4**	**17**
Degree	37	23	19
Weighted Degree	56	31	24
Eccentricity	4	5	5
Closeness Centrality	0.471014	0.430233	0.44358
Harmonic Closeness Centrality	0.528205	0.505293	0.486988
Betweenness Centrality	1,377,354,928	718,868,764	1,354,677,244

Eigen Centrality	0.346309	0.3053	0.260636

The organisations unrelated are a low number (3.6%) and they are mainly P. However, this represents an improvement in the interconnection of the network compared to the first phases of European bioeconomy projects. Indeed, looking at the first subperiod (2012-2017), it emerges that 10.5% of organizations had no connections, while in the second subperiod (2018-2023) this percentage fell to 4.9%. The lowest percentage in the whole period is explained by the low number of entities unrelated in both periods. Indeed, some were unrelated in the first period but related in the second period, and vice versa some others.

In the comparison between the two subperiods, the main results concern the loss of centrality of the private companies. Indeed, in the first subperiod two private companies ranked in the first ten positions (namely, Novamont and Barilla) in terms of degree centrality. Moreover, Barilla ranked 3rd in terms of eigenvector centrality, and 4th in terms of closeness centrality, testifying a central role both in affecting and brokering the network, while Novamont ranked 4th in terms of betweenness centrality, underlining its role of gatekeeper.

Instead, no private companies are listed in the first ten positions when ranked by degree, by eigenvector centrality and by closeness centrality in the second subperiod. Nevertheless, in terms of betweenness centrality, Novamont maintains its importance holding the 5th position and confirming the aforementioned role of gatekeeper.

Furthermore, the differences between the two subperiods emerge particularly when comparing global network measures (Tab. 5). The increase of the average degree and graph shows that together with the growth of participants (from 181 to 243) even the interconnection among actors increased: hence, the organisation's participation in EU-funded projects evolved from singular or international consortium approaches to collaborative consortia formations alongside domestic entities.

Table 5. Global network measures for the whole period (2012-2023) and for two sub-periods (2012-2017 and 201-2023)

	2012-2023	***2012-2017***	***2018-2023***
Number of Nodes	273	181	243
Number of Edges	1276	469	900
Average Degree	9.348	5.182	7.407
Average Weighted Degree	12.154	5.956	9.103
Graph Density	0.034	0.029	0.031

Network Diameter	6	6	7
Average Clustering Coefficient	0.563	0.706	0.610
Average Path Lenght	2.567	2.842	2.732

Moreover, there is a decrease in both average clustering coefficient and average path length. The former indicates greater cohesion of the network taken as a whole, while the latter takes into consideration the individual nodes and its decrease indicates greater cohesion between actors.

5. Discussion

The Italian knowledge and innovation network for the bioeconomy based on European funds is mainly led by researchers from research institutes or universities. This emerges clearly from all the indicators considered. This could lead to an advancement in research more than in innovation (Nepelski et al., 2019). Indeed, innovation is strictly connected with technological advancement (Ahuja, 2000) and commercialization (Giurca and Metz, 2018), two aspects that concern more private for-profit companies than research entities or the other categories involved (Ahuja, 2000). Similarly to what we found, even Stöber et al. (2023) found that the core of the bioeconomy innovation network in the urban region of Stuttgart is led by research institutes. Even (Giurca, 2018) found that most of the central organisations of Germany's wood-based bioeconomy innovation system are governmental or federal research institutes. Instead, the findings of López Hernández and Schanz (2019) are somewhat different. In their SNA on Colombian bioeconomy, in addition to agricultural research institutions, they identify, as most prominent, some governmental agencies. These agencies are considered by the Authors as central to enabling framework conditions for bioeconomy development. In this vein, the Italian network we found differs from the Colombian one. Indeed, although in our findings some of the most central entities are research institutes which depend directly on the ministries (i.e. CNR depends on the Ministry of University and Research, and CREA depends on the Ministry of Agriculture), they cannot be considered governmental agencies. Hence, the peripherical role of public bodies in the Italian knowledge and innovation network may suggest a gap in structuring the enabling conditions for the innovation in the bioeconomy. However, even in the Colombian bioeconomy the majority of actors belong to the private for-profit category and they do not hold central positions (López Hernández and Schanz, 2019) like in the Italian case. This means that no representatives of industry have a focal role in affecting these networks. Nevertheless, in terms of knowledge flows, one Italian company, Novamont, represents a gatekeeper, a role that is not held by any public body or organization belonging to the "Other" category.

The explanation for the repeated structure found in the literature, i.e. the public research entities as the most central ones, could lie in several explanations. FPs are public funds for research, that moved in forty years from almost exclusively linear approaches to collaborative ones (Çetinkaya and Erdil, 2016). Hence, at the beginning, the research entities were among the main recipients of such funds (Protogerou et al., 2010b; Sekerci and Alp, 2023). This may have created a path dependency that explains the central role of research entities in the network we found. Moreover, another reason may lie in the better internal organization of research institutions to take part in such projects (Stöber et al., 2023). Indeed, due to the never-ending research of funds for research and innovation (Russo and Rossi, 2009), universities and research organisations have equipped themselves with administrative structures that are able to follow all the stages (from proposal to implementation) of European projects (Stöber et al., 2023). Furthermore, in order to advance in research, these entities are more encouraged, compared to other entities, to seek collaborations to integrate complementary resources in the research processes (Nepelski et al., 2019). Hence, their high centrality may result in an efficient knowledge diffusion among heterogeneous actors (Russo and Rossi, 2009; Stöber et al., 2023). However, one of the negative consequences of the very predominant position of the three most central nodes of the Italian network (i.e. CNR, UNIBO and CREA) may be a dependency on these actors (Stöber et al., 2023). Indeed, the removal of these actors could significantly weaken the found Italian network and for this reason, it can be identified as a “sensitive network” (Hartmann-Sonntag et al., 2009). Nevertheless, the analysis of the dynamics in the last ten years shows that something changed, with an increased participation of all the categories. This growth, together with the increased connectivity among actors, made the network less sensitive to shocks (Stöber et al., 2023).

In this vein, based on König et al. (2009) and Saviotti (2009), we distinguish between *dynamics* and *evolution* of the system. The former refers to the incremental variations that usually occur during long periods. The latter refers to the structural changes in the network (or system) that rarely occur but, when they happen, require a long period of network readjustment.

Following these definitions, in the last ten years, the Italian knowledge and innovation network faced a dynamic process rather than an evolution. This aspect, which may seem just a theoretical speculation, has an important consequence on the innovation side. Indeed, the fact that the network experienced a dynamic process means that it is close to equilibrium (König et al., 2009), while it is widely accepted that innovation pushes toward disequilibrium (Berkhout et al., 2006; Pyka and Scharnhorst, 2009). Furthermore, as we observed in the variations between the two subperiods, the Italian network experienced increased connectivity and a shorter average path length. In this sense, Saviotti (2009) underlines how the increased connectivity has generally an inverse relationship with innovation, in particular referring to industry/technology level. In greater detail, this aspect underlined by Saviotti (2009) is strongly connected with the relationship between equilibrium and innovation. Indeed, an innovation (especially a disruptive one) can be seen as a factor that shocks the network with the introduction of new nodes less or not connected with the pre-existing ones. Consequently, the whole network will suffer from a drop in connectivity and a new phase of variations or readjustments (depending on the impact of this innovation) will follow, and this change will move the network away from equilibrium.

However, the increased connectivity has several other repercussions on the network. In terms of relationships with external entities or other networks, Novotni et al. (2022) point out that greater national integration and cohesion may have a good effect on international cooperation. Instead, looking at the effects within the network, Bauer et al. (2018) link the higher number of ties with a reduction of opportunistic behaviours. Moreover, to maintain the network's relationships, the organisations have to face higher costs (Bauer et al., 2018). However, in exchange for these higher costs, organizations acquire greater competencies, skills (both social and technical) and behavioural additionalities (Caloffi et al., 2013; Protogerou et al., 2010a; Russo and Rossi, 2009). Furthermore, the higher density stimulates more knowledge spillover phenomena (Martin et al., 2023), and can lead to imitation processes (Lundvall, 2016) especially when an organization suffers from resource shortages or gaps (Ahuja, 2000). The topic of knowledge spillover is particularly important in the case of interdisciplinarity. Indeed, as was noted by Bauer et al. (2018), the exchanges between industries can achieve a higher degree of novelty compared to the exchanges within the same industry. Hence, given the interdisciplinary nature of the bioeconomy, this aspect has the potential to be significant for the future of the sector. However, as pointed out by Rosenberg (2009) interdisciplinary is less effective when is based on top-down decisions and FPs may be considered top-down approaches. However, an answer to this issue may be represented by the high interest in participatory and multi-actor processes that characterise many of the projects funded under FPs (Balland et al., 2019; Schut et al., 2014). Hence, the increased joint participation of different categories in the same projects that we found in the Italian case seems to be moving towards an application of the helix scheme (be it triple, quadruple or quintuple) that allows the development of more systemic knowledge and innovation. In this environment, there could be room for more bottom-up approaches that overcome the limits of the inefficiency of top-down interdisciplinarity.

Furthermore, the involvement of these different typologies of actors and, within the private sector, different types of firms – even from unrelated industries or cross-sectoral – can be seen as a symptom of the maturity of the sector (Nepelski et al., 2019). Indeed, this means that nowadays the Italian bioeconomy is not only focused on developing new technologies – recognized in the literature as the first phase of a new sector or industry (Gustafsson et al., 2016; Klepper, 1997) – but is involved in secondary phases of industry growth such as commercialization and stakeholders' engagement (Bijon et al., 2023; Van Lancker et al., 2016). This maturation is also confirmed by another point of view: following the aforementioned work by Saviotti (2009), an increase in connectivity can be considered a movement towards maturity.

This study is limited by its inability to detect any informal or external incentives implemented by Italian policymakers to implement the current network. However, based on the reported peripherical role of national public bodies, it is possible to say that European policies had an important role in structuring the bioeconomy knowledge and innovation network. Anyhow, the public nature of the three most central actors suggests the need for further investigation into the relationships between policymakers and research flows.

Another important limitation concern relationships with fundamental parts of the innovation system that are not covered by this methodology. In particular, there is the impossibility of catching some national actors who do not participate in European projects but are a fundamental part of the national innovation system. Examples are startups, who, generally, have few resources to participate in such kinds of projects but have an important role in bringing new knowledge and innovation, or education entities like technical schools or lifelong learning providers, who strongly contribute to spread knowledge and competencies. Furthermore, the approach adopted in this study focuses only on national entities, even if the collaborations with EU and non-EU entities is one of the pillar of FPs (Calignano and Trippl, 2020; Çetinkaya and Erdil, 2016). Hence, to better understand the Italian knowledge and innovation system, further analysis that take into account even relationships with foreign entities are deemed necessary.

6. Conclusion

In this study, we focused our attention on Italy's bioeconomy network, analysing organizations involved in European projects from 2012 to 2023 through Social Network Analysis. The results shed light on the Italian knowledge and innovation network, identifying as most central actors for all the indicators analysed three public research organisations (two research institutes and one university). Based on the eigenvector centrality, a measure of the nodes most connected with the most central nodes, we also found that the core structure of the network is based on research entities. We also found that this core structure is common in other countries, and it can be related to a path dependency in public funds allocation.
Other typologies of actors (i.e. Private for-profit entities, Public bodies, and Others) do not occupy central positions, except in the case of closeness centrality, a measure of actors' capacity to affect the network. The diverse origins of the nodes that exhibit high closeness centrality may enable the network to achieve efficient and rapid information flow across different sectors. However, based on the betweenness centrality, we discovered a weak capacity of non-research entities to act as gatekeepers. In fact, only one private company (Novamont) assumes that role. Moreover, we found that, considering two subperiods of the network (2012-2017, and 2018-2023), dynamics within the network changed over time. The P entities lost centrality from one subperiod to the other, while connectivity increased notably between the two subperiods. Based on innovation network literature, this growth in ties might have had a negative effect on the innovativeness of the network, but, at the same time, it might have contributed to the strength and resilience of the whole knowledge and innovation system for the bioeconomy (KISB) – of which the network we found is only a part – and, more in general, the national bioeconomy.

In any case, this study represents a first step toward a better understanding of the Italian KISB and the policies that this system needs to fill the gaps and promote sustainable development. For example, further analysis is deemed necessary in order to understand if the increased connectivity was caused by a growth in terms of technological knowledge (market-oriented) or general knowledge (diffusion and network-oriented). These elements are fundamental to setting effective innovation policies, in particular, to compensate for system failures.

Chapter 4 – Assessing the linkages and the information flows in the Italian KISB

1. Introduction

In recent years, the economic development of the EU has faced both structural problems – e.g. climate change – and contingent ones – e.g. the Russia-Ukraine conflict. These problems deeply changed the socio-economic-environmental context (European Court of Auditors, 2024). In fact, just considering the two examples provided, the repercussions on the Union have been to accelerate some processes – such as green and digital transitions – whose completion is now considered strategic (EC, 2020b, 2020a, 2022b; Regulation (EU) 2021/2116, 2021). Among these processes, the need for energy diversification, reducing dependence on fossil fuels, and establishing sustainable industrial activities (such as clean technologies) are considered key issues on the Union's political agenda (Draghi, 2024).

In the mid-long term, the bioeconomy can represent a key sector to achieving these objectives. However, to provide this contribution, the sector has to solve some internal critical issues that undermine the possibility of a cohesive or, at least, coherent action (D.; Viaggi et al., 2021; Vogelpohl et al., 2022; Vogelpohl and Töller, 2021). One of these critical issues is the need for greater integration among all the sectors that compose the bioeconomy. Integration is a core element of the bioeconomy concept: it is not a mere sum of sectors, but rather an integration of them. Indeed, in the bioeconomy perspective, interconnections among sectors increase and the boundaries among them blur (Bugge et al., 2016; D'Amato et al., 2017; Wei et al., 2022). These interconnections concern several dimensions, such as resources, actors, value chains, and value webs (Viaggi, 2022). Providing an exhaustive example may help to understand this characteristic of the bioeconomy.

Considering resources, there are nearly endless prospects for discovering organic compounds from by-products of established supply chains (Panoutsou et al., 2020; Zilberman et al., 2013). In this way, by-products from one supply chain (or sector) can flow into a completely different supply chain (or sector) (Zilberman et al., 2013). Through this new interconnection, even information (that can be considered a resource) flows from one sector to the other, reducing distances and creating new shared knowledge. This new knowledge can be practical (*know-how*) or theoretical (*know-what*). In both cases, when it comes to being implemented – thus moving from invention to innovation (Schumpeter, 1939) –, it has to be in line with the strategic goal of sustainable development. This cannot be achieved without a dialogue that includes all the actors involved in sustainable practices and services (Angouria-Tsorochidou et al., 2021; Bijon et al., 2023; Bohn et al., 2023; Bryden et al., 2017). In this process, even other stakeholders, such as citizens or NGOs, can contribute to innovation and knowledge development, for example in participatory processes to assess new biotechnologies (Bohn et al., 2023). However, such kind of involvement requires an intense effort in terms of communication and dissemination (e.g., to simplify complex concepts, to outline pros and cons of new biotechnologies, etc.).

This brief overview expresses, at the same time, the complexity of the bioeconomy and the importance of optimal relationships and information flow to create a shared knowledge on the topic with the ultimate purpose of fostering the whole sector. In order to take into account all the dimensions mentioned (resources, interconnections, knowledge development, engagement, etc.), a systemic approach is deemed appropriate (Loos et al., 2018; Pyka, 2017). In particular, the Knowledge and Innovation System for the Bioeconomy (KISB) allows for a holistic vision that goes beyond sectoral or partial visions. Furthermore, this approach enables the investigation of the relationships and the information flows to identify areas of interventions for specific and tailored policies.

However, to date, studies on KISB are rare, with little knowledge on how innovation and knowledge are developed, transferred and implemented in the bioeconomy. Furthermore, to the best of the Authors' knowledge, no studies focused on the evaluation of linkages among all the actors involved in the bioeconomy of a specific area.

The aim of this study is to assess the relationships and information flows within the Italian KISB. More in detail, in order to achieve this main objective, we proceeded through two sub-objectives, namely: the assessment of the linkages; and the evaluation of the information flow. To the best of our knowledge, this is the first attempt to explore and understand these two sub-objectives, in particular in the Italian KISB. Furthermore, we applied a novel methodological approach, the Graph-Theoretical Techniques (GTT). Developed and applied in the field of Agriculture Knowledge and Innovation Systems – AKIS – (Amerani et al., 2024; Kassem et al., 2022; Temel et al., 2003), this methodology has not found application in the bioeconomy innovation studies. The GTT helps to identify the dominant and subordinate components of the KISB, as well as the main promoters and targets of the information flows. Moreover, to better understand the processes of knowledge transfer and innovation creation in the Italian context, we collected feedback from key members of the Italian KISB. The mixed method approach (both quantitative and qualitative data) provides a better description of the Italian KISB. In this

sense, this study contributes to the Innovation Systems (IS) literature through the identification of structural elements and features of a deeply multidisciplinary, intersectoral and technology-oriented IS (D'Amato et al., 2022; Hurtado and Berbel, 2023).
The paper is structured as follows. In the next section, materials and methods used in the study are exposed. In section 3, are illustrated the main results, which are then discussed in section 4. Finally, in section 5 the main conclusions are outlined.

2. Materials and methods

2.1. Graph-Theoretical Technique approach

In order to assess the linkages and information flows among actors of the KISB, we applied the Graph-Theoretical Technique (GTT). This approach was developed by Temel and his team (Temel, 2006, 2016; Temel et al., 2003; Temel and Karimov, 2019), combining graph theory and systems analysis (Amerani et al., 2024). It consists of a series of squared matrices and structures. More in detail, the structures are the results of a process of refinement of the matrices. The final aim is to provide several pathways for quantifying relationships, information flows and cause-effect nexus among categories of actors (Kassem et al., 2022; Temel et al., 2003). It helps to identify key features of the links: the intensity and the influence of each relationship; the dominant and subordinate linkages between the components; the cause-effect structure; the sharing, receiving and learning capacity; the promoters and targets of the information; the information flow structure (Amerani et al., 2024; Kassem et al., 2022). In this approach, only linkages among different categories of actors are explored, while linkages *intra-category* (e.g. universities with other universities) are not considered.

Examples of categories of actors from previous studies on AKIS include: Policy component; Research component; Information component; Farmers' organizations; Extension services; Secondary technical education; Higher education; and agricultural credit component (Temel et al., 2003; Kassem et al., 2022).

To be consistent with the previous study on Social Network Analysis of the Italian organisations that participated in EU-funded projects, we decided to keep the same categories as reference for the KISB. The categories of stakeholders are five, namely: Higher or Secondary Education Institutes (H), representing mainly universities but also higher education institutes and post-school institutions; Research Institutes (R), both public and private; Private for-profit companies (F), including mainly biotech, agri-food, and consulting companies; Public Bodies (B), from national (Ministries) to locals (Regions, regional agencies, municipalities, etc.);

Other (O), representing aggregative entities, such as clusters, consortia, associations of firms, associations of consumers, foundations, NGOs, etc.

In the following sections, we present the series of squared matrices and structures that constitute GTT. To make it clear, we proceed with an invented example.

Linkage matrix

The linkage matrix is a square matrix and has the purpose of showing all the possible binary linkages among stakeholder groups within a system. To clarify through an example, let's assume that the system is formed by 4 (invented) categories: (X), (Y), (W), (Z). The categories are placed in the diagonal, while the interactions are conventionally delineated clockwise (Fig. 11).

$$A(LM) = \begin{pmatrix} \mathbf{X} & XY & XW & XZ \\ YX & \mathbf{Y} & YW & YZ \\ WX & WY & \mathbf{W} & WZ \\ ZX & ZY & ZW & \mathbf{Z} \end{pmatrix}$$

Figure 11. Linkage matrix, example

Hence, the linkage described by WZ in the third row and fourth column is the claimed relationships between organisations of category W with the organisations of category Z (W→Z). On the contrary, the ZW term in the fourth row and the third column represents the asserted connection of Z with W (Z→W).

To know the total number of k-edged pathways within the system, the formula is:

$$\frac{n!}{(n-k-1)!}$$

Where n represents the number of categories of actors in the system, and k represents the number of edges in a pathway. In the given example, n = 4, and k = 1. Therefore the total number of one-edged pathways in the system is 4!/(4-1-1)! = 12.

Coded Linkage matrix

To show the actual system, a code is used: 1 if the linkage exists, 0 if not. The resulting matrix is called the coded linkage matrix (Fig. 12a). Furthermore, the coded linkage matrix allows for

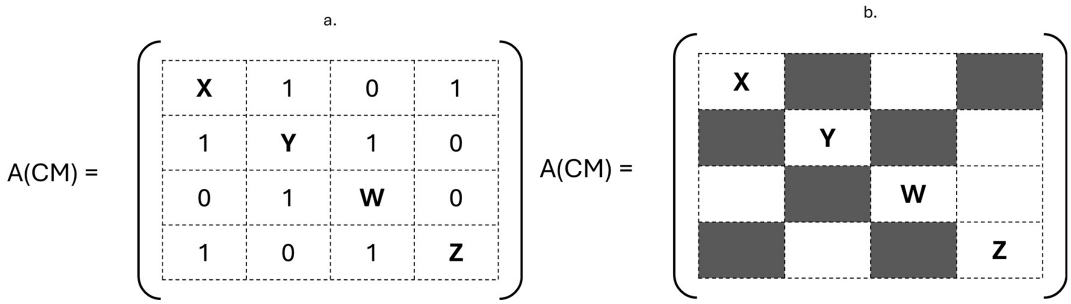


Figure 12. a. Coded Linkage matrix, example; b. visual pattern, example

several visualisations. The simplest is a visual pattern where code 1 (existing link) is represented with dark cells, while code 0 (non-existing link) is blank (Fig. 12b).

Refined matrix

The strength (or intensity) of the existing linkages may be assessed based on a three-point scale (weak, medium and strong). The resulting matrix is the Refined matrix (Fig. 13a). The refined matrix can still be visualised through the visual pattern, changing the dark cells with different shades or effects (Fig. 13b).

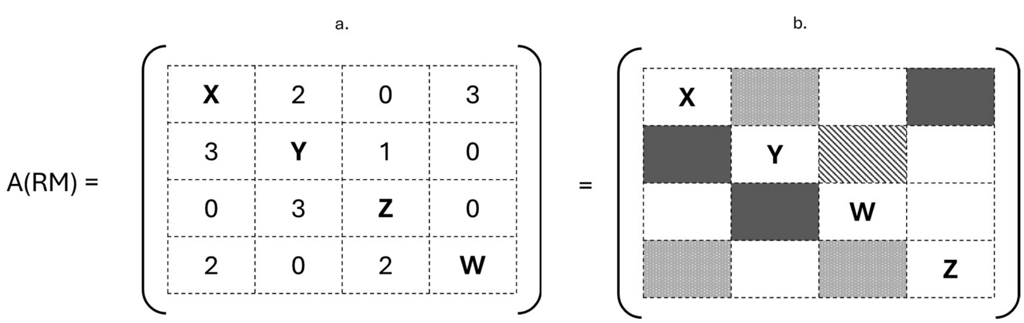


Figure 13. a. Refined matrix (RM), example; b. visual patter of RM in grey scale

Adjusted matrix

In order to represent how strongly one organization believes in influencing others, the refined matrix may be adjusted by multiplying with the following scale: strong (s = 1), medium (m =

$$A(AM) = \begin{pmatrix} \mathbf{X} & 2.s & 0 & 3.w \\ 3.s & \mathbf{Y} & 1.w & 0 \\ 0 & 3.m & \mathbf{W} & 0 \\ 2.s & 0 & 2.m & \mathbf{Z} \end{pmatrix} = \begin{pmatrix} \mathbf{X} & 2 & 0 & 0.99 \\ 3 & \mathbf{Y} & 0.33 & 0 \\ 0 & 1.98 & \mathbf{W} & 0 \\ 2 & 0 & 1.32 & \mathbf{Z} \end{pmatrix}$$

Figure 14. Adjusted matrix, example

0.66), weak (w = 0.33), none (n = 0). The resulting matrix is called the adjusted matrix. However, unlike previous studies (e.g. Amerani et al., 2024; Kassem et al., 2022; Temel et al., 2003), we decided to obtain the adjusted matrix by multiplying the refined matrix with the degree of influence obtained through the questionnaire (Fig. 14).

Cause-Effect Structure of Adjusted Matrix

At this point, the cause-effect structure (as called by Temel et al., 2003) can be drawn. Based on how the matrix was built, each row represents the influence of one category over all the others, while each column represents the influence that one category undergoes by the other categories. Hence, the rows represent the causal component (here called simply Cause or C), while the columns represent the effective component (here called simply Effect or E). The measure of total cause of the *i*-th component (C_i) of the system is given by the following formula:

$$C_i = \sum_{j=1}^{n} AM[i][j]$$

The sum of a specific row in the *i*-th position of matrix AM is given by adding all the elements in the *i*-th row across each column *j* (where *j* is from 1 to *n*, and *n* is the number of categories of the system).

Similarly, the total effect of the *j*-th component (E_j) is calculated by the formula:

$$E_j = \sum_{i=1}^{n} AM[i][j]$$

Hence, for each category is it possible to calculate C and E (Tab. 6). Furthermore, the cause-effect structure of the adjusted matrix may be represented with a scatter plot (Fig. 15), using coordinates C and E. In this way, the dominant or sub-ordinate components are found: below

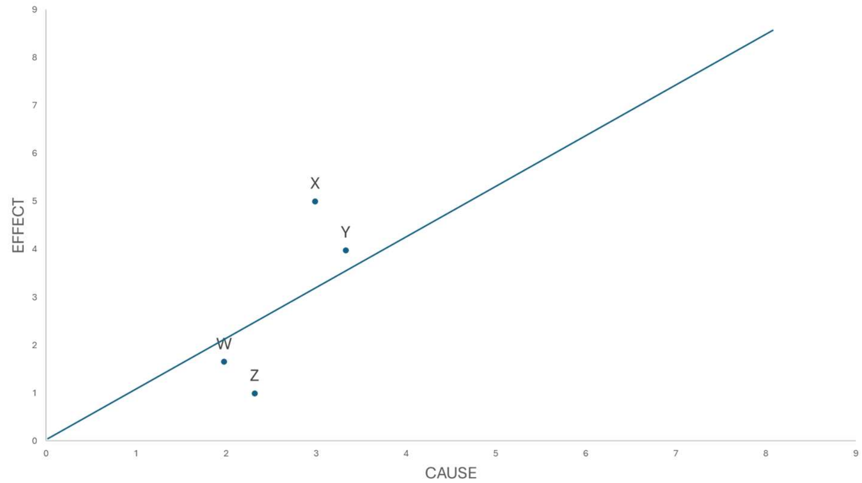


Figure 15. Cause-Effect structure, example

the diagonal, there are the dominant components that influence the system more than others influence them; above the diagonal, there are the sub-ordinate components that are more influenced by the system than being an active influencer of the other categories.

Table 6. Total Cause and Total Effect values per each category of actor, example

Category of actor	Total Cause	Total Effect
X	2.99	5
Y	3.33	3.98
W	1.98	1.65
Z	2.32	0.99

Density of the Adjusted matrix

The density of the adjusted matrix is defined as the percentage of existing binary linkages to the potential ones (Kassem et al., 2022). The formula to calculate it is the following:

$$d = \frac{b}{[n(n-1)]}$$

Where b is the total number of current binary influences, and n is the number of categories in the system. Density ranges from 0 to 1. When density is equal to 0 there are no connections between actors. Instead, with d =1 all the actors influence each other.

In our example, d = 7/12 = 0.58.

Information Flow matrix

Another way to understand the relationship between actors in an Innovation System is done considering the information flow matrix (IFM). This is guaranteed by the capacity of the actors

a.

$$A(IFM_{\sigma}) = \begin{pmatrix} \mathbf{X} & \sigma^{XY} & 0 & \sigma^{XZ} \\ \sigma^{YX} & \mathbf{Y} & \sigma^{YW} & 0 \\ 0 & \sigma^{WY} & \mathbf{W} & 0 \\ \sigma^{ZX} & 0 & \sigma^{ZW} & \mathbf{Z} \end{pmatrix}$$

b.

$$A(IFM_{\rho}) = \begin{pmatrix} \mathbf{X} & \rho^{XY} & 0 & \rho^{XZ} \\ \rho^{YX} & \mathbf{Y} & \rho^{YW} & 0 \\ 0 & \rho^{WY} & \mathbf{W} & 0 \\ \rho^{ZX} & 0 & \rho^{ZW} & \mathbf{Z} \end{pmatrix}$$

c.

$$A(IFM) = \begin{pmatrix} \mathbf{X(\lambda)} & \sigma^{XY}\rho^{XY} & 0 & \sigma^{XZ}\rho^{XZ} \\ \sigma^{YX}\rho^{YX} & \mathbf{Y(\lambda)} & \sigma^{YW}\rho^{YW} & 0 \\ 0 & \sigma^{WY}\rho^{WY} & \mathbf{W(\lambda)} & 0 \\ \sigma^{ZX}\rho^{ZX} & 0 & \sigma^{ZW}\rho^{ZW} & \mathbf{Z(\lambda)} \end{pmatrix}$$

Figure 16. a. Information flow matrix for sharing capacity; b. Information flow matrix for receiving capacity; c. Information flow matrix, examples

composing the system to receive, learn and share information. These capacities are quantified through the questionnaire and are represented by ρ (receive), σ (share), λ (learn). Except for the diagonal, which represents the learning capacity, the other cells are the results of the multiplication of the two matrices represented in Fig. 16a and 16b. Therefore, in the final IFM (Fig. 16c) the information flow is given by the capacity of one category to share with and receiving from another category. In our example, in cell WY (third row, second column), the information flow is given by W's capacity to share with Y (σ^{WY}) multiplied by W's capacity to receive information by Y (ρ^{WY}).

Capacity matrix of Information flow

Substituting the values of each capacity in the information flow matrix, we obtain the capacity matrix of information flow (Fig. 17). In particular, the values are the conversion of the four-

$$A(CMIF) = \begin{pmatrix} \mathbf{X(\lambda)} & ss & 0 & sw \\ ws & \mathbf{Y(\lambda)} & mw & 0 \\ 0 & mm & \mathbf{W(\lambda)} & 0 \\ ww & 0 & wm & \mathbf{Z(\lambda)} \end{pmatrix} = \begin{pmatrix} \mathbf{X(\lambda)} & 1 & 0 & 0.3 \\ 0.3 & \mathbf{Y(\lambda)} & 0.2 & 0 \\ 0 & 0.4 & \mathbf{W(\lambda)} & 0 \\ 0.1 & 0 & 0.2 & \mathbf{Z(\lambda)} \end{pmatrix}$$

Figure 17. Capacity matrix of Information flow, example

point scale (i.e. none, weak, moderate, and strong – Fig. 17) into numbers (i.e. 0, 0.33, 0.66, and 1 – Fig. 18). The final capacity matrix of information flow is the result of the multiplication of the two capacities, rounded up to the first decimal place (Fig. 17).

Adjusted Capacity matrix of Information flow

The Adjusted Capacity matrix of Information flow is the product of the Capacity matrix of information flow by the Refined matrix. In this way, the information flow structure is weighted, providing a better visualisation of the information system (Fig. 18).

$$A(ACMIF) = \begin{pmatrix} \mathbf{X(\lambda)} & 2 & 0 & 0.9 \\ 0.9 & \mathbf{Y(\lambda)} & 0.2 & 0 \\ 0 & 1.2 & \mathbf{W(\lambda)} & 0 \\ 0.2 & 0 & 0.4 & \mathbf{Z(\lambda)} \end{pmatrix}$$

Figure 18. Adjusted Capacity matrix of Information flow

Information flow structure

Thanks to the Adjusted Capacity matrix of Information flow, it is possible to outline the information flow structure. To do so, as done previously in the other identified structure (i.e. Cause-Effect structure), the sum of each row provides the capacity of a category of actors to be an information promoters (Pr). More in detail, the formula to evaluate this capacity is:

$$Pr_i = \sum_{j=1}^{n} ACMIF[i][j]$$

Where *i* and *j* range from 1 to *n,* and *n* represents the number of categories. Instead, the sum of each column represents the capacity of a category of actors to be an information target (Ta). Similarly, to calculate the information target we adopted the formula:

$$Ta_j = \sum_{i=1}^{n} ACMIF[i][j]$$

Even in this case *i* and *j* range from 1 to *n,* and *n* represents the number of categories. The results from the examples are reported in Tab. 7. Finally, using the two values Pr and Ta identified for each actor as coordinates within a scatter plot, it is possible to represent the structure of the information flow (Fig. 19). Even in this case, the diagonal splits the categories of actors into three components. Below the diagonal there are the Promoters, those who promote the information flow rather than being targets of the flow (promotion > reception). Instead, above the diagonal, there are the Targets, those actors who receive more information flows than those who promote (promotion < reception). Finally, on the diagonal, there are the Connectors, in which promotion and reception are equal. These actors may act as gatekeepers in terms of information flows.

Table 7. Total Promotion and Total Reception values per each category, example

Category of actor	Total Promotion	Total Reception
X	2.9	1.1
Y	1.1	3.2
W	1.2	0.6
Z	0.6	0.9

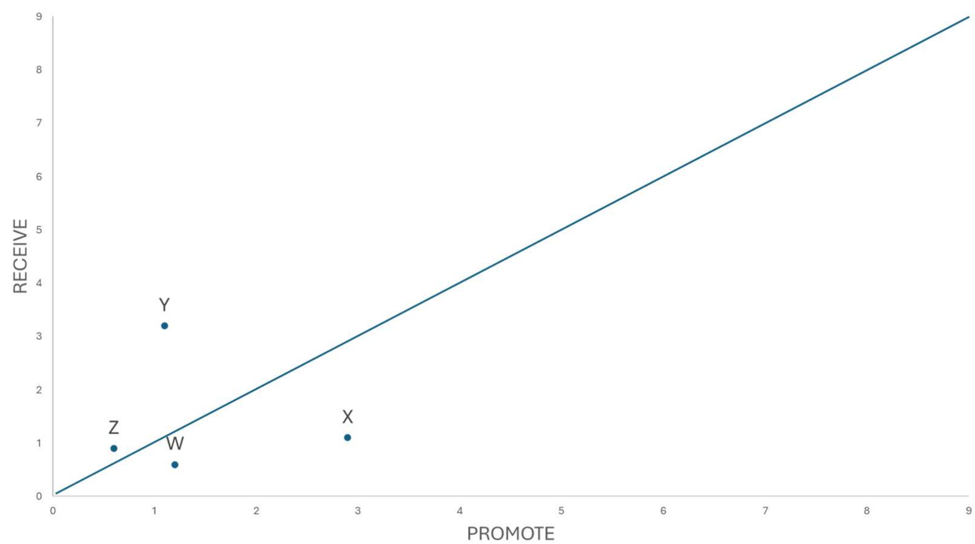


Figure 19. Information flow structure, example

2.2. The questionnaire

The questionnaire was designed on QualtricsXM™[6], a specialised online software. The questionnaire was anonymous and it included 9 questions, after a brief introduction to the study. A clarifying image, in which reported examples of collaborations, was provided in this introduction. The questionnaire was completely self-evaluating. It means that the respondent had to reply always self-evaluating his or her organisation. Specifically, in the first question, the respondents had to indicate the typology of the organisation they represented, within a pre-

[6] QualtricsXM, October 2024, Provo, Utah, USA, URL: https://www.qualtrics.com

defined list. After that, they had several matrices to fill out with Likert scales, providing as options: *none, very weak, weak, medium, strong, very strong*. Each of these matrices asked for different aspects of the relationship between the respondents' organisation and the other entities. Hence, the first matrix was asked to indicate the intensity of the relationships, while in the second matrix, the capacity to influence the other companies was recorded. In the third, fourth, and fifth questions, it was asked to indicate their opinion about the capacity, respectively, to receive, assimilate and share information about the reported typologies of actors. Finally, the last two were open-ended questions, to allow respondents to clarify any aspect of the answers given in the questionnaire (Question 8) and to add any other reflection about innovation, knowledge creation and knowledge transfer in the Italian bioeconomy.

The questionnaire was validated in two steps. First, submitting it to colleagues and asking them for suggestions and to help in finding typos or mistakes. The second step was to conduct three semi-structured interviews with three representatives of key organisations in the Italian bioeconomy. The interviews added qualitative insights to the research and, at the same time, helped to finally validate the questionnaire before sharing it.

2.3. Study area, sample and data analysis

The research was conducted in Italy. The KISB in this country is still not clearly depicted. However, in a previous study, we identified the main national actors composing the network of organisations involved in EU-funded projects about the bioeconomy. Taking advantage of the organizations identified and the categories of actors represented, we planned this study and we identified the key actors to contact in the first instance. In fact, the research strategy was to target and involve key stakeholders who have a better overall vision of the current Italian bioeconomy rather than mass dissemination of the questionnaire to any subjects, who could be unaware of the complexity of the sector. In this vein, 52 emails were first sent to identified key stakeholders. These stakeholders belonged to all the 5 categories. More in detail, the contacted persons were selected as representatives of universities, public and private research institutes, Italian and European public entities (e.g. National Coordination Group of Bioeconomy of the Presidency of the Council of Ministers), private companies (mainly from food and biotech industries), private consulting firms, trade associations and clusters. To the all selected actors was asked to fill out the questionnaire and to share the link among those they considered to be relevant actors in knowledge development and innovation in the Italian bioeconomy (snowball sampling). In particular, trade associations and clusters were fundamental to spreading the questionnaire to their networks of firms. Because of the snowball sampling technique adopted, we are not aware of how many people received the link. However, 96 persons initiated filling out the questionnaire. Among these, 42 abandoned at the first response, without filling any matrices.

Hence, the final sample is composed of 54 respondents. Nevertheless, all five categories took part, as illustrated in Tab. 8.

Table 8. Overview of respondents, per category, in absolute values, to the questionnaire

Category	Respondents	Completed
H	18	13
F	9	8
R	15	14
B	2	2
O	10	8

As emerges in Tab. 8, some answers were not completed for all the matrices. However, since the questionnaire was structured with matrix questions, where responses were mandatory in order to proceed, even partial responses resulted in complete answers within individual matrices. In other words, while the questionnaire as a whole may be incomplete, the responses provided for the individual matrix questions are complete. This is the reason why we considered for each matrix all the answers recorded. Data were analysed through Excel. More in detail, once downloaded data from QualtricsXM™, each reply was converted into numbers, namely: *none* = 0*, very weak* = 0.1*, weak* = 0.25*, medium* = 0. 5*, strong* = 0.75*,* and *very strong* = 1. For each typology of actor (e.g. biotech company), data were aggregated averaging. These results were then grouped by category and the average of each category was calculated. The resulting average was then transposed into different scales with the relationships reported in Tab 9.

Table 9. Transposition of the acquired values into the two reference scales (Scale 1 and Scale 2)

Average result	Scale 1	Scale 2
$0 \leq x \leq 0.2$	0	0
$0.2 < x \leq 0.4$	1	0.33
$0.4 < x \leq 0.6$	2	0.66
>0.6	3	1

In the following section, results are listed following the GTT approach. In particular, in the first part, the assessment of relationships between categories in the Italian KISB is provided. In the second part, we move to the assessment of the information flow in the system. Finally, the third sub-section presents a summary of the responses gathered from the three interviews and the two open-ended questions within the questionnaire.

3. Results

3.1. Assessment of relationships in the Italian KISB

3.1.1. Linkage matrix

The Linkage matrix (LM) is the result of interactions among the five categories considered. Its representation is provided in Fig. 20.

LM =

H	HF	HR	HB	HO
FH	**F**	FR	FB	FO
RH	RF	**R**	RB	RO
BH	BF	BR	**B**	BO
OH	OF	OR	OB	**O**

Figure 20. Linkage matrix of the Italian KISB

This matrix clarifies the relationship considered in each cell of the following matrices. For example, in all the matrices that will follow, the cell in the third row and fourth column will represent the relationship B → R (i.e. the relationship that public bodies, B, claimed to have with research institutes, R). The total number of possible edges is [5!/(5-1-1)!] = 20 (see methodology).

3.1.2. Coded matrix

Based on the answer received, all the possible relationships exist (Fig. 21). More in detail, sometimes individual relationships are absent (e.g. one NGO with food industry) or very weak (e.g. one public research institute with incubators), but, on average, each category exceeds the threshold value to consider the relationship as existing.

CM =

H	1	1	1	1
1	**F**	1	1	1
1	1	**R**	1	1
1	1	1	**B**	1
1	1	1	1	**O**

Figure 21. Coded matrix of the Italian KISB

In the Coded matrix (CM), the existing relationships are represented by the value "1." Due to these results, we did not translate the CM into a visual format (see methodology).

3.1.3. Refined matrix

The Refined matrix (RM) shows the strength of linkages as perceived by different categories (Fig. 22). On average, these findings depict a scenario of medium-high intensity of linkages among categories. Indeed, no weak (1) linkages are reported, with only medium (2) or strong

RM =

H	2	3	2	2
3	**F**	3	2	2
3	2	**R**	2	2
2	2	3	**B**	3
3	2	3	2	**O**

Figure 22. Refined matrix of the Italian KISB

(3) relationships. In particular, by consulting the rows we obtain an overview of the intensity of the relationships perceived by a category (e.g., H), while in the columns we find the perceived intensity of relationships of the other categories (in the previous example case, i.e. F, R, B, and O) with that category (H). Based on that, we notice that R and H reported less intensity of relationships than the others with them. Instead F, B and O reported higher intensity compared to the relationships reported by others.

3.1.4. Adjusted matrix

By asking about the influence of their organization on other organizations, we obtained the basis for calculating the Adjusted matrix (AM). This matrix is the result of the three-grade influence scale (weak, medium, strong) multiplied by RM – hence, multiplied by the intensity of the relationship (Fig. 23).

$$AM = \begin{pmatrix} \mathbf{H} & 2.m & 3.m & 2.w & 2.w \\ 3.w & \mathbf{F} & 3.m & 2.w & 2.m \\ 3.s & 2.m & \mathbf{R} & 2.m & 2.m \\ 2.s & 2.m & 3.s & \mathbf{B} & 3.s \\ 3.m & 2.m & 3.m & 2.m & \mathbf{O} \end{pmatrix} = \begin{pmatrix} \mathbf{H} & 1.32 & 1.98 & 0.66 & 0.66 \\ 0.99 & \mathbf{F} & 1.98 & 0.66 & 1.32 \\ 3 & 1.32 & \mathbf{R} & 1.32 & 1.32 \\ 2 & 1.32 & 3 & \mathbf{B} & 3 \\ 1.98 & 1.32 & 1.98 & 1.32 & \mathbf{O} \end{pmatrix}$$

Figure 23. Adjusted matrix of the Italian KISB

The results show the highest influences in RH, BR, and BO; the lowest influence values were found in HB and FB.

3.1.5. Cause-Effect Structure of Adjusted matrix

The AM does not only provide an overview of the individual influences but, based on Temel (2003), summing the values in a row or in a column, it is possible to figure out, respectively, the causal (Cause or C) and the effective (Effect or E) components of the system (Tab. 10).

Table 10. Total Cause and Total Effect values per each category of actors of the Italian KISB

Category of actor	Total Cause	Total Effect
H	4.62	7.97
F	4.95	5.28
R	6.96	8.94
B	9.32	3.96
O	6.6	6.3

The component that causes less innovation is H (4.62), while, the maximum capacity to cause innovation is expressed by B (9.32). On the other hand, B is also the category that is less affected by the system (3.96). Instead, R represents the category with the highest value in terms of total effect (8.94).

Plotting the identified values, it is possible to easily recognize the five categories (Fig. 24) as dominant and subordinate components of the system.

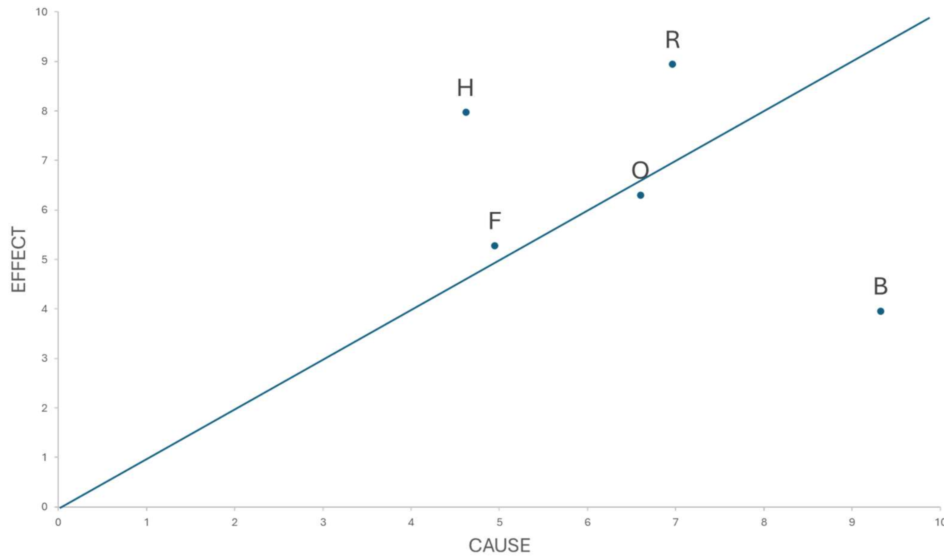


Figure 24. Cause-Effect structure of the Italian KISB

The dominant components lie below the diagonal, while above the diagonal there are the sub-ordinate categories. The only dominant component – i.e., a component that influences the system more than others influence it – is B. Instead, H and R are sub-ordinate components of the system, being influenced by the system more than they can influence the system. Finally, F and O lie are close to the diagonal, meaning that their cause and effect are relatively equal. Such kinds of components are considered interactive components of the system.

The considered KISB has a density (d) equal to 1. In fact, the actual linkages correspond to the number of potential ones. This means that the structure is fully identified, and each component influences the others.

3.2. Assessment of Information Flows in the Italian KISB

3.2.1. Information Flow Matrix

The Information Flow matrix (IFM) aims to identify the promoters and receivers of information. It is based on three capacities of each component (Fig. 25c): learning capacity (λ); sharing capacity (σ); receiving capacity (ρ). In our study we obtained two further matrices, splitting information flow sharing capacity matrix (IFM_s – Fig. 25a) and information flow receiving capacity matrix (IFM_r – Fig. 25b).

a.

$$IFM_{\sigma} = \begin{pmatrix} \mathbf{H} & \sigma^{HF} & \sigma^{HR} & \sigma^{HB} & \sigma^{HO} \\ \sigma^{FH} & \mathbf{F} & \sigma^{FR} & \sigma^{FB} & \sigma^{FO} \\ \sigma^{RH} & \sigma^{RF} & \mathbf{R} & \sigma^{RB} & \sigma^{RO} \\ \sigma^{BH} & \sigma^{BF} & \sigma^{BR} & \mathbf{B} & \sigma^{BO} \\ \sigma^{OH} & \sigma^{OF} & \sigma^{OR} & \sigma^{OB} & \mathbf{O} \end{pmatrix}$$

b.

$$IFM_{\rho} = \begin{pmatrix} \mathbf{H} & \rho^{HF} & \rho^{HR} & \rho^{HB} & \rho^{HO} \\ \rho^{FH} & \mathbf{F} & \rho^{FR} & \rho^{FB} & \rho^{FO} \\ \rho^{RH} & \rho^{RF} & \mathbf{R} & \rho^{RB} & \rho^{RO} \\ \rho^{BH} & \rho^{BF} & \rho^{BR} & \mathbf{B} & \rho^{BO} \\ \rho^{OH} & \rho^{OF} & \rho^{OR} & \rho^{OB} & \mathbf{O} \end{pmatrix}$$

c.

$$IFM = \begin{pmatrix} \mathbf{H(\lambda)} & \sigma^{HF}\rho^{HF} & \sigma^{HR}\rho^{HR} & \sigma^{HB}\rho^{HB} & \sigma^{HO}\rho^{HO} \\ \sigma^{FH}\rho^{FH} & \mathbf{F(\lambda)} & \sigma^{FR}\rho^{FR} & \sigma^{FB}\rho^{FB} & \sigma^{FO}\rho^{FO} \\ \sigma^{RH}\rho^{RH} & \sigma^{RF}\rho^{RF} & \mathbf{R(\lambda)} & \sigma^{RB}\rho^{RB} & \sigma^{RO}\rho^{RO} \\ \sigma^{BH}\rho^{BH} & \sigma^{BF}\rho^{BF} & \sigma^{BR}\rho^{BR} & \mathbf{B(\lambda)} & \sigma^{BO}\rho^{BO} \\ \sigma^{OH}\rho^{OH} & \sigma^{OF}\rho^{OF} & \sigma^{OR}\rho^{OR} & \sigma^{OB}\rho^{OB} & \mathbf{O(\lambda)} \end{pmatrix}$$

Figure 25. Information flow matrices of the Italian KISB: a. Information sharing flow matrix; b. Information receiving flow matrix; c. overall Information flow

Capacity Matrix of Information Flows

The estimation of the capacities of sharing and receiving ranges from medium to strong (Fig. 26). Considering σ, the strongest relationships are claimed by F, B and O, but only F and O perceive a strong capacity twice (i.e. FH, and FR; OR, and OB). More in detail, F considers a

$$CIFMs = \begin{pmatrix} \mathbf{H} & m & m & m & m \\ s & \mathbf{F} & ss & m & m \\ m & m & \mathbf{R} & m & m \\ m & m & m & \mathbf{B} & s \\ m & m & s & s & \mathbf{O} \end{pmatrix} \qquad CIFMr = \begin{pmatrix} \mathbf{H} & m & m & m & m \\ s & \mathbf{F} & s & s & m \\ s & m & \mathbf{R} & m & m \\ m & m & s & \mathbf{B} & s \\ s & m & s & m & \mathbf{O} \end{pmatrix}$$

Figure 26. Capacity matrix of Information sharing flow (CIFMs) and Information receiving flow (CIFMr) for the Italian KISB

strong capacity to share with research entities (both H and R). Considering O, the relationship with B is remarkable, given that is the only symmetrical relationship in which both claim to share strongly with the other (B→O and O→B). R and H are both characterised by a medium capacity to share with others. Similarly, moving to their capacity to receive (ρ) from others, these two categories keep medium capacity, except in the case of RH, considered by R as strong. However, looking at the columns of $CIFM_r$, all the other categories perceive as strong their capacity to receive from both H and R (except in the case of HR, which is a medium, showing an asymmetry with RH).

By multiplying $CIFM_s$ with $CIFM_r$, the final CIFM is calculated (Fig. 27), showing the overall ability to be a player in the information flow.

$$CIFM = \begin{pmatrix} \mathbf{H(m)} & mm & mm & mm & mm \\ ss & \mathbf{F(s)} & ss & ms & mm \\ ms & mm & \mathbf{R(s)} & mm & mm \\ mm & mm & ms & \mathbf{B(s)} & ss \\ ms & mm & ss & sm & \mathbf{O(s)} \end{pmatrix} = \begin{pmatrix} \mathbf{H(M)} & 0.4 & 0.4 & 0.4 & 0.4 \\ 1 & \mathbf{F(s)} & 1 & 0.7 & 0.4 \\ 0.7 & 0.4 & \mathbf{R(s)} & 0.4 & 0.4 \\ 0.4 & 0.4 & 0.7 & \mathbf{B(s)} & 1 \\ 0.7 & 0.4 & 1 & 0.7 & \mathbf{O(s)} \end{pmatrix}$$

Figure 27. Overall Capacity matrix of Information flow for the Italian KISB

Furthermore, in the diagonal of CIFM, λ is shown. In this vein, all the categories perceive as strong the capacity of their organisations to learn, with the sole exception of H, which records a medium value. In the off-diagonal cells, the highest values are reached in FH, FR, BO and OR (1). In the case of CIFM, the relationship between B and O loses its symmetry, due to the medium capacity of O to receive from B. No weak capacity are reported.

3.2.2. Adjusted Capacity Matrix of Information Flows

In order to weight each capacity by the intensity of each relationship, CIFM is multiplied by RM. In this way, we obtain the Adjusted Capacity Matrix of Information Flows (ACMIF – Fig. 28).

$$
ACIFM = \begin{pmatrix} H(m) & 0.4 & 0.4 & 0.4 & 0.4 \\ 1 & F(s) & 1 & 0.7 & 0.4 \\ 0.7 & 0.4 & R(s) & 0.4 & 0.4 \\ 0.4 & 0.4 & 0.7 & B(s) & 1 \\ 0.7 & 0.4 & 1 & 0.7 & O(s) \end{pmatrix} \times \begin{pmatrix} H & 2 & 3 & 2 & 2 \\ 3 & F & 3 & 2 & 2 \\ 3 & 2 & R & 2 & 2 \\ 2 & 2 & 3 & B & 3 \\ 3 & 2 & 3 & 2 & O \end{pmatrix}
$$

$$
ACIFM = \begin{pmatrix} H(m) & 0.8 & 1.2 & 0.8 & 0.8 \\ 3 & F(s) & 3 & 1.4 & 0.8 \\ 2.1 & 0.8 & R(s) & 0.8 & 0.8 \\ 0.8 & 0.8 & 2.1 & B(s) & 3 \\ 2.1 & 0.8 & 3 & 1.4 & O(s) \end{pmatrix}
$$

Figure 28. Adjusted Capacity matrix of Information Flow for the Italian KISB

Based on the final ACMIF, the highest values are reached in FH, FR, BO and OR. This means that there are strong information flows from F to research entities (i.e. H and R); furthermore, O receives strong flows from B, but promotes information towards R. Considering the lowest values (0.8), ten relationships are included (HF, HB, HO, FO, RF, RB, RO, BH, BF, OF). It is important to underline that these relationships are the result of medium intensity, therefore, although low, they cannot be considered weak relationships. However, two considerations can be made in this vein. First, both the research categories claim a medium-low capacity of exchanging information with no-research entities. In fact, both have three relationships out of four with the lowest value (0.8) and in all cases these relationships are with the no-research entities (F, B, and O). This may mean that research institutions have difficulty in creating strong information flows with other components of the system. Second, F is the only one with all the other four categories that claim to have medium-low information flow with it. Indeed, looking at its column, all four relationships (HF, RF, BF, OF) have a value of 0.8. This underlines the difficulty of the system to reach the private sector (medium overall capacity of being a player in the system and medium capacity creating strong relationships).

3.2.3. Information flow structure

Following the same steps made for the cause-effect structure, each row and each column was summed, providing, respectively, the total promotion and total reception ability of each category (Tab. 11).

Table 11. Total Promotion and Total Reception values per each category of actors of the Italian KISB

Category of actor	Total Promotion	Total Reception
H	3.6	8
F	8.2	3.2
R	4.5	9.3
B	6.7	4.4
O	7.3	5.4

Regarding the main promoters, the category with the highest ranking is F (8.2), followed by O (7.3). Instead, in terms of reception, F is the last one, with a value of 3.2, while the maximum value is reached by R (9.3), followed by H (8). The latter is even the one with the lowest value on the promotion side (3.6).

The visualisation of the information flow structure of the Italian KISB is shown in Fig. 29.

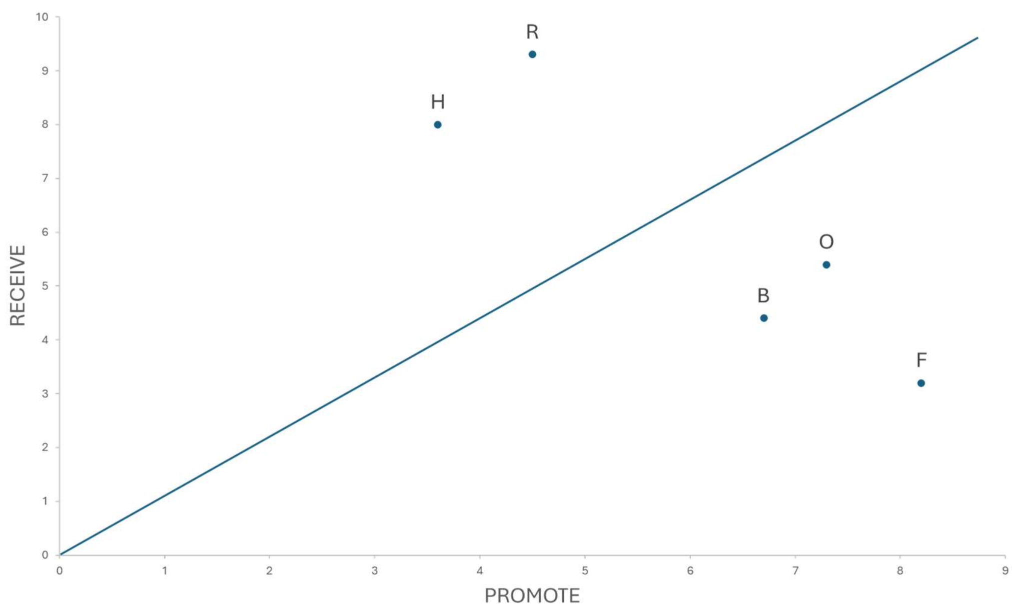


Figure 29. Information flow structure for the Italian KISB

In the plot, we can observe a polarization into two main groups. On one side there are the promoters (promotion > reception), consisting of F, O and B. On the other side, there are the targets (promotion < reception), represented by R and H. No connectors (promotion ≈ reception) are reported. In fact, even if B and O are closer to the diagonal compared with the other categories, they cannot be considered connectors.

3.3. Qualitative insights

In response to the request for further clarifications on the relationships assessed in the questionnaire, one interviewee, representing the National Coordination Group of Bioeconomy of the Presidency of the Council of Ministers (GCNB), underlined the focal importance of clusters in acting as intermediaries between GCNB and private companies. Hence, in this case, the relationship is not direct (B→F), but indirect: B→O→P. Another observation came from one representative of a public research institute (R), who complained about the poor possibility of interacting with B (in particular ministries and government bodies). Furthermore, the same respondent calls for more exchanges with civil society and information bodies (O category). Finally, a representative of an NGO underlines the importance for their organization to be part of an initiative which allows the creation of a network with local entities and valorises the circular bioeconomy.

Considering the second open-ended question (i.e. "any reflections on innovation, knowledge creation and knowledge transfer in the bioeconomy in Italy"), several in-depth answers on the topic have been received. To summarise, two main aspects are underlined about bioeconomy innovation and bioeconomy in general: i) the split between the political agenda and the productive context; ii) the difficulty of implementing the development model proposed by the bioeconomy (circular and sustainable) at a local level.

Based on the answers recorded, the first aspect (i) is valid for both the Italian and global contexts. More in detail, aspect (i) refers to the increasing number of political occasions where specific strategies for the bioeconomy are debated, such as the G20 meeting in Brazil (GIB, 2024) or the ongoing European discussion on reviewing its strategy (EC, 2025). However, for one respondent these political debates seem more a way to find international fields of debate rather than as a real model of sustainable development. In this vein, as underlined by one of the interviewees, at the national level there are many political forms of reception of what emerges at the international level, such as the aforementioned GCNB. Nevertheless, one respondent expresses the need to valorise the GCNB, while one of the interviewees, representing a cluster, points out that there is a problem in the local and regional implementation of the strategic elements proposed by the GCNB. More in detail, this interviewee proposes that the approach to bioeconomy innovation and implementation should be disseminated at the national level and then contextualised at the regional level. This leads to the second aspect (ii), which emerges from several points of view from the responses collected. Despite the difficulties encountered so far in the full implementation of the bioeconomy, from the responses collected, it is possible to outline some key aspects (and the corresponding key players) to enable this sector. First, the aforementioned need to make a national vision and regional contextualisation calls in action mainly representatives of B (in particular national and regional governments). Local or regional contextualisation requires an important preliminary phase of study of the local context in terms of biomass flows, biowaste, technological capacity, etc. Under this aspect, the role of research entities (H and R) is perceived as pivotal by one of the interviewees. Greater efforts should be made in an attempt to involve the primary production component, as emerged in two interviews: to date, there are difficulties in inserting this national component into bioeconomic circuits. On this aspect, one respondent underlines a "general sense of conservatism [of farmers] that slows down innovation if it is not already demonstrably economically convenient." Nevertheless, respondents did not indicate which category should make these efforts. In addition, the F component is not the only one that should be involved more in the bioeconomy innovation and implementation process: several answers from researchers indicate how important interaction and involvement with civil society is. To be implemented this involvement should be done both through greater communication efforts (especially from H and R) and through collaborative approaches, such as *open innovation*, *open science* and *citizen science*.

Finally, some issues emerged in terms of knowledge transfer and networking. First of all, several responses noted a lack of ad hoc sharing activities (both formal and informal). Furthermore, in the national context, there is still a high level of sectorisation which does not favour exchange between different market sectors that may have possible common interest in the circular bioeconomy. In general, the answers highlight the absence of a critical mass of operators to refer to for knowledge and innovation transfer – one respondent even states that "The transfer of knowledge is still at a larval stage in Italy." An example of this lack of references is given by one respondent who underlines the absence of stable and known communication channels specific to the bioeconomy. Furthermore, a researcher underlines the high risk of knowledge dispersion that this lack of critical mass of operators can cause.

4. Discussion

4.1. The role of components in the KISB

The lack of specific literature on GTT in the bioeconomy does not allow us to make considerations or comparisons with other systems. More in general, to the Authors' best knowledge, there are no studies, both practical and theoretical, that analyse (or try to) the optimal system. In other words, the state of the art does not allow to figure out which should be the optimal position in the outlined structures – i.e. cause-effect structure and information flow structure – of every single component so that the system works effectively. In the case of the bioeconomy, and in particular the EU one, the optimal system should implement value chains that contribute to sustainable development (de Vries et al., 2021). However, based on the wide literature on innovation and, particularly, on bioeconomy innovation, it is possible to highlight some elements found in this study. In particular, considerations on both single agents and the system as a whole can be outlined (Kassem et al., 2022; Temel et al., 2003).

Regarding the single agents that compose the Italian KISB, one of the most interesting results of this research is the position taken by research entities (H and R). These components are placed in the subordinate group in the cause-effect structure and are perceived as targets of information flows. These findings challenge the intuitive expectations on research entities as promoters of innovation and diverge from the linear interpretation of the innovation process (Godin, 2006). However, even Rametsteiner and Weiss (2006) found that H and R are not seen by innovators as important innovation-enabling stakeholders in the forest-based bioeconomy. On the contrary, Lovrić et al. (2020) found that, in the same sector, cooperation with universities and research institutes is seen positively. Hence, the issue is controversial. However, in the Italian KISB, a possible explanation of why H and R are seen as targets and not promoters is the fact that these entities are the ones that request more information for research purposes and often they do not reciprocate by sharing information useful for innovation purposes (Ankrah and AL-Tabbaa, 2015; Compagnucci and Spigarelli, 2020; De La Torre et al., 2018). An empirical example is given in this study. We asked for information from all the members of KISB but many of the respondents will not see or have access to the results of this research. As underlined by Rybnicek and Königsgruber (2019) in their literature review, this can be connected to the different outcomes that researchers and firms may have, creating a mismatch in the *objectives* they have. In our case, this aspect can be extended to all the other no-research entities, and may partially explain why the other components, such as F, perceive as strong their capacity to share with research entities and medium the capacity to receive from H and R. This is also in line with the results found by Vega-Jurado et al. (2021), who explored the limited benefit perceived by Spanish firms in collaborating with public research institutes. On the other hand, even H and R do not perceive as strong the innovation flow towards no-research entities. This result may be related to the disproportion between the high number of no-research entities and the research entities existing in the KISB. In fact, whether a company (F) or an association (O) establishes strong relationships with one research centre and two universities, the organization may be led to perceive that it possesses a strong linkage with H and/or R components. Instead, the way reverse is not possible: one university (H) or research centre (R) that, for example, holds only three strong relationships with private companies cannot consider as strong the relationship with F. This is because H and R are aware of the very high number of private companies that compose F in the KISB. This aspect clearly emerges in our previous Social Network Analysis on the EU Framework Programs participants, where the F members have the highest participation rate (>50% of the network) but lower degrees (i.e. number of edges a node has) compared to the H and R members.

Considering the implementation of the bioeconomy, based on the qualitative insights, H e R may assume the role of facilitators towards civil society and territorial realities. In this vein, a contribution from Bijon et al. (2023) provides an example of how to engage stakeholder dialogue within the bioeconomy. However, the preferred ways to build relationships with O members are: participation in initiatives and projects (as emerges from the results of this paper); fostering the so-called third mission of universities (Compagnucci and Spigarelli, 2020), i.e. “contribution to society”; implementing entrepreneurial pathways from research to market (Garay et al., 2015).
However, the fact that OR is one of the strongest relationships in terms of information flow represents an opportunity for the system to fill the gap between O and researchers: exploiting the same relationships, efforts can be made to strengthen even RO.

As we found, in the Italian KISB, the role of O is of primary importance. Indeed, as emerged from the interview with the representative of B, the clusters are the principal intermediaries between B and F. This is an aspect that emerges even in the literature, with the contribution of Alfano et al. (2023), which focuses on one of the main Italian bioeconomy clusters, the SPRING cluster and underlines the role of this cluster in pushing associate organisations towards the most innovative business models. Furthermore, Kamath et al. (2023) underline the importance of bioclusters in helping to lead the Basque pulp and paper firms towards green transition. However, given the paramount importance given by B to O, the medium capacity of O to receive information from B represents a weakness in the system that should be addressed. Furthermore, in the information flow structure, O is considered a promoter, while in the aforementioned papers, its incisive role is performed through the intermediation between the political agenda and the firm's needs (Alfano et al., 2023; Kamath et al. (2023). Hence, further analysis should be done to explore this aspect of the Italian KISB. Moreover, associations, foundations and NGOs can have a primary role even in primary producers' engagement

(Chmielińskii and Wieliczko, 2022; Fieldsend et al., 2020; Fieldsend et al., 2021). As we saw in our results, this part of the system is difficult to reach. In addition, even for this research, no primary producers replied to our questionnaires, and none of the contacted stakeholders indicated any primary producers as a key agents in the Italian bioeconomy.

Considering the F component as a whole, it represents the main promoter of information flow. This may be connected with the proximity of private companies to the market that forces them to raise public awareness of the bioeconomy (Lang et al., 2023; Salvador et al., 2021) or find biotechnology legitimization (Losacker et al., 2023). However, the claimed strong information flow with H and R is an aspect that deserves further analysis (both qualitative and quantitative) to understand the mechanisms that regulate such interactions, in particular in terms of main forms of interactions, funding, and resource sharing.

Finally, considering B, several considerations can be made. Not surprisingly, B is the only dominant component of the cause-effect structure, underlining its power in the bioeconomy field (D'Amato et al., 2022). On the other hand, the very low effect value of B and the low influence that both H and F claim to exercise on B may represent a weakness in the system, with the policymakers little inclined to synthesize information and innovations coming from both the world of research and the business world. Also, in this case, further investigations are necessary to define the power relations between these agents and B's responsiveness to change caused by innovation.

The difficulty in finding a reference point for the bioeconomy that we found in our results was experienced even by us submitting the questionnaire. Indeed, nowadays, it is difficult to find specific public administrative offices or sections for the bioeconomy in the Italian regions, with its implementation still fragmented in different sectors (Viaggi, 2018a). The main public authority is the aforementioned GCNB, which represents 5 ministries and 20 regions. However, the role of the GCNB is to coordinate and provide a vision for the Italian bioeconomy and not to implement the bioeconomy locally. This latter task falls to local and regional authorities. In fact, several regions in Italy have adopted their own strategies for the bioeconomy (Joint Research Centre European Commission, 2022). Nevertheless, based on D'Adamo et al. (2022), there still remain deep discrepancies in regional transitions to the bioeconomy in Italy, with southern regions significantly underperforming compared to the national average. In this sense, Hurtado and Berbel (2023) analysing the Circular Bioeconomy of Andalusia – a Spanish region that for climate, biomass production and main value chains can be compared to southern Italian regions – found that a key element for the development of the bioeconomy is the support provided by the government to learning and knowledge-related processes. However, to overcome the problems that intersectoral innovation (D'Amato et al., 2022) may cause and to push knowledge co-production towards maturity (D'Amato et al., 2022; Scheiterle et al., 2018), policymakers should implement a mix of innovation policies, as underlined by (Wydra, 2019).

4.2. Limitations and future research

The present study represents an attempt to quantify relationships between different actors in the Italian KISB. However, it had to face several limitations. First, the low number of respondents – in particular in some categories, such as B – does not allow us to consider this study as exhaustive. Nevertheless, it is important to underline that the limited number of respondents is part of a specific respondent selection strategy. In fact, we decided to target key actors of the system rather than mass distribution (for example sharing the questionnaire via social media). The key actors were identified based on the Social Network Analysis carried out in the previous study. Furthermore, to enlarge the network of respondents (avoiding the risk of contacting only organisations involved in EU projects), when we shared the questionnaire via email, we asked to any subjects to share with any actor that they consider relevant for innovation and knowledge development in the Italian bioeconomy. Hence, the network of experts involved allows us to consider the collected responses as valuable. However, future research may be carried out with a wider audience of respondents, through a more widespread distribution of the questionnaire. Another limitation is the low number of categories considered. Future analysis may focus on a broader number of categories, for example highlighting the different sectors' components. Furthermore, this study is completely based on the subjective perspectives of respondents. In alignment with the distinction provided by Giurca (2018), this investigation focused on the "network we see." The next steps should be done in the direction of exploring the "network we have." To do so, in addition to the further research on specific relationships already indicated in the previous sub-section, an in-depth analysis of objective indicators of joint activities (e.g., shared patents, joint publication of documents or joint training of students/staff) should be carried out.

5. Conclusions

The application of GTT on the Italian KISB provided several insights. The structure is fully identified (Temel et al., 2003), i.e. any possible relationship among all the categories exist. On average, medium to high intensity characterises these relationships. Considering the cause-effect structure of the Italian KISB, the *public bodies* category is the only one that causes innovation, while *higher and secondary education establishments* and *research institutes* are sub-ordinated categories. Finally, *private for-profit and other* are interactive components. Instead, looking at the information flow structure, no intermediaries (called connectors) are found. In fact, in this case, only two groups emerge: the promoters, consisting of *private for-profit*, *other*, and *public bodies*; and the target, represented by *higher and secondary education establishments* and *research institutes*. Moreover, considering individual linkages, we found that *private for-profit* companies claim a strong capacity to share with research entities, while these entities claim a medium capacity to receive by private for-profit companies, showing an asymmetry that may be explained by the different number of components of the two categories (few research entities for many private for-profit companies). Another important strong relationship is that between *public bodies* and *other* category. In this case, public bodies claim a strong capacity to share with other, but this latter category perceives as medium its capacity to receive from public entities. This asymmetry may have important repercussions on the diffusion of knowledge and innovation in the Italian bioeconomy because of the important role that *other* category has in mediating between public bodies and businesses, between public bodies and various stakeholders. Therefore, this aspect would merit further research.

Chapter 5 - Discussion

5.1. Approach of the thesis

The present dissertation takes as a theoretical reference the framework outlined by Kurtsal et al. (2023) for the AKIS (Fig. 30). In this framework, the dynamism of an IS is depicted from a policy perspective, specifically through the development of improved policies. The starting idea is that the current body of legislation substantially shapes an IS (AKIS in the case of Kurtsal et al., 2023). However, policy gaps arise from the interaction among actors and the varying degrees of policy enforcement. The research and identification of these gaps allow for

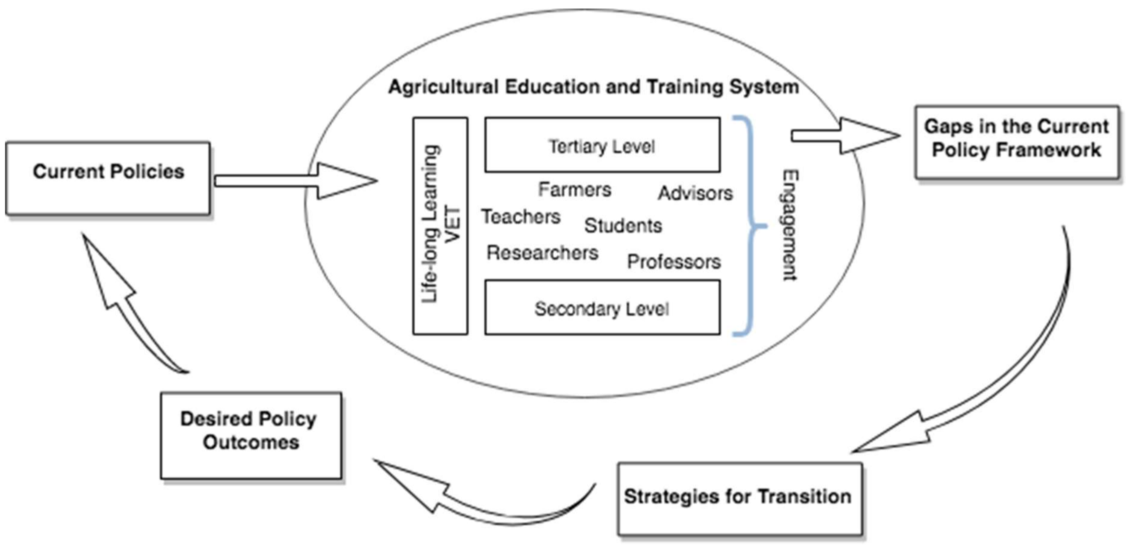


Figure 30. The framework for policy transition proposed by Kurtsal et al. (2023)

tailored policy interventions. Subsequently, a new body of policies is introduced with the aim of reshaping the IS or its mechanisms. What has been exposed through Kurtsal's framework is the basis of innovation and network policies, which aim to compensate for the failures of the system (Aragón et al., 2012).

In an attempt to transpose this framework in the field of the bioeconomy, several questions arise. The first question was whether the IS concept had ever been applied to the bioeconomy. Secondly, we asked ourselves whether current policies are sufficient to outline an IS for the bioeconomy. Finally, a third question was whether it is possible to provide a description of the relationships and information flows within an IS for the bioeconomy, so that current gaps in the system may be found. The central focus of this doctoral dissertation revolves around the exploration of these three inquiries, which we aimed to address.

Hence, after finding a scope for the KISB and its main peculiarities, we tried to adapt this framework to a real context, taking the Italian bioeconomy as a reference. In the Italian context, we first tried to outline a knowledge and innovation network based on the EU innovation policies (i.e. research projects under the FPs), and then, we analysed the relationships and the information flow within the whole KISB.

In detail, the following main results can be highlighted:

1- In the first study, we conducted a systematic literature review to explore the application of the IS framework in the field of the bioeconomy, aiming to characterise the KISB. Nowadays, this framework is missed. In fact, we found that several approaches were adopted, but usually, the approach adopted was the one best fitting for the purpose of the research, with rare examples of seeking a holistic framework that describes innovation processes within the bioeconomy, as also confirmed by Van Lancker et al. (2016), Viaggi et al. (2021) and Bröring et al. (2020).

   Despite this gap in the literature, one of the main results of this study is the possibility of applying and benefiting from a specific KISB: The mechanisms and dynamics examined in this study go further beyond the simple technology-oriented or linear approach to innovation, requiring systemic approaches that take into account the complex amount of skills and professionals needed to implement bioeconomy processes (e.g. in biowaste management as underlined by Taffuri et al., 2021). Furthermore, we found some peculiarities that should characterise the KISB. First, based on the result that *intense cooperation* and a *complex knowledge base* are the most common factors, we outlined how the multi-actor approach and multidisciplinary are fundamental in the bioeconomy innovation processes and it is not possible to avoid this in the KISB. Second, we found a more intense stream of research in the field of collaborations rather than innovations. In this sense, the efforts made by scholars can strongly contribute to outlining a KISB, for example including the analysis of knowledge development. Third, even if less represented, the innovation-oriented papers add insights in terms of challenging aspects of commercialisation in the bioeconomy and their attitude towards the concept of *stakeholder*. Finally, we found that there is a wide scope for KISB and the connected concept of microKISB (i.e. the innovation subset of the whole KISB that operates at the organisation's individual level) in both business-centred and policy-centred research. Therefore, KISB and microKISB must be designed in such a way that they can represent an interesting and useful tool for all the actors involved in the bioeconomy innovation process like policymakers, business actors, and researchers.

2- In the second study, we focused on a specific national context, Italy, trying to describe the emerging Horizon projects-based network. Based on the widely known Social Network Analysis approach, the results shed light on the Italian knowledge and innovation network, identifying as the most central actors three public research organisations (two research institutes and one university). More in detail, the eigenvector centrality, a measure of the nodes most connected with the most central nodes, points out that the core structure of the network is based on research entities (i.e. Higher or Secondary Education Institutes, and Research Institutes). We also found that this core structure is common in other countries, such in the cases of (Stöber et al., 2023) and Giurca (2018) and it can be related to a path dependency in public funds allocation as also underlined by Sekerci and Alp (2023).

   Other typologies of actors (i.e. Private for-profit entities, Public bodies, and Others) do not occupy central positions, except in the case of closeness centrality, a measure of actors' capacity to affect the network. The diverse origins of the nodes that exhibit high closeness centrality may enable the network to achieve efficient and rapid information flow across different sectors. However, based on the betweenness centrality, we discovered a weak capacity of non-research entities to act as gatekeepers. In fact, only one private company (Novamont) assumes that role. Moreover, we found that, considering two subperiods of the network (2012-2017, and 2018-2023), dynamics within the network changed over time. The private for-profit entities lost centrality from one subperiod to the other, while connectivity increased notably between the two subperiods. Based on innovation network literature, this growth in ties might have had a negative effect on the innovativeness of the network as also underlined by Saviotti (2009), but, at the same time, it might have contributed to the strength and resilience of the whole knowledge and innovation system for the bioeconomy (KISB) – of which the network we found is only a part – and, more in general, the national bioeconomy (Caloffi et al., 2013; Gerassimidou et al., 2023; Protogerou et al., 2010b; Russo and Rossi, 2009).

3- Finally, in the third research, we applied the Graph-Theoretical Techniques (GTT – Temel et al., 2003) on the Italian KISB to assess the relationships and information flows among the several components of the IS. We found that the structure is fully identified, i.e. any possible relationship among all the categories exist (in line with what we found in the previous SNA), and, on average, medium-high intensity characterises these relationships. Furthermore, the GTT methodology allows the identification of the cause-effect structure of innovation and the information flow structure. Considering the cause-effect structure of the Italian KISB, *Public bodies* are the only category that causes innovation, while *Higher or Secondary Education Institutes*, and *Research Institutes* are sub-ordinated categories and *Private for-profit* and *Other* are interactive components and these results differs from findings of López Hernández and Schanz, (2019), and Lovrić et al. (2020) but are in line with Rametsteiner and Weiss (2006). Instead, looking at the information flow structure, no intermediaries (called in this case *connectors*) have been found. In fact, in this case, only two groups emerge: the promoters, consisting of Private for-profit, Other, and Public bodies; and the targets, represented by *Higher or Secondary Education Institutes*, and *Research Institutes*. These results are in line with Alfano et al (2023), Kamath et al. (2023). Furthermore, in this study, several qualitative insights helped us to depict a better picture of the Italian KISB. First, the respondents pointed out a lack of a critical mass of actors serving as a reference point for innovation, and the absence of stable and well-established reference channels. Second, there is difficulty in engaging primary producers in the bioeconomy circuits, as also underlined by Chmielińskii and Wieliczko (2022), and Harrahill et al. (2023). Finally, knowledge transfer is considered to be still at the "larval stage" – as reported by one of the respondents.

Based on the obtained results, and following the whole analysis done in this dissertation, we can outline the transposition of Kurtsal et al. (2023) framework into the bioeconomy, as outlined in Fig. 31.

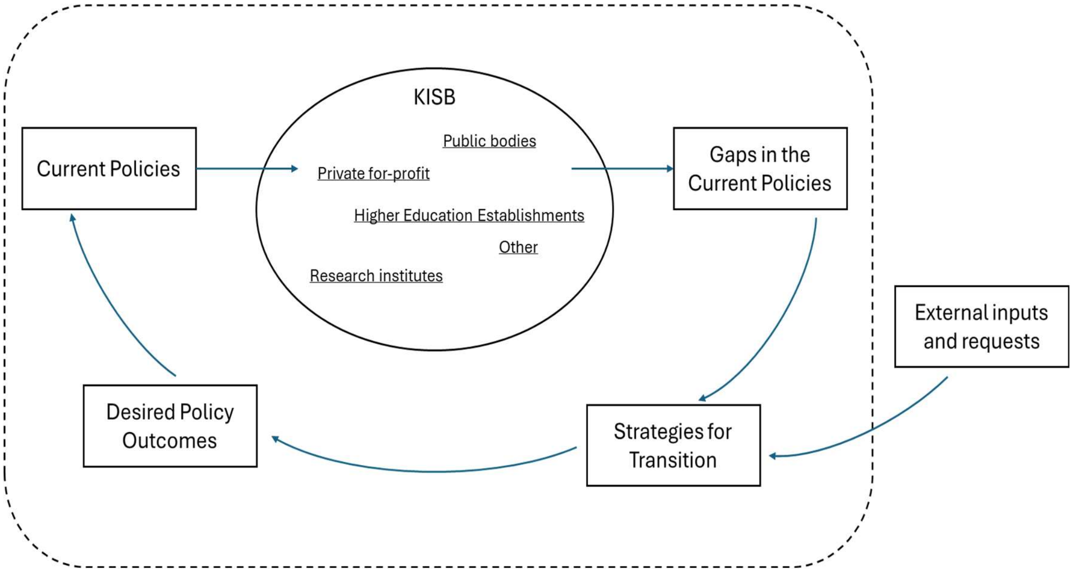


Figure 31. Readaptation of the framework proposed by Kurtsal et al. (2023) to the bioeconomy context. Authors' elaboration

After identifying knowledge gaps in the literature on the topic of KISB (first study), the next step (second study) was to identify a perspective from which it was possible to outline the current KISB in a specific area. We decided to take into consideration one specific innovation policy: the EU Framework Programs. This policy framework resulted in a knowledge and innovation network, whose main components are Research Institutes, Higher or Secondary Education Establishments, Private for-profit companies, Public bodies and Other. A further step in the knowledge of the Italian innovation system was to identify strengths and gaps in relationships and information flows among actors, to find leverage points for future tailored policies. Furthermore, within our analysis of the innovation process in the bioeconomy, we found the paramount importance of external inputs and requests, such as those regarding sustainability or ethical dilemmas.

5.2. Limitations and future research

Every chapter of this dissertation had to face several limitations, namely:

1- The literature review focused on very specific criteria that excluded part of the innovation processes. Among these, we considered only papers that expressly addressed bioeconomy visions, and not sectoral visions. Furthermore, we excluded the linear approach of innovation and contributions provided before 2017, the year we chose as the lower limit of our study. These exclusions may have limited the descriptive capacity of the analysis. Therefore, further insights for theoretical advancements in knowledge creation and innovation development in the field of bioeconomy may emerge from a broader analysis that takes into account the criteria here excluded. For example, future research may address a systematic literature review to identify similarities and differences among the innovation systems of the various sectors that compose the bioeconomy. In this way, instead of adopting an exclusively bioeconomic perspective – as done in our study –, it may be possible to proceed with a sectoral analysis that is then merged into a bioeconomic vision. We also believe that such analysis should include the linear approach to innovation, because this approach characterises (or has characterised) some of the sectors related to the bioeconomy.

2- The Social Network Analysis performed is limited by its inability to detect any informal or external incentives implemented by Italian policymakers to implement the current network. To overcome this limitation, further investigation into the Italian innovation policy is necessary. To do so, a mixed method may be performed, combining a systematic analysis of policy documents (strategies, policy objectives, policy instruments, etc.) with interviews with key policymakers (national and regional) and experts from public agencies. Furthermore, another important limitation concerns relationships with fundamental parts of the innovation system that are not covered by this methodology. In particular, there is the impossibility of catching some national actors who do not participate in European research projects but are a fundamental part of the national innovation system. Examples are startups, which, generally, have few resources to participate in such kinds of projects but have an important role in bringing new knowledge and innovation, or education entities like technical schools or lifelong learning providers, who strongly contribute to spreading knowledge and competencies, but usually participate in other forms of financing. Future research may include or focus on different forms of European founding to target educational entities, start-ups and spin-offs, and then merge into the network we found. Finally, the approach adopted in this study focuses only on national entities, even if collaborations with EU and non-EU entities are one of the pillars of FPs. To evaluate the degree of international collaborations of the Italian bioeconomy organisations should be targeted in future research. This might be investigated applying the same approach but considering two (or more) countries, e.g. Italy and Germany.

3- The third study collected a low number of respondents, compared to the high number of participants in the Italian KISB. In particular, in some categories, such as *public bodies*, the number does not allow us to consider the study as exhaustive. To overcome this problem, the obtained results may be part of a future participatory study, in which representatives of the main categories are gathered to discuss both which actors are missed and which issues did not emerge from our study. Such study may take advantage, for example, of the system thinking approaches. Another limitation is the low number of categories considered, made to be in line with the categories identified in the Social Network Analysis study. Future research could increase the number of categories, through greater capillarity. For example, the private for-profit companies may be divided following their specialisation (biotech, farms, food industry, etc.) or the public bodies following their geographical scope (national, regional, local). Furthermore, the study is completely based on the subjective perspectives of respondents, limiting the explanatory power of the results obtained. In this sense, we suggest a deeper analysis of the objective features of the relationships between actors, such as joint R&D funds, joint projects, shared staff, shared training activities, etc.

In addition to research that overcomes the limitations listed so far, two main research pathways are suggested for a deeper knowledge of the Italian KISB. First, taking into account the framework represented in Fig. 5.2, efforts should be made to understand the best approaches to address the final part of the cycle, i.e. gaps in current policies, strategies for transition and desired policy outcomes. In this vein, to find gaps in current policies, in addition to the EU innovation policies explored in this thesis, all the domains related to the bioeconomy should be considered, both at the national and European levels. Furthermore, to find strategies and the expected outcomes, research may benefit from systemic approaches that exploit co-creation processes and stakeholder engagement, taking advantage of the contextual factors outlined and the subjects identified in this thesis.

The other important pathway is the reconnection of the Italian KISB with the higher and lower geographical levels. On the higher level, the connections with the wider context of European KISBs may be explored in the direction of identifying how internationally collaborating entities bring back to the national KISB the knowledge, information and innovations learned. Instead, concerning the lower geographical level, it may be interesting to figure out the local KISB in order to understand leverage points for local implementation of the bioeconomy.

Finally, the application of the methodologies adopted in this thesis in different EU KISBs may provide a deeper knowledge of how an effective KISB is structured or how a weak KISB may improve its performance. In general, these studies will improve the bioeconomy innovation literature, contributing to the theoretical advancements.

5.3. Policy implications

As emerged in the fourth chapter of this thesis, from a political point of view, the bioeconomy is gaining growing consensus worldwide. Two recent global events can be cited as examples of this momentum. In September 2024, after 9 months of discussion, the G20 Initiative on Bioeconomy (GIB) reached a consensus among G20 members on the 10 High-Level principles of Bioeconomy (GIB, 2024). This important achievement provides the basis for a global common understanding of the bioeconomy and was promoted and coordinated by Brazil's G20 Presidency. The other important event is the Global Bioeconomy Summit (GBS) organised in October 2024 in Nairobi, Kenya, after four years since the last edition (GBS2020). This event gathers all the principal stakeholders engaged in the bioeconomy worldwide, and, for the first time is not hosted in a European country. Besides the specific achievements of these events, the fact that they were promoted and hosted by, respectively, a Latin American and a sub-Saharan country, shows how the bioeconomy is spreading as an element of interest for the sustainable development of all continents (Johnson et al., 2022; M'barek and Wesseler, 2023).

Even in Europe, more than 10 years after the first strategy (EC, 2012), the bioeconomy still represents a pillar of sustainable development (M'barek and Wesseler, 2023) and its implementation represents a strategic element of the Union, as the ongoing process for renewing the EU Strategy confirms. However, the global debate on bioeconomy challenges the EU institutions to find a balance between a proper position to propose to the others ("the European way to the bioeconomy") and the ability to absorb and integrate proposals coming from political realities outside the EU. Similarly, the EU member states, participating in European and global debates, should be able to mediate between their own political position – that reflects the characteristics of their territory in terms of resources, culture, labour, etc. –, and the positions of other states.

Hence, to participate in this democratic process of defining development strategies, each member state should be aware of all the dimensions that contribute to set policy objectives (Imbert et al., 2017). One of these dimensions, particularly relevant for the bioeconomy, is knowledge development and innovation. Exploring systematically the processes that bring to new knowledge or to implementing innovations, the State becomes more aware of any policy gaps or system failures, with the consequence of being able to intervene on specific leverage points (Kurtsal et al., 2024).

With this dissertation, we aimed to contribute to providing an instrument that may help policymakers to better understand the processes, the mechanisms, the relationships and the information flows that regulate and shape a national knowledge and innovation system for the bioeconomy (KISB).

This understanding can play an important role in this historical moment, in which EU member countries are starting the debate that will bring to the new EU strategy for the bioeconomy. Furthermore, by raising awareness in the relationships among different stakeholders, the KISB approach may shed light on the national or local implementation of the transition toward bioeconomy. In this sense, the case study taken into account in this thesis, Italy, showed difficulties in the local implementation process of the bioeconomy (especially difficult involvement of primary producers, insufficient adaptation of development models to local needs through specific studies, and lack of reference figures and channels for innovation and knowledge transfer). Therefore, we can summarise that the KISB approach, making states aware of their strengths and weaknesses in the innovation system, may contribute to shedding light on a double level, one national and local and the other one international. We might define it as a "double light cone knowledge" (Fig. 32).

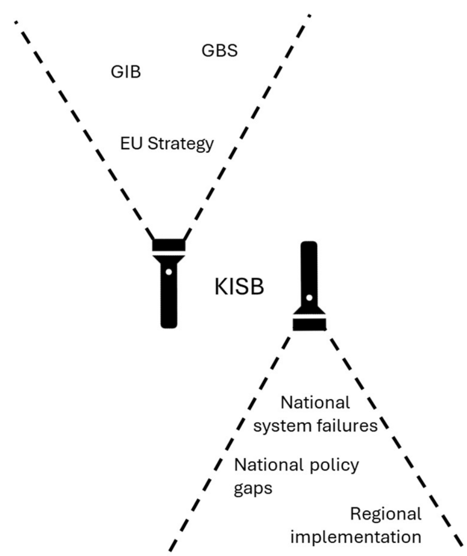


Figure 32. The double light cone knowledge facilitated by KISB approach. Authors' elaboration

In line with these premises, the findings of this dissertation outline three main policy implications:

1- The Italian bioeconomy strategy (BIT) was first released in 2017; an update, called BIT II, followed in 2019 (Fava et al., 2021). This strategy is considered a bottom-up policy (Imbert et al., 2017), because of the focal role of private companies in encouraging and contributing to the design of the strategy (Varanini et al., 2024). Furthermore, during the policy development of the first strategy, an online public consultation was held to stimulate However, the consultation collected only 41 responses, mainly from universities, and representatives of companies from industrial or agricultural sectors (Agenzia per la coesione territoriale, 2016; Varanini et al., 2024). This low capacity of reaching the public bodies in the bioeconomy field was observed also in our study on the assessment of relationships in the KISB. Moreover, based on what we found in this dissertation, and in particular findings from Chapter 2 and Chapter 4, the aforementioned engagement of civil society should be one of the policy objectives of the future (Angouria-Tsorochidou et al., 2021; Bijon et al., 2023; Bohn et al., 2023; Bryden et al., 2017). In fact, in Chapter 2 we found how the ethical dilemmas affect the commercialisation of bio-based products; while in Chapter 4, we reported the observations made by several respondents regarding the greater attention to be paid to civil society, both in terms of better communication and in terms of involvement. This latter aspect has been suggested to be addressed through participative approaches, such as open innovation and citizen science. Hence, specific initiatives or projects should be promoted by policymakers in this sense. Moreover, based on the position of the various components of the system within the cause-effect and the information flow structures (Chapter 4), it is possible to figure out some further indications. First, the dominant position of public bodies and in particular the high influence toward the categories "research institutes" and "other" represent leverage positions to promote and expand the flow towards the system. However, the fact that the public bodies have the second lowest reception capacity, may be considered a limit of the system (Ansell et al., 2021; Graber, 2003), because it could be a symptom of a poor receptivity to bottom-up proposals or requests from the various operators in the system. Therefore, the public component should make efforts towards greater receptivity. Second, civil society actors, such as associations and foundations, need to enhance their ability to receive and process information. Improving their receptivity is crucial to ensuring that they can effectively respond to and participate in the ongoing flow of knowledge, helping bridge the gap between experts and the general public (Borge and Bröring, 2020). In fact, looking at the information flow structure, nowadays this component is not a connector but a promoter. To enable this change in role, policymakers should stimulate the receiving capacity through greater involvement in *ad hoc* initiatives (e.g., Taffuri et al., 2021) and policy planning (Tarsitano et al., 2023). In this vein, the research institutions can largely contribute through the wide range of participatory and multi-actor approaches existing in research. Moreover, knowledge co-creation is not only a way to increase the connections with other actors, such as civil society, but also to generate insights that are both economically and socially relevant (D'Amato et al., 2022).

2- In our assessment of relationships of the Italian KISB (Chapter 4), some issues emerged in terms of knowledge transfer. To summarise, the main concerns are: the absence of a critical mass of operators or specific communication channels to refer to for knowledge and innovation transfer; the lack of *ad hoc* sharing activities, both formal and informal; the high level of sectorisation which still does not favour exchange between different market sectors that may have possible common interest in the circular bioeconomy. To overcome these problems, several steps can be undertaken. First, based on Garay et al. (2015), a suitable innovation system should be coordinated by an organism in charge of scientific-technological policies, that promotes the creation of companies. In this sense, the Italian National Bioeconomy Coordination Group (NBCG) represents this organism. However, as pointed out by one of the respondents, the NBCG should be valorised more, establishing improved forms of bilateral communication channels to share and receive information. This should be done because, as underlined by Hurtado and Berbel (2023), the bioeconomy is characterised by the pervasiveness of information asymmetries, the intensity of knowledge and innovation, and the confluence of several technological areas. Second, the government should foster learning and knowledge-related processes (Hurtado and Berbel, 2023), and stimulate improved know-how (Borrello et al., 2023) to increase awareness in the bioeconomy. This aspect calls into question the higher and secondary education establishment, which should be coordinated by a central entity such as NBCG to figure out the educational pathways best fitting for the national or regional bioeconomy (Hurtado and Berbel, 2023). In particular, specific courses that go beyond the sectoral vision in favour of a bioeconomic vision should be established at different training levels (McAlexander et al., 2022; Urmetzer et al., 2020), meeting the demand to overcome sectoral visions. Third, the government should support commercialisation grants, investments, and entrepreneurship (Borge and Bröring, 2020; Borrello et al., 2023; Kuckertz et al., 2020). In other words, the public sector should foster the development of entrepreneurial systems (Kuckertz et al., 2020). This should be done to increase the dynamism of the system. This aspect not only concerns policymakers but calls into action even the private for-profit and the research components, particularly universities (Compagnucci and Spigarelli, 2020). Indeed, the KISB should be attractive for private investments – Kuckertz et al. (2020) suggest co-investment schemes to target venture capital investors –, and be fertile for contamination between research and business (Garay et al., 2015). More in detail, tailored programs must be created to assist researchers and students in fulfilling the third mission in the bioeconomy field (Kuckertz et al., 2020) through the development of spin-offs and start-ups (Garay et al., 2015). Specific offices, technology transfer centres, incubators and science parks are needed to support entrepreneurship (Compagnucci and Spigarelli, 2020; Garay et al., 2015) and must be supported by research entities and policy bodies (Garay et al., 2015).

Furthermore, a growing availability of educational resources dedicated to the bioeconomy and the support to bioeconomy entrepreneurship would increase the dynamism of the entire KISB, creating, at the same time, more operators in the sector and more opportunities for exchange, both formal and informal.

3- In the Social Network analysis carried out in Chapter 3, we found that the network increased during the years both in the number of participants and connections among Italian partners. Through network policies, policymakers have two main possibilities in the governance of future participation of Italian organisations in EU-funded projects. On one hand, there is the possibility of stimulating the strengthening of actual connections more than new entrants, resulting in higher behavioural additionalities (Caloffi et al., 2013), alignment in shared tacit knowledge and common vision about bioeconomy (Giurca and Metz, 2018), and, in general, a higher trust among participants (*ibidem*). Nevertheless, this strategy may bring to a lock-in situation (Rubach et al., 2017) – in which innovation is not focal anymore, favouring the other advantages mentioned above – or to an increase in redundancy of information, bringing the network to inefficiency (Ahuja, 2000). On the other hand, there is the possibility of stimulating the entry of new subjects, which, bringing disequilibrium, may stimulate competitiveness and, ultimately, knowledge creation and innovation (Buchmann and Pyka, 2015). In this case, the main risks are the increase in transaction costs, loss of common vision and, more in general, distrust within the network.

Chapter 6 - Conclusions

This thesis aims to contribute both theoretically and practically to advance the analysis of Knowledge and Innovation Systems for the Bioeconomy (KISB). It was developed through three main steps. First, in a systematic literature review, we explored the scope of the KISB and its main peculiarities. In the second and third steps, we tried to adapt this framework to a real context. Taking the Italian bioeconomy as a reference, we first tried to outline the shape given to the knowledge and innovation network by the EU innovation policies (i.e. research projects under the FPs). Once we found the main actors and their roles in the network, we moved to the third step, analysing the relationships and the information flow within the whole KISB.

More in detail, we found that a specific bioeconomy framework is nowadays missing. Several approaches were adopted, but rarely with the aim of a theoretical advancement for the whole bioeconomy literature, preferring to adopt the approach best fitting for the purpose of the research. Rarely the seeking of a holistic framework that describes innovation processes within the bioeconomy was the main objective of the study. However, the unique KISB allows for the examination of mechanisms and dynamics that go further beyond the simple technology-oriented or linear approach to innovation. The complex amount of skills and professionals needed to implement bioeconomy processes (e.g. in biowaste management or bioenergy production) call for approaches that take into account the wider socio-economic and environmental picture. In this vein, we found that some peculiarities should characterise the KISB to represent the contextual factors that characterise the innovation process in the bioeconomy. First, intense cooperation among different actors and complex knowledge base are the most commonly described factors in the bioeconomy innovation processes, showing how multi-actor approaches and multidisciplinary are fundamental in the bioeconomy. Second, we found a more intense stream of research in the field of collaborations rather than innovations. In this sense, the efforts made by scholars can strongly contribute to outlining a KISB, for example including the analysis of knowledge development. Third, even if less represented, the innovation-oriented papers add insights in terms of challenging aspects of commercialisation in the bioeconomy and their attitude towards stakeholder and multistakeholder analysis. Finally, we found that there is a wide scope for KISB and the connected concept of microKISB (i.e. the innovation subset of the whole KISB that operates at the organisation's individual level) in both business-centred and policy-centred research.

Therefore, KISB and microKISB must be designed in such a way that they can represent an interesting and useful tool for all the actors involved in the bioeconomy innovation process, mainly policymakers, business actors, and researchers.

These theoretical premises helped us to apply the KISB framework in a real context. Therefore, we focused our attention on Italy's bioeconomy network, analysing organizations involved in European projects from 2012 to 2023 through Social Network Analysis. The results shed light on the Italian knowledge and innovation network, identifying as the most central actors for all the indicators analysed three public research organisations (two research institutes and one university). Furthermore, we also found that the core structure of the network is based on research entities rather than private for-profit companies. However, some subjects from other categories of actors (i.e. Private for-profit entities, Public bodies, and Others) can quickly affect the network due to their strategic position in the system that allow them to connect centre and periphery of the system. In addition, the diverse origins of these nodes may enable the network to achieve efficient and rapid information flow across different sectors. However, we also discovered a weak capacity of non-research entities to act as gatekeepers, i.e. entities that, thanks to their position in the system, can control, moderate or facilitate the flows of knowledge between two or more actors. In fact, only one private company (Novamont) assumes the gatekeeper role. We also considered two subperiods of the network (2012-2017, and 2018-2023), identifying the changed dynamics within the network over time. In particular, the role of private for-profit entities lost centrality from one subperiod to the other, while connectivity increased notably between the two subperiods. Based on innovation network literature, this growth in ties might have had a negative effect on the innovativeness of the network, but, at the same time, it might have contributed to the strength and resilience of the whole knowledge and innovation system for the bioeconomy (KISB).

Finally, the assessment of the linkages and the information flows among Italian organisations provided further insights on the Italian KISB. On average, the relationships analysed are characterised by medium-high intensity. More in detail, processing the causal relationships associated with innovation in Italian KISB, public bodies stand as the only dominant category. Instead, research entities occupy a subordinate role in the system; while private for-profit and other entities act as interactive participants. However, when analysing the information flow structure, no intermediaries or connectors are detected, with only two main groups emerging: the promoters, which include private for-profit entities, other entities, and public bodies; and

the target group, which is represented by higher education establishments and research institutes.
Furthermore, integrating qualitative data from interviews and open-ended questions, we discovered that the main concerns of respondents are the lack of a critical mass of actors serving as a reference point for innovation, and, at the same time, the absence of stable and well-established reference channels. Moreover, several aspects affect the local implementation of the bioeconomy, such as weak knowledge transfer – considered at its infancy – or the obstacles encountered when attempting to engage important components of the system like primary producers.

The aforementioned results obtained in this research describe the strengths and weaknesses of the Italian KISB, facilitating the analysis of the necessary trajectory for implementing the bioeconomy within the Italian context. In this sense, we found that a future Italian bioeconomy strategy (an eventual BIT III) should focus on involving civil society in the policy development process, making an effort to improve communication and providing the different stakeholders with the right tools to address ethical dilemmas that characterise bioeconomy innovation. Indeed, key recommendations from the research stress the importance of participatory approaches, such as open innovation and citizen science, to foster collaboration between public bodies, research institutions, and civil society. Public entities, which hold significant influence in the system, should enhance their receptivity to better connect with other stakeholders. Civil society actors, like associations and foundations, need to improve their ability to process information and engage in the knowledge flow. Policymakers are encouraged to support initiatives that stimulate this engagement, ensuring that knowledge co-creation not only strengthens connections between actors but also generates economically and socially relevant insights for the bioeconomy's future development.

Furthermore, we found several challenges in knowledge transfer. To address these issues, we argue that a well-coordinated innovation system is crucial, with the Italian National Bioeconomy Coordination Group (NBCG) that can play a key role. However, it should be further empowered to create bilateral communication channels for knowledge exchange, addressing the bioeconomy's complexity, information asymmetries, and cross-technological needs. Secondly, the government should foster learning and knowledge-related processes by enhancing bioeconomy awareness through coordinated educational pathways. Higher and secondary education institutions should offer specialized courses that encourage a broader bioeconomic vision, moving away from sector-specific approaches. Thirdly, public sector support is essential in promoting commercialization grants, investments, and entrepreneurship. This involves creating an attractive environment for private investments, fostering research-business collaborations, and supporting researchers' and students' entrepreneurship through spin-offs, start-ups, technology transfer centres, and incubators. In this way, enhanced educational resources and support for bioeconomy entrepreneurship would increase the sector's dynamism, providing more operators and opportunities for formal and informal knowledge exchange. This would strengthen the overall KISB system and boost Italy's bioeconomy.

Finally, based on the Social Network Analysis carried out in this thesis, policymakers should face a strategic choice in managing the participation of Italian organizations in European projects on the bioeconomy. On one hand, they can foster deeper connections among existing participants to enhance trust and shared knowledge. This would strengthen current ties, improving alignment and cooperation. The risks associated with this choice are the creation of inefficiencies, lock-in situations and an overall reduction in innovation. On the other hand, they can stimulate the introduction of new actors with the aim of increasing innovation and competitiveness. In fact, new participants may contribute to the network with new ideas. However, this choice may lead to higher transaction costs and reduced trust among actors. Hence, a balanced approach is essential to ensure both collaboration and ongoing innovation in the bioeconomy.

In conclusion, two factors have stimulated this dissertation. The curiosity to deepen the complexity of the bioeconomy innovation processes and the desire to be able to outline an overall vision of this sector that takes into account all the subjects involved in it. Therefore, the adoption of the Innovation Systems model applied to the bioeconomy aimed to respond to these two stimuli. The dynamism and the wide number of sectors and subjects involved in the bioeconomy make us aware that the efforts made in this PhD thesis are only the first step towards a better understanding of knowledge development and innovation processes in this meta-sector. However, we believe that the KISB approach can largely contribute to implement the bioeconomy, providing insights to both the policy component (e.g. policymakers, economists and political scientists) and the business component (e.g. private companies, venture capitalists, trade associations, business scientists). Indeed, for both these components, the proposed systemic framework allows to find areas of strength and weakness where targeted interventions should be taken or where further investigations should be carried out. In other words, this framework allows to intervene on system failures due to its capacity of identifying entry points for policies that enable the bioeconomy development. A development that, as we aimed since the beginning of this dissertation, takes into account the complexity of the sector, considering all the different subjects, relationships and interests involved.

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