From Meta to Micro, from Fuzzy to Concrete:

Examining Structures of Knowledge and Innovation in the Bioeconomy

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It's not possible.

— CASE

No; it's necessary.

— Cooper

INTERSTELLAR, 2011

Chapter 1

Introduction

1.1 Setting a Grim Scene

> *"The difficulty lies, not in the new ideas, but in escaping from the old ones, which ramify, for those brought up as most of us have been, into every corner of our minds" (Keynes, 1936, p. VIII)*

Changing from an old system to a new one is never an easy task, and this applies, markedly, also to the challenges ahead for society in the 21^{st} century. After relying on a fossil-based, ever-growing economy since industrialisation, humanity manoeuvred itself into a dilemma: while we were able to raise life expectancy, access to education and a decent standard of living significantly – progressing human development –, we did so by disregarding the ecological consequences completely and now face a severe, unprecedented challenge of climate change in the form of global warming (Walther et al., 2002). While in a stable climate, "[...] the amount of energy that Earth receives from the Sun is approximately in balance with the amount of energy that is lost to space in the form of reflected sunlight and thermal radiation" (Arias et al., 2021, p.39), specific drivers, like an increase in greenhouse gases – water vapour, CO_2, methane, nitrous oxide (N_2O) among others – prevent radiation from escaping and thus lead to a temperature increase of Earth's atmosphere and surface (Kweku et al., 2018). The significant correlation between atmospheric CO_2 levels and surface temperature can be underlined by reconstructing past climate settings with the help of natural archives and, following this notion, can also be used to model future Shared Socio-economic Pathways (SSP) scenarios (Fig. 1.1), which, for the first time, are unprecedented in a multi-millennial context and result in continued worldwide loss of ice, increase in ocean heat content, sea level rise and deep ocean acidification (Arias et al., 2021). The three in Fig. 1.1 depicted scenarios (blue, yellow and red) show these possible future pathways through 2300, using Earth system model emulators calibrated to the assessed global surface temperatures, with maps on the right visualising the blue and red scenario effects to earth regions. While the optimistic SSP1-2.6 (blue) already leads to a significantly higher temperature, especially in the polar regions, SSP5-8.5 (red) alarmingly underlines the urgency of climate change.

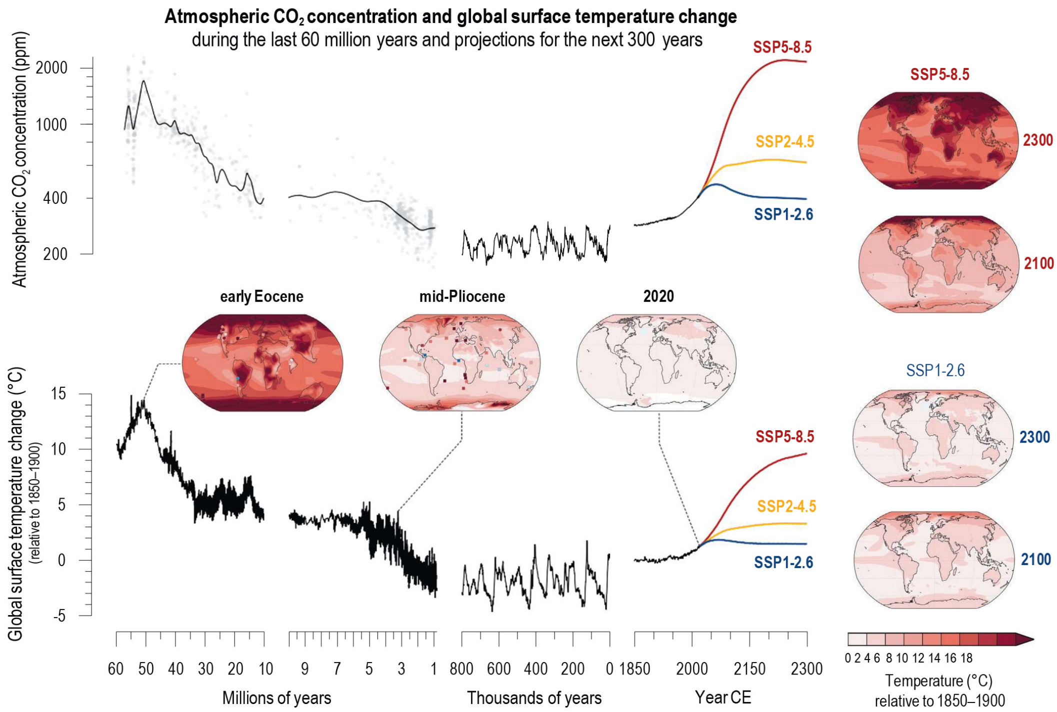


Figure 1.1: Changes in atmospheric CO_2 and global surface temperature (relative to 1850–1900) from the deep past to the next 300 years (Arias et al., 2021)

Since all aspects of our society are directly or indirectly influenced by climate and weather conditions, as Frieler et al. (2017) highlight, looking at the consequences of temperature change in the three scenarios (Table 1.1) emphasises the drastic effects society is going to face.

	Near term, 2021-2040		**Mid-term, 2041-2060**		**Long term, 2081-2100**	
Scenario	Best estimate (°C)	Very likely range (°C)	Best estimate (°C)	Very likely range (°C)	Best estimate (°C)	Very likely range (°C)
SSP1-2.6	1.5	1.2 to 1.8	1.7	1.3 to 2.2	1.8	1.3 to 2.4
SSP2-4.5	1.5	1.2 to 1.8	2.0	1.6 to 2.5	2.7	2.1 to 3.5
SSP5-8.5	1.6	1.3 to 1.9	2.4	1.9 to 3.0	4.4	3.3 to 5.7

Table 1.1: Changes in global surface temperature (IPCC, 2021)

In all scenarios, the global surface temperature will increase until 2050, with further global warming exceeding 1.5°C and 2°C until the end of the century unless significant reductions in greenhouse gas emissions occur in the coming decades (IPCC, 2021). Change in global surface temperature has immensely detrimental effects on multiple interwoven systems, some of which trigger positive feedback loops (Bajželj & Richards, 2014), lead to a significant increase and frequency of droughts (Naumann et al., 2018), imbalance Earth's cryosphere (Chadburn et al., 2017; Slater et al., 2021), and radically impact biodiversity and ecosystems (Dietzel et al., 2020; Molnár et al., 2020; Warren et al., 2018), to name just a few. The most recent report by the Intergovernmental Panel on Climate Change (IPCC) therefore concluded not without reason:

> *"The cumulative scientific evidence is [with very high confidence] unequivocal: Climate change is a threat to human well-being and planetary health. Any further delay in concerted anticipatory global action on adaptation and mitigation will miss a brief and rapidly closing window of opportunity to secure a liveable and sustainable future for all" (Pörtner et al., 2022, p.33)*

However, it took quite some time for policy to react to this threat substantially, and much valuable time was lost. While an early wave of environmental activism that focused on local and relatively reversible forms of pollution (e.g. oil spills or dumping hazardous wastes at sea) had an influence, the discovery of the ozone hole and the publication of the Brundtland Commission Report in 1987 can be seen as the definitive starting point of the global climate change regime (Bodansky, 2001). The IPCC was established a year later (1988) by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) as an intergovernmental institution to provide "[...] regular assessments of the scientific basis of climate change, its impacts and future risks, and options for adaptation and mitigation" (IPCC, 2022). The founding of the IPCC heavily influenced the United Nations Framework on Climate Change Convention (UNFCCC – 1992) and thereby the annual Conference of Parties (COP), initiating the process of fixing national greenhouse gas emission reduction targets for some developed countries and leading to the Kyoto Protocol in 1998 (Helm, 2008). Although regarded as an inherently flawed agreement for its unconvincing emission targets and an essential set of countries (USA, China, India, Australia) not ratifying it, the Kyoto Protocol still initiated a global shift of including climate change into national agendas, even if it missed being the turning point it was supposed to be and, in the end, cost valuable time (Rosen, 2015). When the Stern review was published in 2006, headlining "There is still time to avoid the worst impacts of climate change if we take strong action now" (Stern, 2006, p.2) and calling for immediate drastic action, criticism was still raised on a lack of answers to central questions about how desperately a climate policy is needed, how fast it should be and how costly it will be (Nordhaus, 2007). Indeed, the response from science was rather negative:

> *"It is very grim. The trends are in the wrong direction, the timescale is short, and a Kyoto-style new agreement from 2012 is unlikely to make much difference to the underlying (upwards) trends in emissions. Without a fundamental rethink, we are likely to be doomed [...]" (Helm, 2008, p.236)*

The trend continued with the 2009 Copenhagen Accord, in which participants decided to constrain carbon dioxide emissions and take measures against climate change in both the short- and long-term – however, again without legally binding commitments (Haibach & Schneider, 2013). It should take another six years until the Paris Agreement was adopted at the 21st Conference of the Parties in December 2015 (United Nations, 2015), which marked the first legally binding agreement on global action against climate change, with a goal to limit global warming to preferably 1.5°C compared to pre-industrial levels. Adopted and signed by 196 countries, it is generally regarded as positive by science (Anderson, 2015) and global politics (Tollin, 2016). Also in 2015, the UN adopted the 2030 Agenda for Sustainable Development, including 17 Sustainable Development Goals (SDGs) at its core and thus providing a set of encompassing goals international policy can strive towards. Since then, the sustainability and climate change regime experienced a significant upswing and now is a common theme in politics, markets, and education and influences various aspects of everyday life, be it through pop culture, movements like Fridays for Future or Extinction Rebellion. It seems that in the early 2020s, the climate catastrophe has finally reached its needed, menacing status across all layers of society.

1.2 A Glimmer of Hope?

Clearly, reaching the IPCC's communicated goal of limiting global warming to 2°C requires far-reaching policies and measures. Of the many approaches that have been discussed and proposed over the years, the bioeconomy emerged as particularly promising by being one of the most researched (Bugge et al., 2016; Golembiewski et al., 2015), long-lasting (Birner, 2018) and agreed-upon (de Besi & McCormick, 2015) ones. At its core, the bioeconomy can be understood as an approach to transforming the economic system, which was until recently focused solely on unlimited growth on a finite planet no matter the costs, into a bio-based one (Prochaska & Schiller, 2021) – an economy, that shifts away from being fossil-based, to being based on renewable materials and thus being as sustainable as possible. The bioeconomy thereby overlaps with 11 of the 17 Sustainable Development Goals, contributing significantly to their reach.

For this transformation to happen and for the bioeconomy to succesfully fulfil its role, innovation is seen as the most vital element due to the need to overcome a fossil-based lock-in – and the paradigm that every sustainability transition has an innovation at its base.

For more than 15 years, the bioeconomy term has been spreading at the global policy level, although the basic features date back to the late 1970s (Georgescu-Roegen, 1978): These include renewability, CO_2 reduction, circularity – especially in closing loops in waste processing, recycling and promoting biodegradability – and last but not least, providing new and better functions such as higher stability, longer life, lower toxicity, lower resource consumption and sustainability for products (Patermann & Aguilar, 2018). Since 2004, the concept diffused – a cross-fertilisation with sustainability cannot be ruled out – with differing speeds in European countries, with Finland, Germany and the Benelux states as its frontrunners (von Braun, 2018) until the concept resulted in the European Bioeconomy Strategy in 2012. This strategy was aimed at accelerating the deployment of a sustainable European bioeconomy, focused on ensuring food security and the sustainable management of resources, the reduction of non-renewables, limiting and adapting to climate change as well as strengthening European competitiveness (European Commission, 2012). Looking at the last ten years, the bioeconomy seems to be undergoing a genuine upswing: Interest in the bioeconomy is growing not only within the EU but also at the global level, with more than 40 countries developing plans for more significant consideration of bioeconomy principles or even national bioeconomy strategies (Dietz et al., 2018; Meyer, 2017; Pietzsch & Schurr, 2020). Bioeconomy has also been recognised in funding mechanisms, since it was also introduced in the EU Framework Programme for Research and Innovation Horizon 2020 and its successor, Horizon Europe; in the first as a subsection and in the second as one of the leading clusters for the framework program (European Commission, 2020a). After Europe's Bioeconomy Strategy got revised in 2018 to better support the climate objectives formulated in the Paris agreement and the 2030 Sustainable Development Goals (European Commission, 2022), the launch of the European Green Deal – Europe's new growth strategy – in 2019 should mark the most advanced reform package in recent decades (Palahí et al., 2020), with bioeconomy contributing to all of its dimensions and objectives (European Commission & Directorate-General for Research and Innovation, 2020):

> *"The bioeconomy, an economy powered by nature and emerging from nature, has, if managed in a sustainable way, major potential to help deliver ambition set by the Green Deal." (Palahí et al., 2020, p.2)*

So it seems that in this great transformation to combat global warming, the bioeconomy is understood by a growing number of policymakers and governments as an essential driver, helping to reduce greenhouse gas emissions and shift the economy to being climate neutral while staying growth-wise within the limits of the earth system.

The rationality of the transformation away from fossil raw materials to achieve the formulated goals is beyond question. However, critical voices regarding the bioeconomy have been raised on the research side. Perspectives and scopes on the bioeconomy vary substantially according to the institutional and disciplinary background (McCormick & Kautto, 2013) and authors therefore see the bioeconomy primarily as a multi-dimensional concept (Bauer et al., 2018; Birch, 2017; de Besi & McCormick, 2015; Golembiewski et al., 2015; Peltomaa, 2018; Purkus et al., 2018; Staffas et al., 2013; van Lancker et al., 2016; Vivien et al., 2019; von Braun, 2018), instead of its early notions of spanning specific sectors. The delimitation of the term itself is, therefore, highly fuzzy (Golembiewski et al., 2015; Moosmann et al., 2020), which is reflected in more and more public institutions using it merely as a buzzword (Vivien et al., 2019). With the term being an attractive catchphrase to a wide range of political actors by always holding some truth for different application settings (Staffas et al., 2013), harsher critiques do not come surprisingly:

"[...] bio-economy could be better framed as a political economy of nothing."
(Birch, 2017, p.915)

Nevertheless, despite their critique, authors also underline the potential bioeconomy holds for supporting the transition toward a more sustainable economy (Birch, 2021; Purkus et al., 2018; Vivien et al., 2019). Returning to the IPCC report mentioned at the beginning, it is clear that the approach of the bioeconomy, at its core, can be extremely valuable: One of the report's key statements is that strengthening ecosystems alone would not be sufficient to achieve the climate target, even in the best-case scenario, but technical and sustainable innovation are also needed – both of which being leitmotifs for bioeconomy as well (Kardung et al., 2021; Saviotti, 2017). For the bioeconomy, innovation is seen as a critical driver for its success since transforming the largely fossil-locked economy requires significant novelties to be achieved and implemented (Jander et al., 2020) – a tremendously challenging task. This challenge is even more apparent when considering the paucity of research literature on innovation in the bioeconomy, which, with few exceptions, remains at the meta-level, thereby indirectly contributing to the already high fuzziness of the topic.

Bioeconomy may be a political macro concept, but it has to be implemented on a much smaller micro-scale, thus raising urgent questions about *where it takes place*, *who is involved* and *how it works*. All of these questions are also central to economic geography, especially in light of emerging literature on sustainability transitions (Loorbach et al., 2017). Nevertheless, only a few concise works (Bugge et al., 2016; de Besi & McCormick, 2015) so far combine bioeconomy's need for detail and comprehensiveness with economic geography's multiplex toolkit that is well equipped with instruments able to examine *how innovation works* (e.g. Audretsch & Feldman, 1996), *which actors are involved* (e.g. Asheim & Gertler, 2006) and *where it takes place* (e.g. Boschma, 2005; Morgan, 1997). This dissertation, therefore, uses tools and theories of the well-suited research field of economic geography to shed light on the emerging and highly relevant topic of innovation in the bioeconomy. It seeks to fill the research gaps of innovation drivers in the bioeconomy, knowledge structures and actors in an EU-funded, policy-driven network as well as the transformative potential in low-tech value chains. The overall objective of the work is to contribute to the clarification of the bioeconomy's fuzziness and the concretisation of the meta-level concept at the meso and micro scales.

1.3 Conceptual Outline and Structure of this Thesis

This thesis is structured into three chapters that pose the following central research questions:

1. **What characterises and drives innovation in the bioeconomy?**
2. **What does a European bioeconomy network look like, and which implications does it entail?**
3. **How is knowledge transferred and innovation achieved in a low-tech, agri-food value chain, and which role does the bioeconomy play?**

Answers to these central research questions are achieved by first tackling the topic on a meta-scale with a literature review (1) and, from there on, progressively zooming in deeper, first touching the macro-level by operationalising an understanding of bioeconomy, then identifying and analysing on a meso-level the European bioeconomy network (2), before finally, at the micro-level, looking at value chains in a case study fashion (3). Fig. 1.2 illustrates this approach.

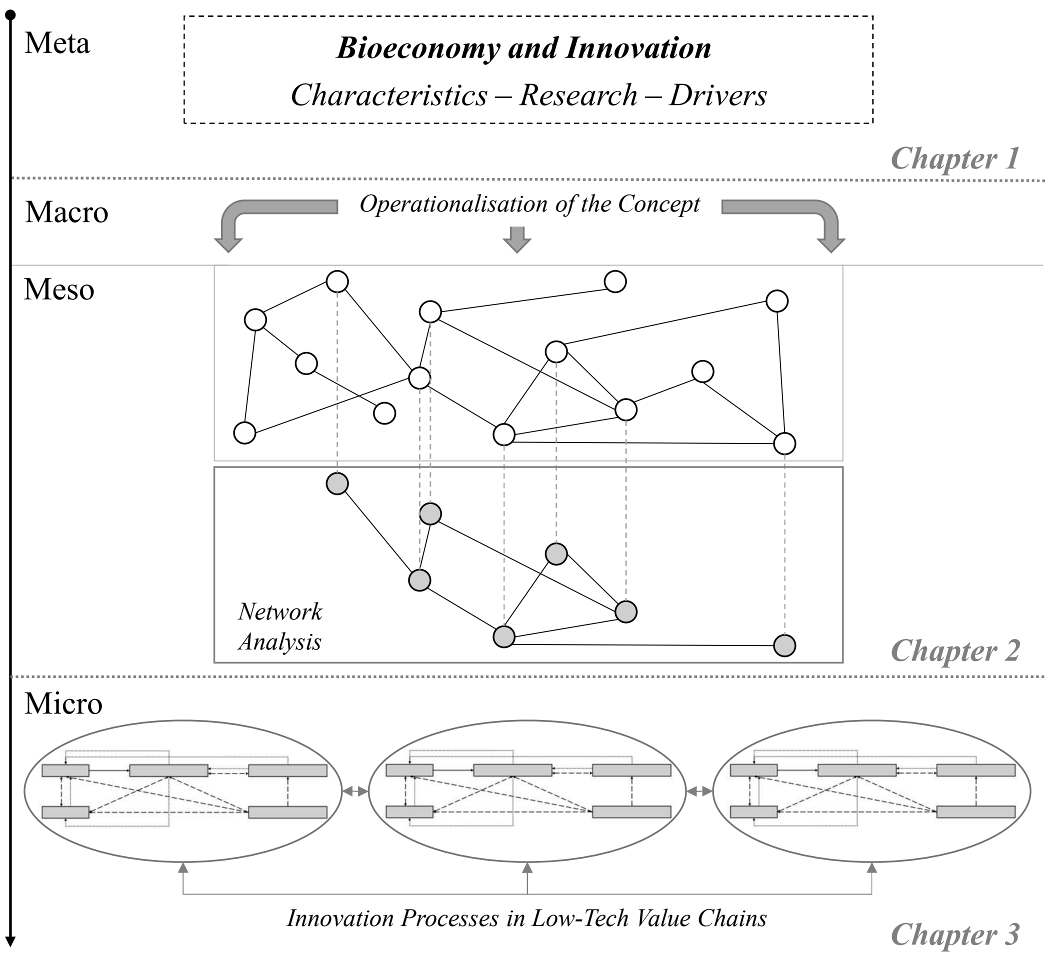


Figure 1.2: Structure of the thesis

Following this structure, the dissertation looks at bioeconomy innovation at different levels through the lens of economic geography. By progressing from the meta to the micro-scale, it tries to find answers to how the interrelated concepts of bioeconomy and innovation are embedded in these respective contexts while consecutively concretising bioeconomy and de-fuzzing it. To do that, it adopts a mixed-methods approach that starts general and ends specific, going from the meta-scale of literature, over the macro-scale of three distinct areas in which bioeconomy is discussed, to the meso-level of central actors of a European funding network before, lastly, considering case studies at the micro-scale. Throughout, the thesis aims to spatialise the bioeconomy by shedding light on the term and its drivers across multiple geographic layers (Boschma & Frenken, 2006). It thereby not only offers new insights into dimensions of innovation in the bioeconomy but also contributes to the discipline of economic geography by applying some of its essential theoretical ideas to an emerging political framework that has enormous potential – when done right – to help reach climate targets. Proceeding, the following central ideas are utilised in the chapters:

In Chapter 2, a concretisation of general approaches to innovation research for the application to the research field of the bioeconomy takes place. Initially, bioeconomy and innovation are conceptually introduced, and a consideration of their respective developments over time and their characteristics undertaken. Afterwards, a literature review on how innovation is understood in the research field of the bioeconomy is conducted. The chapter then culminates in developing a deduced set of criteria believed to drive innovation in bioeconomic settings.

Chapter 3 then ventures from the meta to the macro and meso-scale. Two baseline premises motivate it conceptually and methodologically: first, the apparent demarcation problem of the bioeconomy, leading to concerns expressed regarding its operationalisability and thus its ability to be researched by quantitative methodology, and, second, also strongly influenced by this, the lack of holistic analyses of networks in the bioeconomy. These two premises' are flanked by a growing research literature on network analysis in economic geography that revolves around the idea that networks fulfil an incubation role for innovation by linking actors together and positively influencing the transfer of knowledge (Broekel & Boschma, 2012; Broekel & Mueller, 2018). As innovation is regarded as a critical driver for the bioeconomy, Chapter 3 aims to analyse a funded research and development network – Horizon 2020 – and comprehensively examine its actor and knowledge dynamics to detect favourable structures and configurations in the light of the bioeconomy. The aforementioned challenge of fuzziness the bioeconomy presents for quantitative research needs to be solved in the first step. With the help of various data science tools, three different spheres – a political, a scientific and a social sphere – are scraped, crawled, and textmined on the macro-level before being combined into a robust set of keywords identifying the concept of the bioeconomy. Since it includes the term in its structure and provides an extensive and accurate data basis, the last European framework programme, Horizon 2020, is a natural fit as a meso-scale scope. With the help of the keywords, funded projects applying bioeconomic principles are identified, their participants extracted and afterwards transformed into an affiliation network, on which detailed social network analysis is carried out. By doing so, details on central actors and new insights into knowledge flow in large research and development networks are found, while also, for the first time, a concise, holistic European bioeconomy network is visualised and profoundly analysed.

With Chapters 2 and 3 focusing on high-level structures, Chapter 4 zooms into the micro by examining low-tech, agri-food value chains on the actorial firm level embedded in an innovation system setting. The European sugar industry is chosen as an exemplary case due to its maturity and bioeconomic processing setting. Besides highlighting theories on innovation systems, sustainable innovation and sustainability transitions, light is also being shed on specific settings for both bioeconomic and low-tech agri-food value chains, while open innovation and innovation modes are assessed alongside. After being combined into a structure-providing analytical framework, the theory is expanded by an in-depth look into the European sugar industry, its history, market- and policy development, as well as essential actors and actor categories relevant in the sugar value chain. Motivationally, Chapter 4 picks up literature threads on how innovation is achieved in mature, low-tech industries and merges them with the fact that agricultural, especially agri-food industries, can be a pivotal player in a transformation towards a bioeconomy but are substantially underrepresented in research. The sugar industry provides an inherently compelling case. Due to a recent market liberalisation that acted as an external shock to the sector, a significant underlying bioeconomic potential started to surface, determined by the industry revolving around a completely biogenic resource. Three European case regions were selected to investigate the implications of this, and the same actor groups along the regional sugar value chains were interviewed and analysed using Qualitative Content Analysis. While centring on sustainability transitions and innovation systems and how knowledge and innovation work in the particular case of sugar, Chapter 4 additionally identifies and discusses a unique value chain configuration for agri-food and a potentially different perspective towards value chains in the bioeconomy altogether.

Finally, in Chapter 5 the results of this dissertation are summarised and its limitations discussed, before describing contributions to the literature and formulating policy recommendations.

Chapter 2

Characteristics of Innovation in the Bioeconomy

Abstract

In recent years, the research field of the bioeconomy has experienced significant global growth, based on an increasing number of annual publications in the last ten years. The bioeconomy received a strong political push by European policymakers after the instalment of a “knowledge-based bio-economy” 15 years ago. While playing an essential role in recent EU policies, the bioeconomy still lacks a coherent understanding across multiple layers, especially regarding innovation activities. Innovations undoubtedly form one of the basic building blocks of the success of the knowledge-based bioeconomy and its increasing reach, but it must nevertheless be noted that frequently they are not well-understood, and misconceptions prevail. Therefore, this study attempts to characterise innovation in the bioeconomy. Based on a theoretical discussion of different concepts and aspects of innovation and a literature review at the intersection of bioeconomy and innovation, a catalogue of criteria about what can influence innovation in the bioeconomy is proposed. Thus, seven criteria categories are deduced, and multiple keywords are assigned to each. The proclaimed categories are then discussed and helped to identify innovation triggers for the bioeconomy. Thus, the work attempts to propose a realistic foundation and theoretical assessment of innovation in the bioeconomy to reinforce future discourse.

Keywords: bioeconomy, innovation, literature review, catalogue of criteria

2.1 Introduction and Motivation

In 2004, based on the "knowledge-based bioeconomy" the term "bioeconomy" found its way into the policy discussion in Europe (Golembiewski et al., 2015). Fourteen years later, within the framework of the Global Bioeconomy Summit (GBS) in 2018, over 700 representatives from politics, science, civil society, as well as the business sector from more than 70 countries gathered to discuss the challenges and future of the bioeconomy (von Braun, 2018). As an outcome of such an event, one may expect a polished action plan of what exactly the next steps towards the implementation of the bioeconomy need to look like. The actual result, however, tends to reduce one's optimism. The question of a universal and streamlined definition of what precisely bioeconomy means, includes, and implicates on a global level remained unanswered. All that was gained is another document that offers general recommendations and states urgency without providing concreteness. Especially against the backdrop of an official European Commission document – released about a year before the summit – explicitly stating the need for a common framework and giving concrete recommendations, making the whole event appear redundant. Not surprisingly, more and more authors have started to raise questions on the negative aspects of the recent developments in the bioeconomy. It has become "a buzzword used by public institutions" (Vivien et al., 2019, p.1), is criticised "for being a weak form of ecological modernisation aiming for increased exploitation of natural resources" (Bauer, 2018, p.1) and the ongoing academic discussion "about its environmental aspects and its questionable and variegated integration of sustainability perspectives" (Albrecht, 2019, p.3) gains increased publicity. At its core, bioeconomy is not just a catchword if some things are kept in mind (Golembiewski et al., 2015; Peltomaa, 2018). First, framing and defining the bioeconomy as a single industrial sector will not yield satisfactory results. Various authors state the need to refer to the bioeconomy as a multi-dimensional concept instead of a sharply defined sector. One of the main reasons for that is the fact that the bioeconomy in itself is exceedingly fuzzy (Golembiewski et al., 2015), still in its infancy (Golembiewski et al., 2015; von Braun, 2018) and is, per se, nothing new (Pietzsch & Schurr, 2020). These points have considerably influenced the predominant definition problem of the bioeconomy. In general, the bioeconomy concept entails the sustainable use of renewable biomass instead of finite fossil resources to develop and produce various bio-based, value-added products, services, and energy. These work as substitutes for existing fossil fuel-based products, services, and energy and are a part of a broader societal transition to a low-carbon future (Birch, 2019; van Lancker et al., 2016). The concept also promotes the circular economy concept as a natural fit (Näyhä, 2019) as well as the adoption of cascading, meaning to initially process biomass into high-value products before using the residues for lower-value applications until a minimum of waste remains at the end (van Lancker et al., 2016). With being primarily conceptually based, we can think of the bioeconomy "as a wholesale shift in the way our economies – and necessarily our societies and polities – are organised and coordinated such that they are no longer based on fossil fuels" (Birch, 2019, p.2).

However, holding this kind of conceptual flexibility, the bioeconomy can be exploited to promote different and contrasting objectives (Peltomaa, 2018) and is diverted as an irrelevant buzzword in many publications, policies, and reports. It has proven attractive to many different actors because it can mean something to everyone – it is many things to many people (Staffas et al., 2013; Vivien et al., 2019). Its holistic approach can thus be seen as its strength on the one hand but also as its weakness on the other: a "fetishisation of everything bio-" (Birch & Tyfield, 2012, p.3) takes place, while the role of the bioeconomy as a powerful meta-discourse (Bauer et al., 2018) should not be underestimated (Birch, 2019). Thus, the bioeconomy has the potential to affect a fundamental change in the industry (Schütte, 2018), although it is not as straightforward as many researchers, politicians, and decision-makers frame it.

The global economy faces a lock-in into a fossil-based and CO_2-intensive production mode (Pyka, 2017), a significant hurdle for the bioeconomy to overcome. It is generally assumed that the climate change induced by greenhouse gases can be mitigated by efficiency improvements, CO_2 sequestration, and the switch from fossil primary energy sources to a variety of renewable resources (Hess et al., 2016). McCormick and Kautto (2013) see the solution in a transformative change that involves long-term approaches and interactions at all levels of society. Their vision is supported by Birch (2019), as he sees the bioeconomy as a socio-technical transition along the lines of Geels (2002). However, "[...] the geographical dimensions of such transitions are often ignored or overlooked in existing research" (Birch, 2019, p.19) but are a vital element for a successful transition. "It is not, then only a social and technical transformation, it is, as much, a material transformation, changing the social, technical, and material elements" (Birch, 2019, p.19). For this transition, innovation is seen by various authors as one, if not the critical factor for moving forward (Bauer et al., 2018; Birch, 2019; Golembiewski et al., 2015; Purkus et al., 2018; Pyka, 2017; Schütte, 2018; van Lancker et al., 2016). However, the innovation term is also used inflationary, even more so in the bioeconomic context. Especially in some EU policies, the combination of both terms – bioeconomy and innovation – needs to be critically reviewed (Birch & Tyfield, 2012). Furthermore, the research landscape regarding innovations in a bioeconomic context appears to be quite empty so far (van Lancker et al., 2016), even though the authors mentioned above mutually agreed on it being one of the building blocks of the bioeconomy itself. Thus, the primary motivation for this study is to showcase what the innovation term explicitly implicates for the concept of bioeconomy and which factors can influence innovation in a bioeconomic context, not least since this combination has so far been largely neglected. In order to address innovations in the bioeconomy, both terms need to be reviewed on their own before looking at their combination. A theoretical foundation is built throughout the first two sections to grasp the individual concepts. Based on a subsequent literature review, the characteristics of innovation in the bioeconomy are approached by establishing a catalogue of criteria intended to indicate factors contributing to the emergence of innovations in the bioeconomy.

2.2 Theoretical Considerations

2.2.1 Framing the Bioeconomy

The emergence of the bioeconomy can mostly be seen as the result of chance and necessity (Patermann & Aguilar, 2018). The European Commission has provided, managed, and implemented the biotechnology and life sciences framework since 1982; the experience gained through the reports and concepts helped present the draft of the knowledge-based bio-economy (KBBE) in Brussels in 2005. After the knowledge-based bio-economy was adopted in 2007 under the German EU Presidency, different activities took place in the member states. Still, all aimed in the same direction: the best possible use of the four unique properties of biological resources. These include renewability, CO_2-friendliness, recyclability, and the provision of new and better functions. As a result of the preparation of the EU bio-economic strategy in 2012, the idea of a new initiative on a larger industrial scale was developed, which focused on developing new bio-based value chains through new biorefining concepts. The BBI (Bio-Based Industry) initiative became a reality and represented the most significant industrial and economic cooperation financially undertaken in Europe in industrial biotechnology (Patermann & Aguilar, 2018). Interest in the bioeconomy is growing not only within the EU but also at a global level. More than 40 countries have developed plans for a more substantial consideration of bioeconomic principles or national bioeconomic strategies (Pietzsch & Schurr, 2020). Hess et al. (2016) conducted an in-depth international survey, focusing on the official bioeconomic positions of the respective governments. One result of this study was that the development of a bioeconomy is almost always a top-down, policy-driven process. A decisive factor is that all nationally pursued goals are oriented towards the overarching, global model of sustainability, which was declared at the UN Conference on Environment and Development in 1992. This basis was expanded in 2015 by the UN Sustainable Development Goals (SDGs); a total of 17 SDGs apply to all states and are to be implemented by 2030. The following targets are often regarded as the most relevant ones for the bioeconomy (Fritsche & Rösch, 2017):

- **Goal 2:** eradicate hunger, achieve better nutrition and food security, promote sustainable agriculture
- **Goal 6:** ensure availability and sustainable management of water and sanitation
- **Goal 7:** ensure access to affordable, reliable, sustainable and modern energy for all
- **Goal 12:** ensure sustainable consumption and production patterns
- **Goal 13:** take action to combat climate change and its effects
- **Goal 15:** protect, restore and promote the sustainable use of terrestrial ecosystems, manage forests sustainably, combat desertification, halt and reverse land degradation and halt biodiversity loss

Because of the lack of a general guideline and the looming implementation obligation, definitional approaches of scientists, institutions, and political representatives are often based solely on these SDGs. The problem is beginning to surface: initially, in 2004, the OECD defined the biobased economy as "[...] a concept that uses renewable bioresources, efficient bioprocesses and eco-industrial clusters to produce sustainable bioproducts, jobs, and income" (Patermann & Aguilar, 2018, p.3). Thus the idea of the bioeconomy has been formulated as an abstract concept right from the beginning and is therefore fundamentally vague. Without guidance, the interpretation of this multi-dimensional concept is primarily dependent on who is interpreting it. This led to a current, wide-scale problem of definition; a standard definition would help to harmonise and synchronise the efforts of all possible players to promote and realise the concept worldwide. However, it seems that common definitional ground is not an urgent problem. The Bioeconomy Summit in 2015 stated that they "[...] have not aimed for a unified definition [...]" but do "[...] note that an understanding of bioeconomy as the knowledge-based production and utilisation of biological resources, innovative biological processes, and principles to provide goods and services across all economic sectors sustainably is shared by many [...]" (Bioeconomy Summit, 2015). Bugge et al. (2016) approached the problem scientifically and examined the differences in understanding the wide diffusion of the bioeconomy concept. With the help of extensive bibliometric analysis, they distinguished between three visions of what a bioeconomy constitutes (see Table 2.1): Bio-Technology, focusing on research and development and the application of biotechnology in general with science push at its core, Bio-Resource, revolving around purposefully converting resources with the help of interdisciplinary approaches, and Bio-Ecology, revolving around sustainability, circualrity and a more self-contained production mode.

In the literature, the *Bio-Technology Vision* is supported by Birner (2018, p.24), who states that the "emphasis has shifted to the bio-technology innovation perspective of the bioeconomy [...]" and "the opportunity to make economic use of innovations in biotechnology, and, more generally, in the life sciences has become a major rationale for the bioeconomy in recent years". This further underlines the relevance of innovation in the context of the bioeconomy, especially regarding its drivers and mediators. However, Bugge et al. (2016) stress that these visions should not be considered entirely separate from one another but rather are ideal-typical approaches to the bioeconomy. Although actors such as the OECD (biotechnology), the European Commission (bio-resources), and the European Technology Platform TP Organics (bioecology) are directly linked to the various visions, it cannot be denied that the visions are interrelated (Bugge et al., 2016).

Nevertheless, Birner (2018) distinguishes between two types of criticism. The first type criticises the bioeconomy as the "neo-liberalisation of nature", where the concept has been promoted to pursue the interest of big companies. As a consequence, land grabbing is feared, thus identifying a threat to world food security. The "greenwashing" type aims at the labelling "bio-", which often is misused to portray non-sustainable economic systems

	Bio-Technology Vision	Bio-Resource Vision	Bio-Ecology Vision
Aims & objectives	Economic growth & job creation	Economic growth & sustainability	Sustainability, biodiversity, conservation of ecosystems
Value creation	Application of biotechnology, commercialisation of research & technology	Conversion and upgrading of bio-resources	Development of integrated production systems and high-quality products with territorial identity
Drivers & mediators of innovation	R&D, patents, TTOs, Research councils and funders (Science push, linear model)	Interdisciplinary, optimisation of land use, include degraded land in the production of biofuels, use and availability of bio-resources, waste management, engineering, science & market (Interactive & networked production mode)	Identification of favourable organic agroecological practices, ethics, risk, transdisciplinary sustainability, ecological interactions, re-use & recycling of waste, land use, (Circular and self-sustained production mode)
Spatial focus	Global clusters/Central regions	Rural / Peripheral regions	Rural / Peripheral regions

Table 2.1: Key characteristics of bioeconomy visions (Bugge et al., 2016)

as environmentally friendly (Birner, 2018). However, implementing the principle of the circular economy is widely regarded as positive. It is mostly associated with the adoption of closing-the-loop production patterns within an economic system, and with aims to increase the efficiency of resource use and cascading (Birner, 2018). The circular economy can furthermore support the promotion of the bioeconomy as genuinely sustainable. "Biomass-based value webs" can help to point out potentials and showcase the cascading use of biomass and by-products instead of disposing of these as waste (Virchow et al., 2016)

While Bugge et al. (2016) have already identified essential innovation drivers for the three different bioeconomy visions, Birner (2018) considers relevant factors that favour the development of bioeconomy (Table 2.2). Besides natural conditions favoring biomass production, labour, knowledge and capital resources are described, with viable infrastructure, clusters, competition as well as the demand for bio-based products in a supportive role. These get flanked by more holistic factors – chances and shocks as well as socio-cultural factors – that build the systemic framework.

2.2.2 Innovation as a Concept

The introduction cautiously pointed out that bioeconomic innovation is, as well as bioeconomy itself, neither well-defined nor understood. Thus, this study will now focus on the

Factor	Description
Natural conditions	Available land, agroclimatic conditions, population density, access to marine resources, etc., can significantly influence a country's competitive advantage for biomass production.
Labour resource	Governments can considerably influence the qualification of their labour force for the bioeconomy, especially by investing in education and professional training. Those "factor-upgrading" investments can help improve a country's competitive advantage for developing its bioeconomy.
Knowledge resources	Stimulating the development of the bioeconomy by investing in public and private research. Investments in research and innovation are an essential element of most bioeconomy-related strategies.
Capital resources	Investments along entire value chains of bioeconomic products, including research, product development, and marketing. Available capital, especially venture capital for risky investments, is an essential condition for developing the bioeconomy.
Infrastructure	Providing a supportive infrastructure, especially in terms of transport as well as information and communication technologies (ITCs). Early identification of infrastructural needs that are relevant to the bioeconomy is essential.
Demand for products	Strong demand of consumers for bio-based products. Supporting this demand by promoting labels, conducting information campaigns, and fostering social dialogue. Introduction of public procurement to strengthen public demand.
Competition	among firms Healthy competition of companies in their home country fosters their international competitive advantage by forcing them to be innovative and strategic. Subsidising and protecting firms from competition is hardly ever fruitful. Fostering this kind of competition and restricting market dominance can help to develop a healthy bioeconomy.
Clusters	The concept is based on the requirement of a robust and regionally integrated network of related industries supporting each other along the value chain. Clusters benefit from a close interaction between actors but are problematic to be created from scratch. A better method is to identify emerging clusters and support them.
Chances and shocks	Factors that are beyond the control of economic and political actors can play an important role. Favourable chances (discoveries that offer unexpected opportunities) and adverse shocks (sudden price changes or natural disasters) may affect the development of the bioeconomy, assuming they are effectively used.
Socio-cultural factors	Socio-cultural factors are not directly controllable and can range in wide ways from small-scale interests to broad trends. Fostering a strategy while acknowledging these can help to stimulate development.

Table 2.2: Conditions for the development of bioeconomy (Birner, 2018)

theoretical foundations of the term "innovation" while presenting various guiding trends. The general importance and relevance of the concept of innovation were repeatedly emphasised in research both in the 20^{th} century and at the beginning of the 21^{st} century (Fig. 2.1). Especially for the (long-term) competitiveness of companies and regions, it is seen as one of the main driving forces, because of the implementation of novelty and variety. Succeeding in innovation lets companies prosper; innovative countries and regions have a higher income than less innovative ones, and catching up with innovation leaders often means increasing a company's innovation activity (Fagerberg, 2018).

Innovation is seen as a necessary factor for the well-being of firms. However, the meaning of innovation and especially how and when it occurs are still unclear (Fernandes Rodrigues

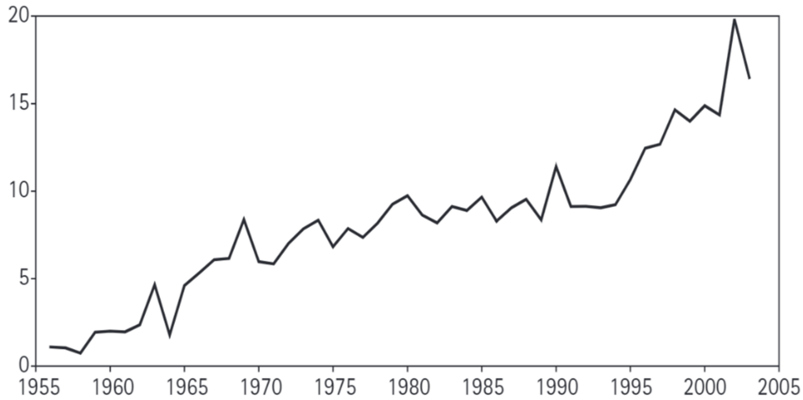


Figure 2.1: Scholarly articles with "innovation" in the title, 1955-2004, per 10000 social science articles (Fagerberg, 2018)

Alves et al., 2018). Innovation is not a new phenomenon, it is arguably as old as humankind (Fagerberg, 2018), and while we know where innovation leads, we know much less about why and how innovation occurs. Since researchers for decades in different working fields have tried to grasp innovation and customise it to fit their specific scientific area, a certain "fuzziness" around the term and its various conceptual framings can be noticed (Fagerberg, 2018). In the following, essential currents of the different types, models, and finally, levels of innovation are briefly presented in order to form a basis for the further discourse.

2.2.3 Innovation: Models, Types, and Levels

When talking about innovation, Schumpeter is also one of the most influential names. He invented the trinity of the innovation process, resulting in the indistinction between invention (new ideas are generated), innovation (ideas are developed into processes and products), and diffusion (spreading these processes and products across markets) (Schumpeter, 1939). Schumpeter, therefore, not only introduced innovation as a process but also made the vital distinction between invention and innovation into two separate concepts, which nowadays more often than not get mixed up. The linear innovation model arose due to interpreters of Schumpeter's work, who anchored it into the context of the technology-push and demand-pull debate (Godin, 2016) and is, without a doubt, one of the first frameworks developed to understand the relation of science and technology to the economy. It implies that innovation starts with basic research, is then followed by applied research and development before ending with production and diffusion (Godin, 2016). However, in Fagerberg's 2018 opinion, innovation has little to do with this linear model. He argues that it is based on the wrongful assumption of innovation being applied science, while in reality, firms usually innovate because of a commercial need to do so (Fagerberg, 2018). Godin (2016, p.35) opposes this by rectifying that the model is merely a "rhetorical entity, [...] a thought figure" that makes the otherwise fuzzy concept of innovation easier for administrators and agencies to grasp. Simple models, like the differentiation into product and process, as well as physical and intangible innovations, can be found as the basis of more advanced concepts (Fig. 2.2).

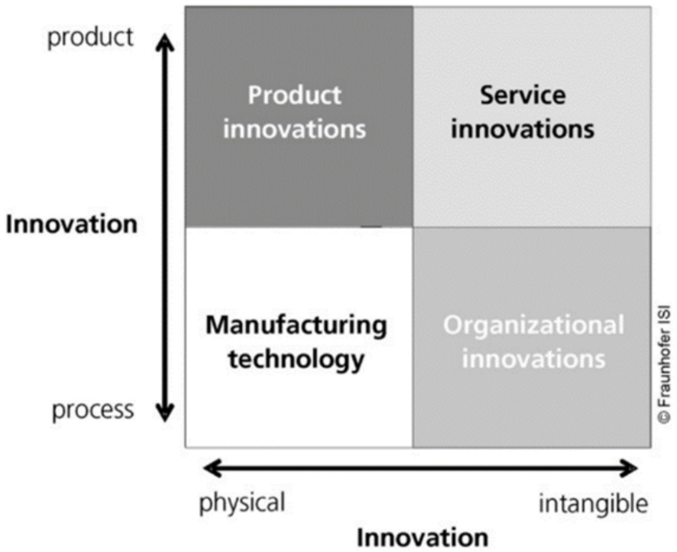


Figure 2.2: Innovation fields in manufacturing firms (Kirner et al., 2009)

Often used for policy recommendations, the innovation systems perspective achieved scientific attention in recent years. It combines all essential economic, social, political, organisational, and other factors that influence the development, diffusion, and use of innovations (Purkus et al., 2018), while also stressing linkages between actors that can be flows of goods, R&D cooperation or other relationships (Pyka, 2017). Thus, all innovation processes can be seen as naturally embedded in innovation systems.

Further, the concepts of Technology Innovation Management (TIM) and Open Innovation (OI) tend to get highlighted in the recent innovation literature on the bioeconomy (Birch, 2009; Golembiewski et al., 2015; van Lancker et al., 2016). TIM "[...] seeks to understand how novel technologies and innovations emerge and how they can be commercialised successfully" (Golembiewski et al., 2015, p.2). It thus attempts to decipher the most-asked question since the days of Schumpeter. OI, on the other hand, is mentioned as a subfield to TIM that is rapidly becoming a dominant approach to innovation conceptually (van Lancker et al., 2016). It can be defined as "[...] the use of purposive inflows and outflows of knowledge to accelerate internal innovation and expand the markets for external use of innovation", thus considering the "boundaries between the firm and its surrounding environment [...] to be more porous which allows knowledge and innovation to move more easily between the two" (van Lancker et al., 2016, p.64). A bit older but of significant relevance is the differentiation between a science and technology-based innovation mode (STI) and practice and interaction-based innovation that relies on learning-by-doing, by-using, and by-interacting (DUI) (Parrilli & Alcalde Heras, 2016). Science, technology and innovation (STI) is centred on large R&D expenditures, including investments in highly qualified academic human capital and new technology and infrastructure. It supports interactions with knowledge-producing centres, such as research institutions and universities, which generate the codified and explicit knowledge that can be used to trigger innovations in the company. STI tends to generate both analytical knowledge and synthetic knowledge bases. Doing-using-interacting (DUI), on the other hand, locates the reason for the generation of innovation in a company in the capacity of it to develop informal and formal exchanges internal to the firm but also linkages with suppliers customers, and competitors. By nature, these interactions create a knowledge base exploited in many engineering-based industries, such as machine tools, shipbuilding, automotive, and energy. Thus, the core difference between the two lies in their different types of interaction (Parrilli & Alcalde Heras, 2016).

These approaches all involve one of the basic terms of the innovation vocabulary: knowledge. Knowledge provides a crucial input to innovation, enabling actors to understand the world and make decisions that affect it (Birch, 2009). The importance lies in differentiating between different types of knowledge: appropriable (restricted access) and non-appropriable (free to access) (Birch, 2009), as well as tacit (knowing-how) and explicit (knowing-that) knowledge (Nonaka & Takeuchi, 1995). These terms are essential in the further course of the study, especially for understanding spillovers and collaborations. It becomes apparent that the concept of innovation can be combined with different approaches, which can be understood as a renewed indication of its adaptability but also provide another argument for its breadth and fuzziness. Besides models, this affects types of innovation as well. Tzeng (2014), for example, distinguishes between the following three leading schools of innovation (see Table 2.3):

	Corporate Capability School	**Entrepreneurship School**	**Culture School**
General Perspective	Economic	Social	Cultural
Nature of innovation	Institutionalised capability	Innovation as grass-roots impetuses	Innovation as deep craft
Inherent logic of innovation	Evaluate	Engage	Envision
Relationship among members	Instruction-based	Identity-based	Intergenerational

Table 2.3: Main schools of Schumpeterian innovation (Tzeng, 2014)

In terms of the bioeconomy, all three schools may apply, thanks to their broad conceptual base. While the Corporate Capability School can be seen with large, historically grown companies in mind, the Entrepreneurial School and Culture School could be combined with a focus on the more dynamic start-up scene and creative class.

Terms like “technical innovation” and “administrative” or “management innovation” were also brought forward, resulting in even more spin-offs, like organisational innovation (Fernandes Rodrigues Alves et al., 2018). The OECD defines organisational innovation as “the implementation of a new organisational method in a firm's business practices, workplace organisation, or external relations" (OECD, 2005, p.177). It is furthermore stated that "[...] other scholars also developed typologies for understanding organisational innovation; however, many of them are overlapped" (Fernandes Rodrigues Alves et al., 2018, p.3), thus providing an argument for a conceptual 'one size fits all'-mentality. Into the same category falls responsible innovation and social innovation. Responsible innovation includes the future-oriented organisation of development. It is defined as a "[...] transparent, interactive process by which societal actors and innovators become mutually responsive to each other with a view to the (ethical) acceptability, sustainability and societal desirability of the innovation process and its marketable products [...]" (von Schomberg, 2012, p.50). On the other hand, social innovation emphasises the importance of active citizenship in innovation (Pyka, 2017). By now, the diverse phenomenon of innovation and some redundancy conceptual-wise should becomes clear (Kirner et al., 2009).

Besides the mentioned knowledge, another core term is creative destruction or incremental versus fundamental change. Nowadays, this dichotomy is also described as the level of innovation, and, spanning back to Schumpeter, creative destruction is regarded as one of the two possibilities for change to occur. The incremental type describes minor improvements along well-known trajectories, while the fundamental, or creative destruction type leads to structural changes, for example the emergence of new and the disappearance of old industries (Pyka, 2017; Suroso & Azis, 2015), meaning a "[...] wholesale transformation of socio-technical systems" (Birch, 2019, p.18). By now, it has become evident that there seems to be a jungle of innovation concepts, lots of "[...] alternative models, with their multiple feedback loops [that] look more like modern artwork or a plate of spaghetti and meatballs than [...] useful analytical framework[s]" (Godin, 2016, p.35). Bioeconomy was identified as a vast concept, and the innovation concept does not look much different; at a basic level, innovation is doing the old in a new way, while the idea behind the bioeconomy is pretty much the same.

2.2.4 Innovation in the Bioeconomy

With the beginning of the 21st century, a paradigmatic shift towards a somewhat sustainable and smart economy is in the air (Pyka, 2017). Bioeconomy, as a concept, initially focused on the supply of goods and services based on biological resources and biotechnological processes. Now, in light of the developments during the last 15 years, more attention is given to the demand side of the bioeconomy and, thus, its general role in society. Viewing the bioeconomy from a more holistic point of view that considers people as customers and citizens as factors as well, reveals the bioeconomy as an element in this process of societal transformation (Birner, 2018). Following that, the argument that it "[...] will not be sufficient to create economic incentives and implement conductive environmental policies" to combat the effects of climate change, but it is ultimately required to have "[...] a great societal transformation, which encompasses profound changes to infrastructures, production processes, regulation systems, and lifestyles, and extends to a new kind of interaction between politics, society, science, and the economy", prevails (Birner, 2018, pp.28-29). Various authors agree that the appraisal of the bioeconomy is one of the central factors for this change, which is unfortunately impaired by a fundamental uncertainty (Pyka, 2017). Creative destruction is mentioned (Birch, 2019; Fernandes Rodrigues Alves et al., 2018; Schütte, 2018), and the transformation process is believed to span a large part of the 21st century (Saviotti, 2017). This process is assumed to lead to the reorganisation of the whole world economic system, thus being an indispensable part of our future society (Bauer et al., 2018). The lack of systematic assessment, however, is seen as one of the hurdles for this transition to take place (Bauer et al., 2018); the diffuse nature and unclearness remain to be seen as problems that need fixing as soon as possible (Purkus et al., 2018).

2.3 Summary of Existing Literature on Innovation in the Bioeconomy

This study builds on existing research on innovation in the bioeconomy in order to identify its main drivers. The data collection was done in 2019 and aimed at collecting peer-reviewed journal articles and book chapters published in English since 2006 to gain insights into the most recent scientific discourses on the matter. By using the advanced search term in the database Web of Science Core Collection (WoS):

TS=(bio-economy AND innovat) OR TS=(bioeco* AND innovat*) OR TS=(bio-eco* AND innovat*)*

a total of 292 publications could be found that contained one of the search terms in either title, abstract or keywords. Applying a snowball process to cover additional important articles ensured optimal coverage (Jarre et al., 2020). The publications found in the research field of bioeconomic innovations from 2006 – 2018 are distributed over the years as follows (Fig. 2.3).

The exponential growth of annual publications since 2014 proves a significant and increasing interest in the topic in recent years. The reason behind that almost certainly lies in the Paris Agreement taking place in 2015 and an increasing number of countries incorporating bioeconomy into their national strategies and policies, thereby triggering scientific interest in the topic. After an initial examination of the titles and abstracts of these 292 publications, only 13 of them seemed to include accurate statements about bioeconomic innovation factors. An explanation based on the earlier theoretical remarks would probably state the high degree of the vagueness of both concepts, combined with the small research environment. The hurdle of lacking assessment and, again, the breadth of the bioeconomy and innovation concept can thus be underlined.

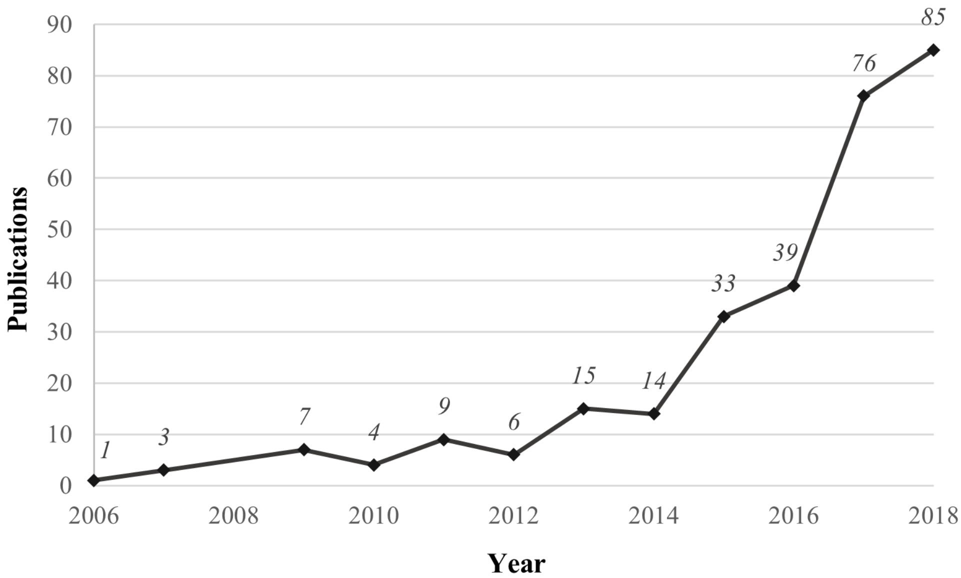


Figure 2.3: Resulting numbers of publications in the database Web of Science (own graphic)

As a first step, the discovered, influential factors of these 13 publications will be discussed. Golembiewski et al. (2015) conducted a publication analysis to achieve an overview of the current research landscape dealing with the bioeconomy and highlight the challenges of technology and innovation management (TIM) for bioeconomy. They state the cross-sectorial character of the bioeconomy and thus the need for interdisciplinary approaches. The need for broader, holistic approaches to the bioeconomy can also be found in other publications. Bauer (2018) speaks of the demand for a long-term, holistic perspective and adaptive policymaking, while Schütte (2018, p.6) states the need for "[...] holistic, systemic perspectives and solutions [...]", Maes and van Passel (2019) dismiss approaches entirely that focus on research and development alone, because a too narrow approach contradicts the basic principles of the bioeconomy; the majority of the authors, therefore, also rejects it.

As already briefly mentioned, knowledge is commonly seen as a core factor for innovation (Kirner et al., 2009), which is no different in the bioeconomic context (Golembiewski et al., 2015). Fernandes Rodrigues Alves et al. (2018, p.6) see knowledge as the "[...] most important resource and thus learning as the most important process [...]". Knowledge is also deeply intertwined with location or space of origin. It can come from diverse locations and in many forms, while every spatial context is unique, meaning that "[...] all knowledge entails geographical specificity in terms of its positioning and embedding in certain places [...]" (Birch, 2009, p.276). Birch (2009) calls that connection the knowledge-space dynamic. He argues that innovation occurs in specific locations where firms and other organisations can access complementary capabilities because of their co-location and proximity, thereby arguing parallel to Boschma (2005). Knowledge can thus leak between actors, lead to an iterative process of learning, as well as bolster the occurrence of bioeconomic innovation (Birch, 2009, 2012). Appropriable, non-appropriable, tacit, and explicit knowledge implicates the same in the context of bioeconomic innovations. A Schumpeterian understanding of innovation solidly underpins Birch's knowledge-space dynamic. Pyka (2017) frames it as a Neo-Schumpeterian approach. In essence, he highligts the complementary interplay in knowledge generation and diffusion processes between firms, consumers, and government institutions (Pyka, 2017), thus emphasising innovation as an interactive process between multiple actors (Bauer et al., 2018). Bauer et al. (2018) as well as Fu et al. (2013) state the crucial link between university research and private sector research, therefore cross-sectoral, while (Birch, 2009) also mentions the relevance of multi-scale, therefore international linkages. The importance of the encompassing environment, as seen in Birch's knowledge-space model, needs to be kept in mind as well (Fagerberg, 2018). By looking at a company's internal processes, factors that influence the emergence of innovation can also be identified. Tzeng (2014), for example, highlights the importance of a long-time commitment to financing the development of new technologies. The author further argues, in the sense of the cultural innovation school, that technical innovation is not necessarily the outcome of digging information out of books or articles but rather is a set of skills that cannot be reduced to a science (Tzeng, 2014). This is further reminiscent of the doing-using-interacting (DUI) mode of innovation, as well as the idea of "innovation out of necessity".

Innovation as a term in a bioeconomy setting is seen as a "[...] rather complex, collaborative, and multi-level process which is embedded in innovation systems [...]" (Kirner et al., 2009, p.447), and it is, in general, a good idea to "[...] broaden one's perspective on innovation" (Tzeng, 2014, p.17). It needs to be assured that differentiation between possible innovation paths is made. Not every firm innovates by developing new products; services can be innovative as well as introducing innovative manufacturing technologies or implementing innovative organisational concepts (Kirner et al., 2009). Fagerberg (2018) states the importance of the environment for innovation. This environment typically consists of suppliers, competitors, media, government, customers, economic conditions, investors, and multiple other institutions working externally. The environment is also a significant factor in the Open Innovation concept. However, Open Innovation in the bioeconomy relies heavily on trust between actors. Most collaborations are undertaken with already known partners to reduce the risk of knowledge theft or involuntarily outgoing spillovers (van Lancker et al., 2016). Of course, one could always argue that a certain openness towards new collaborations and knowledge exchange needs to be the standard case, but it is not an easy goal to achieve. Especially with regard to the bioeconomy concept and its uncertainty, the acceptance of firms seems to be a problem (Pyka, 2017) and is considered a significant hindrance to innovation. Not only that but the lack of acceptance of consumers and thus society, in general, is a hurdle as well (Pyka, 2017). A limited consumer understanding of the bioeconomy might reduce market demand and the innovation capacity as a whole (Wensing et al., 2019), because "[...] a bio-economic innovation will only be successful if consumers accept it" (Pyka, 2017, p.9). This is why authors recommend, besides Open Innovation that includes consumers and users in the innovation process, a bunch of policy changes to address all actors relevant in a given innovation system and, most importantly, to educate and inform them. Staffas et al. (2013) argue that various national strategies and policies include innovation, but few go beyond a general recommendation toward a concrete roadmap. The need for coherence of national and international strategies is stated (Schütte, 2018; Stadler & Chauvet, 2018), as well as a coordinated and in-depth approach that includes entrepreneurial activities, knowledge diffusion, guidance, market formation help, resource mobilisation and the creation of legitimacy (Purkus et al., 2018). While coherence is essential not to work against an overarching bioeconomy strategy, including all of the above parts ensures that all aspects of the bioeconomy are covered as widely as possible. Further, policies especially need to account for the fact that innovation is not only taking place within R&D intensive high tech sectors or in high-tech firms alone but also along the pragmatic lines of DUI and necessity innovations (Kirner et al., 2009). Bauer (2018) explains further that the transition also needs a general change in consumer behaviour and expectations and an institutional change regarding norms, standards, and regulations. Both are inherently difficult to achieve because not only does the economy needs to face and overcome their lock-in status, but humans also need to change lifelong trained behaviours and habits, and, as the dopamine reward circuit showcases, they are pretty bad at changing their impulse control to the better – especially when it comes to bioeconomy, where a lack of comprehension and acceptance predominates in society. Bauer et al. (2018) also state the need to let firms innovate at their own pace because innovation is, as shown, nothing that can be triggered but something that can be positively influenced. What is more, science and technology alone will not manage to solve the transition puzzle; politics need to intervene and help to initiate the change (Bauer, 2018). An appropriate innovation agenda, a national strategy that influences all policy areas, supports new technologies and finds new ways of financing deployment and diffusion of innovation, is needed (Bauer, 2018; Bauer et al., 2018).

2.4 Criteria for Innovation in the Bioeconomy

The findings of the previous section are now compiled within the framework of a criteria catalogue and with the help of the initially identified drivers. van Lancker et al. (2016) deliver a helpful entry point for this. They incipiently state the importance of radically new and disruptive innovations, such as new business models, reconfigured value chains or the creation of entirely new value chains, while also considering the intricate knowledge base of various sciences. Cooperation between different actors can help develop this sophisticated knowledge, while commercialisation and adoption of new bio-economic technologies and products are seen as a challenge due to high switching costs and the locked-in state of the economy. Complex and fragmented policy schemes form another challenge, as many new concepts are expected to comply with several different policy schemes and are subject to regulation from different administrative levels. The authors conclude that "[...] innovation processes [...] are best considered as transdisciplinary endeavors, open to relevant stakeholders, with ample room for iterativety between idea development, invention, and commercialisation". Organisations need to "[strive] to innovate towards the bioeconomy [...]", while "[...] leadership should embrace innovation and openness", and the "organisational culture should reflect this [...]". "Available knowledge, expertise and technology need to be scrutinised, [...] relational capability and absorptive capacity need to be adequate [...]" (van Lancker et al., 2016, p.7). Additionally, Tzeng (2014, p.6) emphasises that "[...] most important pathways include joint or cooperative ventures, contract research, consulting, informal interactions, conferences, and publications". Thus, based on the literature work in the previous sections, the following criteria catalogue was developed (Table 2.4).

No.	Criteria	Keywords
1	**Knowledge and Awareness**	presence of knowledge base; appropriable / non-appropriable knowledge; diffusion and spillover effects
2	**Openness and Collaboration**	vertical / horizontal cooperation; multi-scale linkages; degree of connection; level of trust
3	**Environment**	proximity; biotic, abiotic situation; supportiveness; dynamic / undynamic; suitability for innovation
4	**Assisting Policies and Government**	coordination; holistic approach; coherency and clear understanding; funding and support; creative destruction
5	**Society and Consumers**	acceptance; understanding; certainty; demand for new products
6	**Company Management**	capability; acceptance; interactions; openness; R&D expenditures; long-term planning; demand and need
7	**Feasibility**	technological, social, environmental, ecological feasibility; sufficiency and efficiency; available resources

Table 2.4: Criteria catalogue based on the literature review

In the following, the criteria and accompanied keywords are described in detail, taking the bioeconomy into account.

1. **Knowledge and Awareness**

   First of all, a knowledge base needs to be easily accessible. The broad concept of bioeconomy does not seem to care much about which form knowledge is available. It can be a dedicated R&D unit, a university, or a research institute. It can consist of human capital or an experience shared inside a company, a cooperation with a research institute, the experience values of a company, or any other form capable of providing knowledge. However, the distinction between appropriable and non-appropriable knowledge is also needed because the barriers and hurdles that need to be overcome to get inputs are essential factors for the successful acquisition and should be known to the company. Besides general awareness of the recent activities in their particular working field, an idea about potential spillover effects and how knowledge flows inside and outside the firm are regarded as influential factors. Especially in a growing and still fluctuating area like the bioeconomy, it is important to know current trends.

2. **Openness and Collaboration**

   The distinction between vertical and horizontal cooperation can be seen as "beneficial-when-known-and-exploited". However, multi-scale linkages across more than one layer are highly potent factors for innovation in the bioeconomy. Especially when considering the cooperation and collaborations of a company, the general rule seems to be that the more are present and used, the better because of the unavoidable flow of knowledge and spillover effects to connected actors. Therefore, the degree, intensity, and longevity of the connections and linkages are essential, and trust is a factor between the actors. Trust is also an essential factor of the Open Innovation approach, which supports dismantling strict company boundaries about knowledge transfer and is proven to influence innovation activities. For the bioeconomy, trust between companies can be a factor in combating the widespread problems of uncertainty, fuzziness, and information shortage to help companies cooperate and positively influence each other.

3. **Environment**

   The geographical location and its proximity are also regarded as significant drivers. Locations that favour knowledge and face-to-face interactions are believed to trigger innovations with a higher frequency and are considered the most fruitful option. Of course, biotic and abiotic spheres need to be usable in a way analogous to the principles of the bioeconomy and without violating essential sustainability leitmotifs. Another point represents the current and potential land use of the environment and the question of how this influences the target area or company. The supportiveness of the surrounding environment plays an essential role too. Without it, companies lose a potential partner on a political level and do also run the risk of antagonising it against them, which always creates an obstructing atmosphere. The supportiveness often influences and is directly influenced by the dynamic of a surrounding region and its actors. New ways of thinking, living, and guiding political decisions, as the bioeconomy does, create a favourable environment suitable to handle innovation that may influence their daily living. Additionally, waste-management habits, as well as re-use and recycling activities, shall be looked at, as these can stimulate bioeconomic innovations by providing an already present mindset and, in the best case, infrastructural advantages.

4. **Assisting Policies and Government**

   The local and regional administration needs to have, most of all, a clear and with higher authorities coherent understanding of the bioeconomy concept to support companies and actors at the right places and times. A holistic approach, instead of a narrow, sectorial-based one towards the bioeconomy, can help decision-makers better understand the concept. They can thus analyse implications for the future but also receive an overview over individual connections, which otherwise would have been overseen. In general, having an overview of the whole breadth of the bioeconomy may help immensely when taking strategic decisions that affect multiple layers. Funding and support can thus also reach otherwise overlooked actors and firms, and again, the aforementioned holistic view creates a bigger picture for policymakers to decide on financial support. Acknowledging the need for a transformative change and thus a need for creative destruction of the present lock-in state can go hand in hand with open-mindedness regarding bioeconomy and innovations in general and is therefore seen as another favourable factor. However, it is assumed from the outset that a concrete bioeconomic strategy exists. If this is not the case, these criteria must be fulfilled as soon as possible due to the coordinating and structuring possibilities.

5. **Society and Consumers**

   Not only can politics and governmental activities create a benefitting environment for innovation, but society and its consumers also play a significant role. The importance of their acceptance and understanding of bioeconomic principles has already been described, but a particular degree of certainty regarding future political developments supports them in making educated decisions and taking on a progressive standpoint. On the consumer side, the demand for a new product or process can create an increasingly strong pull and thus urges actors to fulfil it, often innovatively adapting their production systems to the new market demand.

6. **Company Management**

   A company needs the financial and social capability to engage in innovative activities actively. Acceptance and knowledge about said bioeconomic principles are essential for allocating R&D expenditures. The significance of a certain openness was stated, especially towards incoming and not-yet-known linkages and further towards broader ideas, developments, and implications. Long-term planning does not favour innovative undertakings on its own, but when paired with knowledge about the need to change current economic or ecologic behaviour, it can become a driver for innovation by itself. However, this remains to be seen critically from a bioeconomic point of view because the changes tend to occur much more frequently, and the research base moves faster than in comparable industries. Watching the market demand closely and reacting quickly to potential gaps may provide companies with opportunities to establish new products. This flexibility, however, comes at a prize, which companies may not be willing to pay.

7. **Feasibility**

   The feasibility can be seen as an outlier because it is assumed that innovation is not triggered simply because something is feasible or not. Instead, it should be seen as a supportive criterion once an innovation is already on its way to establishment. It was shown that innovation needs implementation; if any technological, social, environmental, or ecological feasibility is not given, implementation will face severe barriers along its way. The same holds for sufficiency and efficiency; innovators need to ensure both for a smooth transition from the invention- to the innovation phase. Lastly, the required resources need to be available and adequate with a sustainable infrastructure in place while also keeping the circular approach of the bioeconomy in mind.

At this point, the question about criteria specific to the bioeconomy rises. The literature review and criteria catalogue have indeed reviewed factors that can positively influence innovation in the bioeconomy. However, none of them seems to be entirely exclusive to the bioeconomy. One may initially think of sustainability as a criterion. Sadly, sustainability is yet another example of a term getting overused. It furthermore encompasses already existing criteria and thus would only add another unnecessary layer on top of the other two, bioeconomy and innovation. A company may undertake activities that result in innovation, but the actual reasoning behind it is often not the need or want to be more sustainable but to be more efficient or effective. Otherwise, when an external entity forces a company to be more sustainable, sustainability can definitely be seen as a trigger for innovation. Actors that use biological resources – biomass – see themselves as sustainable by definition, as their work needs to be sustainable to secure their livelihood for the present and future. Sustainability is promoted on many political levels, present in the policy discussion for at least 20 years, and promoted all over the world, whereas at its core, it is the simple concept of not destroying what one lives on. Sustainability may thus be regarded as a trigger for bioeconomic innovations but will not be included in the above catalogue because of its over-usedness, buzzword character, and unspecific approach. However, the much more straightforward innovation modes DUI and STI provide a surprising fit for bioeconomic innovations. The science-driven STI mode aims to increase the R&D capacity of the actors in the bioeconomic system and increase the cooperation between firms and R&D organisations to achieve the positive effects mentioned above. Its policy is to increase the R&D capacity, support joint R&D projects between firms and universities, support higher education programs, provide subsidies for R&D infrastructure (e.g., laboratories, research centres), give financial support for increasing mobility between academia and industry as well as help commercialising research results (Isaksen & Nilsson, 2013). The user-driven DUI mode aims at fostering organisational and inter-organisational learning and increasing cooperation between, in particular, producers and users. It supports on-the-job learning, with organisational innovations helping to build matchmaking activities and to sustain existing networks, while also stimulating trust-building and joint innovation projects between actors in the value chain (producers-suppliers-users-consumers) as well as influencing joint projects between competing and auxiliary business (e.g., food-health) (Isaksen & Nilsson, 2013). Both perspectives can be adopted for the bioeconomy: STI is typically associated with companies that operate in high-technology industries, such as nanomaterials or biotechnology. At the same time, DUI can be located in energy, engineering, and low-tech industries.

2.5 Conclusion

Innovation plays a vital role in a modern economy and society. Bioeconomy, especially in light of the ongoing development of a new green revolution, appears to manifest as an essential factor when discussing possible ways out of a fossil lock-in. With the help of a literature review and a criteria catalogue, this study highlights what factors possibly influence innovation in the context of the bioeconomy. Its relevance thus lies in providing a holistic overview of the combination of two terms that are by themselves not easy to frame, thus making the first step towards further research on the growing innovation in bioeconomy discourse. The importance of a shift towards this new economic principle has been stated numerous times in recent years. As this catalogue of criteria is based solely on theory, it needs to be validated with practical examples; the work on it is far from finished. However, using it as a mere guideline should provide researchers with a good foundation for their work. The study's general approach towards innovation and bioeconomy topics may also help conceiving them from another, maybe new, point of view. However, what has also become apparent is the lack of criteria unique to the bioeconomy in the literature. Neither the cascading nor the circular economy approach are universally mentioned as triggers for innovation, while they are perfect examples for innovation out of necessity or DUI and thus need to be further investigated. Then again, because bioeconomy cannot be described as a single economic sector but rather as a concept that spans multiple sectors, finding particular innovation criteria for it is difficult. Sustainability was mentioned but got disregarded because of its comprehensive approach. In the end, innovation in the bioeconomy seems to be based primarily on general criteria, which once again underlines its holistic, conceptual basis and calls for further, more in-depth research that tackles more concrete settings and distances itself positively from the meta-level dialogue on the concept.

Chapter 3

What does the "Bioeconomy" look like, and what does it imply?

Portraying Structures of the European Bioeconomy and its Key Actors through Network Analysis of H2020 Data

Abstract

The bioeconomy is believed to be one of the leading strategies in the EU to boost the creation of jobs, growth, and innovation. Investing €3.85 billion over six years under the Horizon 2020 framework, the EU strongly supports this strategy with funding. Nonetheless, research evaluating the broad and dynamic topic of bioeconomy faces a severe problem: the lack of a clear demarcation of the concept. Further, while analyses for specific countries exist, a pan-European perspective on the bioeconomy network and its key actors is still lacking. However, analysing network structures on an international level can yield crucial insights into knowledge and innovation dynamics, both playing a central role in progressing the modern research field. Thereby, this study presents a novel approach towards data on bioeconomy. It distils its definition of "what constitutes the bioeconomy" by mining data sources on the social, funded, and scientific areas of the topic before applying the results to Horizon 2020 project data to identify "bioeconomy" and perform network analysis on the matter, aiming at revealing structures as well as key actors relevant to the diffusion of knowledge. Operationalising an objective methodological approach to analyse project data regarding bioeconomy structures contributes not only to our understanding of innovation networks in this research field but can provide a starting point for studies in other fields grappling with similar thematic demarcation problems and uncertainties.

Keywords: bioeconomy, network analysis, text mining, H2020, innovation, funding data

3.1 Introduction

Some form of narrow-minded instrumentalism seems to manifest in the recent political and scientific discussion on bioeconomy. Bioeconomy is frequently regarded as the band-aid that will fix the "wicked problems" our society is believed to face in the next century (Edwards, 2020): Population growth, higher demand for food, energy, nutrition, raw materials, the depletion of natural resources, declining biodiversity – to name just a few (Bogner, 2019a). Not surprisingly, the European Commission (2020a) also sees bioeconomy as "Europe's response to key environmental challenges the world is facing already today". This development can further be noticed in the growing number of countries with a central strategy to promote bioeconomy and transform their respective economies into more sustainable ones (Dietz et al., 2018). However, the lack of a detailed and, above all, operationalisable understanding of it is repeatedly mentioned as a hurdle to its success (D'Amato et al., 2017; Dupont-Inglis & Borg, 2018; Hetemäki et al., 2017) and is in urgent demand for more proficient and reasonable evaluations as well as monitoring attempts. Bioeconomy, as a term, is consistently described as being quite open, if not even fuzzy (Birch & Tyfield, 2012; Golembiewski et al., 2015; Pietzsch & Schurr, 2017; van Lancker et al., 2016; von Braun, 2018), which gives researchers and especially politicians a hard time framing it. More so, combined with its conceptual narrative, it daunts scientists away from quantitative methods. Thus, this work initially aims to adapt a transparent definitional approach to operationalise a detailed understanding of the bioeconomy and contribute methodologically to the overarching, recent bioeconomy discussion by offering a reasonable procedure. This operationalisation effort is then used to identify, examine and describe the European bioeconomy landscape based on project data via network analysis.

Our society shifts rapidly towards one that is connected over layers upon layers of different networks. Networks are omnipresent (Klärner et al., 2020): people, systems, commodities, productions – the diversity of contexts in which networks are involved are vast (Easley & Kleinberg, 2010). The world has refined the process of accelerating and socialising information and, by doing so, found new ways to solve problems. Besides bioeconomy, social network analysis also benefits significantly from concretely framed data (Stegbauer, 2008). It must thereby be ensured that the structures and networks to be examined are also covered and that essential parts of the structure are not overlooked due to false demarcations (Jansen, 2003). To fulfill this requirement, this work harnesses the potential of centrally collected project data in order to conduct a social network analysis to examine the collaborative network of project actors in the field of bioeconomy with the final goal of shedding light on its unique structural features and thus deducing insights in regards to knowledge and innovation for the European bioeconomy as a whole.

Networks, in general, are seen as innovation accelerators (Fornahl & Brenner, 2004; Russo & Rossi, 2009; J. Scott, 2011b), become increasingly significant for the analysis of big data (Warf, 2015), and are widely regarded as essential infrastructure for the generation and exchange of knowledge (Bogner, 2019a; Fornahl et al., 2011). The last trait can be seen as influential for the bioeconomy since knowledge, and its diffusion are fundamental pillars for its success. Organisations' performance and innovation capability depend on their ability to work in today's networks, but building a broader and more diverse problem-solving network requires a proper organisational structure (Fornahl et al., 2011; Nunes & Abreu, 2020). Being part of a network naturally exposes actors to novel sources of knowledge and usually yields faster access to resources (Allen et al., 2007; Bogner, 2019a; Fritsch & Kauffeld-Monz, 2010). In the last two decades, the promotion of this form of collaborative research and development has become the top priority of the science and technology policies in industrialised countries in Europe (Protogerou et al., 2010b), always accompanied by the pursuit of a more competitive pan-European economy (Cassi et al., 2008). Hence, different framework programs were created by the European Commission, beginning back in 1984. They have been the primary financial tools through which the EU supports research and development activities (European Commission, 2020b), and are seen as necessary processes that help to integrate European research and technological development across member states, to create a wide diffusion of knowledge as well as an increase in innovation and competitiveness by European-based companies (Cassi et al., 2008).

The recently concluded framework program, Horizon 2020, ran from 2014–2020 and tried to ensure Europe's leading position in world-class science and remove innovation barriers across the public and private sectors. Bioeconomy played a significant role in it. Seven priority challenges were formulated for H2020; one of them, "Societal Challenge", addressed a wide range of policy priorities: "Food Security, Sustainable Agriculture and Forestry, Marine, Maritime and Inland Water Research and the Bioeconomy", and received a total funding amount of €3.851 Mio. throughout the framework program (European Commission, 2020b). Programs like this are crucial for creating transnational research collaboration networks, an essential piece of the socio-economic infrastructure supporting the European research area (Cassi et al., 2008). These collaboration networks are also an authoritative source of innovation and can support organisations with their ability to diffuse knowledge effectively and mostly automatically. In a world of networks, it comes as no surprise that the network factor is almost always the significant predictor of high performances (Nunes & Abreu, 2020). However, a world of networks also fuels global competition – no single EU country or organisation can afford the cost of building appropriate capabilities (Protogerou et al., 2010b), which further elevates the role framework programs play.

In recent years, interest in social network analysis not only grew (Curtin, 2016) but a burst of research could be observed due to the increasing availability of large data sets and a leap in processing power of modern computers (Easley & Kleinberg, 2010). At the same time, research on project data remains at a very early stage (Nunes & Abreu, 2020). Furthermore, networks formed in the context of framework programs have so far been the target of only a few empirical works, examining their structure, dynamics, and evolution (Protogerou et al., 2010b). In addition to this circumstance, the role of social network analysis also grows in economic geography; increased attention is noticeable (Glückler & Doreian, 2016; M. Scott, 2015; Ter Wal & Boschma, 2009), and great potential for theoretical cross-fertilisation between geography and social network analysis is seen (Glückler & Doreian, 2016), but the application is far from fully exploited (Ter Wal & Boschma, 2009). Being aimed at receiving a more detailed understanding of learning, innovation, and the governance of economic relations, network studies help deepen our understanding of structural constraints of social and economic processes (Glückler & Doreian, 2016), but continue to be somewhat of an outlier in economic geography; primarily because of problems related to data collection. To counter this tendency, data analysis on funded projects can be seen as a natural fit. It is almost free from bias, and collected data mirrors the reality far better than comparable methods (e.g. roster-recall) (Nunes & Abreu, 2020). Social network analysis also presupposes the availability of complete network data (Ter Wal & Boschma, 2009), which is usually not an easy trait to achieve, but Horizon 2020 data accomplishes that. Data for every funded project during the Horizon 2020 framework program is extensively saved in The Community Research and Development Information Service (CORDIS).

All these traits benefit a fuzzy bioeconomy in the form of a solid research framework. Networks with their ability to transport knowledge effectively are critical for innovation activities and subsequently for economic competitiveness (Cassi et al., 2008; Fornahl, 2005); examining their structural features is a crucial step for understanding their complex systems, how information is spread, and knowledge transmits while also fulfilling an assisting role for future policy design (Protogerou et al., 2010b; Zellner & Fornahl, 2002). Network analysis as a tool holds the ability to look into the character and structure of the network. It can identify which parameters are crucial for knowledge flow and diffusion, something which up until now lacks in the field of bioeconomy – against its fruitful fit, especially when regarding bioeconomy's reliance on knowledge and innovation.

Further, the analysis of EU-funded, policy-driven networks can expose valuable information regarding the organisational fabric and social infrastructure of European funding, leading to a better understanding and strengthening effect for the European research area (Protogerou et al., 2010b), especially in the field of bioeconomy. The gap in research is thus to be filled; the "opportunity should be taken [...] to produce [...] powerful analytical and explanatory studies that can further the agenda of social network analysis in the many substantive fields of [...] science" (J. Scott, 2011b, p.25).

Therefore, this study's goal can be divided into two parts: *First*, it makes a significant operationalisation and methodological contribution by using text-mining on data sets from three different spheres and utilising the results to generate an innovative definitional approach to bioeconomy. *Second*, this approach is then utilised to identify bioeconomy project structures and actors, analyse and interpret them regarding their performances and capability to diffuse knowledge and ultimately formulate hypotheses based on these findings.

Social network analysis conducted on Horizon 2020 project data is believed to yield valuable insights: it examines the collaborative bioeconomy network in order to not only shed light on characteristics of relevant entities and roles within the network but also to provide a new point of view on the European bioeconomy structure and change over time, fostering further policy and funding design and help to streamline its concept and gather insights into its knowledge and innovation dynamics. The study highlights linkages and influencing factors in the network and important actors and analyses them with various methods, tools, and visualisations before hypotheses for the European bioeconomy network are discussed. Combining economic geography practices with social network analysis on a flourishing and growing research area like bioeconomy can hopefully offer a new perspective, motivate more research and provide an in-depth look into its machinations.

3.2 Conceptual Framework

In the following, network theories in general and network research from a geographical point of view will be addressed before recent works on bioeconomy networks are touched upon. These "setting the scene" theoretical considerations are essential for creating a conceptual framework. In addition, various relevant network analysis parameters are presented, which will be used to measure the European bioeconomy network's performance and create an analytical framework to examine its performance.

Radil and Walther (2019) propose that papers illustrate linkages between geographic theory and social network concepts, since researching social networks from an economic geography perspective is not fully established in the research field. They also admonish not only focusing on implementing a single version of social network analysis because that would marginalize social network analysis to merely a set of quantitative tools (Radil & Walther, 2019). Reviewing both the "classic" network theory and the geographic perspective on it as well as their combination will help establish the basic framework for the subsequent network analysis and provide the various measurements' theoretical backgrounds.

3.2.1 General Network Theory

In some shape or form, networks have always been part of our civilisation. However, it was not until the start of the last century that they were looked at through the lens of scientific research. Today, networks are understood as spatial domains over which enormous varieties of activities occur (Curtin, 2016). The use of the term ranges from qualitative conceptualisations to formal structuralist theories (Glückler & Doreian, 2016). Network theory, at its core, is based heavily on graph theory, a mathematical approach in which individuals and groups are represented by points and lines to create an interpretable sociogram (J. Scott, 2011b). In that, the term "network" is considered an informal concept which describes an object composed of elements and interactions (connections) between these elements (Brandes & Erlebach, 2005). The formula used is

$$G = (V, E)$$

where a graph G is an abstract object formed by a set V of vertices (nodes) and a set E of edges (links) that connect pairs of vertices (Brandes & Erlebach, 2005). The axiom of network research assumes that *nodes* can form relationships: *edges* with other nodes (Gamper, 2020). If these relationships happen between human actors of some kind, the bonds formed are *social relationships* – sociology's core. The so-formed social networks, not to be confused with recent digital platforms such as Facebook, Twitter, and Instagram, are real-world phenomena that exist independently of their analysis (Pfeffer, 2010) and can be illustrated and analysed by the formal mathematical model. Social structure can be conceptualised as a network of social ties; social network analysis is thus built upon the assumption that interpersonal, inter-organisational, or inter-country ties significantly influence various positive outcomes (de Nooy et al., 2018).

Networks, in general, can therefore be defined as "a delimited set of nodes or elements and the set of so-called edges running between them" (Jansen, 2003, p.58). A significant advantage of this straightforward definition is that the saame methods and algorithms can describe various types of networks. Hence, there is not precisely one network theory but many different ones, depending solely on the end-user. Gamper, for example, distinguishes between three different grand theories: structuralist determinism, structuralist instrumentalism, and structuralist constructivism. However, these find little use in empiric research; medium-range theories are much more likely to be applied (Gamper, 2020). Moreover, a "coming-together of scientific fields around the topic of network research [has taken place recently] and a full understanding seems to require a synthesis of perspectives from all of them" (Easley & Kleinberg, 2010, p.6). While the application of graph theory has been known for more than two centuries, its popularity increased exponentially for the first time as soon as it started to be applied to study social structures (Nunes & Abreu, 2020). At the beginning of the 1930s, the social psychologist J. L. Moreno created a tool to reveal affective structures in groups of people in order to be able to derive conclusions about group dynamics and called this tool sociometry (Freeman, 2004). During the following decades scientists of various disciplines, often cooperating with mathematicians, expanded this initial framework with graph theory's help into their research fields to use it as an illustrative explanatory model in their respective areas (Trappmann et al., 2011). However, it was not until the end of the 1970s that these various efforts were brought together into a recognized and unifying perspective in literature. Social network analysis was then brought into origin, but it should take twenty more years for the term to take off significantly in the scientific world. With the aforementioned leaps in computing power, the bull run only began in the 1990s and continues still (Trappmann et al., 2011).

3.2.2 Geography in Networks

Geography, as a discipline, was involved since the very start, thus well ahead of the relational turn (Radil & Walther, 2019), and can be regarded as profoundly intertwined with network research. When Tobler (1970, p.234) proclaimed his first law of geography: "everything is related to everything else, but near things are more related than distant things", he (supposedly) unknowingly set the stage for this intertwining. Ten years later, Smith (1980, p.500) reviewed social networks specifically for geographers, connotating them as a "new fad" and argued that the discipline was one of the early adopters of social networks and geographers should take them seriously, as they offer a novel way of thinking (Radil & Walther, 2019). During the 1990s, the "relational turn, [referring] to the increased interest across the social sciences and humanities in how social relationships and interactions constitute various outcomes and phenomena" (Radil & Walther, 2019, p.3), has arisen to become one of the core themes of geography (Müller & Schurr, 2016). One essential element of this broader shift toward relations can be seen in the network metaphor (Marshall & Staeheli, 2015). In doing so, the relational turn also resuscitated the idea of the network, replacing graph theoretic models, which had the negative connotation of being an "asocial conception of social relations and spatial structure" (Hadjimichalis & Hudson, 2006, p.859), with a spatial metaphor for issues of social connectivity flows and interactions between and with places (Radil & Walther, 2019). This metaphor's success amplified the popularity of the actor-network theory (ANT) and assemblage thinking, two prominent relational theories that are among the most acclaimed conceptual approaches in human geography (Müller & Schurr, 2016). They not only directly contributed to the ongoing network conceptualisation in geography but also fuelled the discovery that space is socially produced; it is seen as "no coincidence that the discovery that space is socially produced, and the shift to relational space, arose in tandem with mounting emphasis on networks" (Warf, 2015, p.567). However, in their cores, assemblage and ANT are not that heterogenous: both share a relational worldview, which sees action as a result of connecting initially disparate elements, emphasises a "the whole is more than its parts" mindset, have a topological view of space, where distance is a function of a relations intensity and lastly stress the value of the socio-material, meaning that there are associations of human and non-human elements (Müller & Schurr, 2016).

The leitmotif created by these approaches shaped the network concept in geography considerably over the last 30 years. Quantitative empirical research in economic geography has primarily relied on secondary data from patents, scholarly publications, and R&D initiatives. Various studies advanced the understanding of how knowledge creation is regionally limited and how regions, businesses, and people form, maintain, and dissolve knowledge linkages (Abbasiharofteh & Broekel, 2021). Although economic geography experienced a surge regarding social network analysis over the last decade, a seeming neglect of holistic networks' analysis by focusing more on particular places in networks (Fritsch et al., 2020; Glückler & Doreian, 2016) and "analyses [being] […] carried out at the regional level or at the level of specific technology fields" (Fritsch et al., 2020, p.632) can be noticed, hence the focus of this work on European project structures. Ultimately, the treatment of geography in networks is regarded as a problem while simultaneously creating opportunities for researchers to reconsider social networks as well-fitted structures to understand core geographic concepts (Radil & Walther, 2019). One overarching theme in modern economic geography is the creation and diffusion of knowledge, leading to the emergence of innovation (Gertler, 2003; Howells, 2002). As discussed earlier, both concepts also play a leading role in the bioeconomy; a combination can be seen as beneficial. As the occurrence of knowledge spillovers is directly influenced by human interactions, shaped by place and constrained by distance (Howells, 2002), analysing network structures – under the assumption that connections between nodes do indeed happen to transfer knowledge – can work as an ideal way to shed light onto the knowledge dynamics and implications of a fuzzy research field such as the bioeconomy, especially if the network is based on joint research projects, as it is the case for this study (Brökel et al., 2015). Bioeconomy research benefits from working on pre-determined structures – a project-based affiliation network is believed to be a neat fit.

3.2.3 Project-based Networks and Affiliations

Nunes and Abreu (2020, p.1503) define a funded project collaboration between a set of actors as a "temporary endeavour with a defined beginning and end, designed to create a unique product or service, [which] is expected to be properly managed by the application of knowledge, skills, tools, and techniques to project activities to meet the project requirement, throughout all the different project phases that comprise a project lifecycle". In these endeavours, various organisations, such as firms, universities, and research institutes, are connected in policy-driven cooperative relationships, allowing them to access new resources and augment their core capabilities (Protogerou et al., 2010b); with various types of knowledge frequently being one of the central "new resources" actors are accessing in funded projects (Brökel et al., 2015). Furthermore, project networks or project-based research and development (R&D) networks are based on interpersonal and inter-organisational ties and display a high level of hierarchical coordination. An overarching deadline defines the collaboration and provides a common aim of accomplishing specific project goals. Due to the temporal limit, its structures can be volatile, as actors and connections can change tremendously in a short period (Bogner, 2019a). Projects are mostly publicly funded and focus on precompetitive research designed to bring basic research closer to a practical application (Wanzenböck et al., 2014).

Participants in such joint ventures form the structural nodes that allow the analysis of their activities; they are seen as interlinked (*edge formation*) when they work together on a single project (Ter Wal & Boschma, 2009). These interactions and collaborations in the network context can unveil the participating organisations' dynamics and allow researchers to derive hypotheses regarding the knowledge spillovers (Feldman & Kelley, 2006). Because the units all participate in the same activity, project networks are traditionally referred to as affiliation networks (González Canché, 2018; Latapy et al., 2008; Protogerou et al., 2010b). While affiliations often are believed to be forced by circumstances and are thus seen as less personal ties, the amount of time spent by project participants working on a common goal weakens this argument.

By definition, affiliation networks consist of at least two sets of different vertices – actors (*organisations A-E* in Fig. 3.1) and events (*projects 1-6*); nodes are in two disjoint sets, while their links are always between a node of one set and a node of the other (Latapy et al., 2008). Vertices can thus only be related to vertices in the other set (de Nooy et al., 2018). Fig. 3.1 symbolises this two-mode, or bipartite, structure:

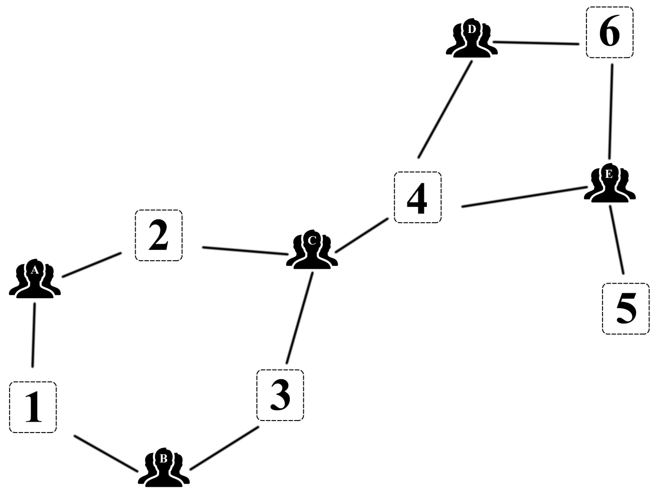


Figure 3.1: Typified two-mode project network (own graphic based on de Nooy et al. (2018))

However, analysing two-mode networks is a complicated endeavour, and tools to analyse classical one-mode networks are far more common and sophisticated (Latapy et al., 2008). Thus, the network depicted in Fig. 3.1 needs to be transformed into a one-mode network (Fig. 3.2), but not without losing some information and other implications that will be discussed in more detail in the limitations (Latapy et al., 2008).

Whenever two organisations participate in the same project in the two-mode network, there is a line between them in the abstracted one-mode network. The accompanying number simplifies the number of projects they both participate in. In the above example, organisations *D* and *E* are both part of projects *4* and *6*; therefore, multiple edges should connect them. For simplicity, however, the line is assorted a line value, line multiplicity or simply a certain weight (de Nooy et al., 2018), while the total number of projects is shown in the black rectangles.

Funded affiliation networks are also often primordial, which means that while there is a co-ordinator who regulates the selection of the network members and the allocation of funds, these networks often tend to follow pre-existing relationships. The network is thus not

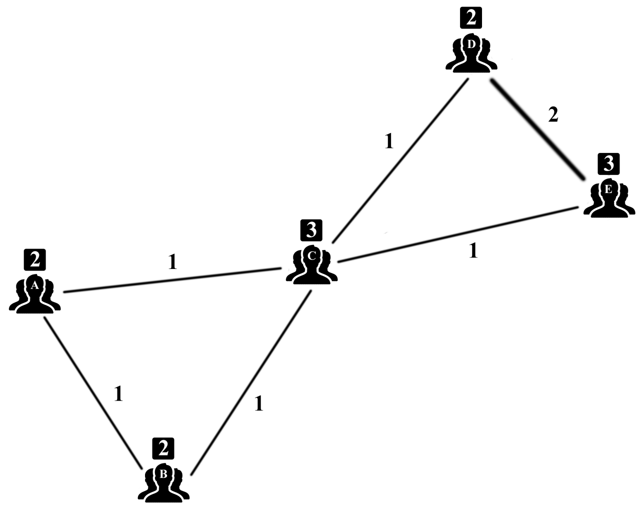


Figure 3.2: Typified one-mode project network (own graphic based on de Nooy et al. (2018))

only artificially generated with a top-down structure, but its initial tie formation between actors follows some particular rules, as well, and is seen as a two-stage mechanism: first, actors search for other actors, with whom they apply for funding and second, the funders decide which cooperations will get funding (Bogner, 2019a). Implications and problems inherent to this structure, like rich-get-richer and similar issues, will again be discussed later. As stated above, participating organisations also share a common goal or purpose, and their collaboration benefits the aim of the project. The resulting network can, therefore, be described as purpose-oriented. Various subtypes of purpose-oriented networks can be distinguished (Edwards, 2020), but they share these constitutive dimensions: purpose, joint effort, membership, and governance (Carboni et al., 2019).

The "Framework Programmes for Research and Technological Development" (FP1 – FP7, as well as Horizon 2020) are the European Commission's medium-term planning instruments, with Networks of Excellence (NoE), as well as Integrated Projects (IP) getting implemented as new foci since FP6 (Amoroso et al., 2018). Cassi et al. (2008, p.284) see the role of the purpose-oriented, EC-funded FP networks in "disseminating information and ideas, providing access to resources, capabilities, and markets, and allowing the combination of different pieces of knowledge, [which] has become of critical importance for innovation and, by extension, for economic competitiveness", yet again underlining the favourable base of this case.

Looking back at Fig. 3.2, one-mode, besides two-mode networks, also have a specific directionality in their connections (González Canché, 2018) and therefore affiliation networks are often represented simply as one-mode graphs of actors joined by undirected edges (Protogerou et al., 2010b). In general, the directionality of an edge describes the type of relationship, the flow of influence, or resources between the connected nodes (J. Scott, 2011a). If the relationship between them is symmetric, an undirected edge is present, and if the relationship can be regarded as asymmetric, the edge is directed, e.g., its direction is of importance (Easley & Kleinberg, 2010). In project networks, the edges' direction is usually seen as undirected for analysis purposes, while each of the ties can also have a particular value attached to them, representing the strength of the individual tie.

3.2.4 Parameters of Social Network Analysis

In the following, relevant network analysis parameters are presented. Specific parameters and aspects influence the generation and spread of knowledge, affecting the innovation capabilities of the whole network. Thus, in subsequent sections, these are looked at to build an analytical framework to examine the capacities and performance of the EU bioeconomy network. This performance depends upon what diffuses, how, and in which structures. In the case of a knowledge-based network, that means first clarifying what knowledge entails and how it can diffuse efficiently (Schlaile et al., 2018). For a fuzzy bioeconomy, the most straightforward definition, as understood in mainstream neo-classical economics, seems a good fit: knowledge is seen as an intangible, public good, which is non-excludable and non-rival in consumption and can thus be regarded as synonymous with information (Arrow, 1972; Solow, 1956). Applying math-based network theory to an abstract collaboration network based on joint project data needs a basic assumption regarding how the spread of knowledge works:

- *First*, is the assumption that there is no need for learning; knowledge can instead flow instantaneously and freely throughout the network. Knowledge is exchanged whenever two actors are connected by participation in a joint project; thus, spillover happens. The codification of the knowledge, tacit as well as implicit, can therefore be ignored.
- *Second*, no transaction cost for sharing knowledge is assumed (Pyka et al., 2009).

Network specifics can be looked at with these assumptions for the diffusion of knowledge. They are constructed to allow for a detailed analysis.

Social network analysis uses graph theory theorems, e.g. directionality and value data, to construct specific network measurements (J. Scott, 2011a). Sui et al. (2014) made an effort to broadly categorise three sets of measurements for social network analysis 3.1.

However, not all sets are relevant for this study's focus on knowledge. The categorisation into three sets instead provides the structure for this section: first, descriptive parameters are explained, followed by structural ones and lastly, those revolving around actor centrality.

Connection	Distribution	Segmentation
Homophily	Bridge	Cliques
Multiplexity	Centrality	Social Circles
Mutuality	Density	Structurally Cohesive Block
Reciprocity	Distance	Clustering Coefficient
Closure	Holes	
Propinquity	Strength	

Table 3.1: Sets of network measurements (Sui et al., 2014)

Descriptive Parameters

As described in section 3.2.3, the network structure examined in this work is a one-mode affiliation network with undirected edges. While edges resemble the connection between two nodes in the network, the *degree* of a node is a measure of the number of direct linkages it has to other nodes (Eder, 2017). Following the assumption that knowledge flows once an *edge* is established, the degree can be regarded as a simple measure for brokering knowledge. Further, the *degree distribution* in the network matters: if a group of actors with a high *average degree* is well connected, knowledge spillovers are of higher quantity, as long as the knowledge exchange mechanism does not change (Bogner, 2019b).

The *clustering coefficient* quantifies the local density of a network and measures the level at which nodes are grouped. It is used to determine the structural homogeneity of the network and makes it possible to identify clusters whose nodes are strong with one another and weakly connected to the outside (Heller-Schuh et al., 2011; Protogerou et al., 2010b), allowing assumptions regarding collaboration intensity.

The *path length* describes the number of steps (*edges*) an actor must go to reach a random other nodes. The *average path length* can thus be a good distance measure in the network (Ghali et al., 2012; Liu et al., 2019). A short average path length also hints at a network structure that allows for a faster spread of new knowledge, thus increasing diffusion efficiency (Bogner, 2019b; Cowan, 2005).

Building upon the clustering coefficient, the *density* measures how connected the network is and can be seen as relevant for community building (subgroups) and cliquishness. It is calculated by dividing the number of actual connections by the number of possible connections and results in a value between 0 and 1, while 1 means that every actor is connected to every other actor (de Nooy et al., 2018; Edwards, 2020; Stegbauer, 2008). Cohesive subgroups are dense areas in a network that typically have more ties within their group than the rest and consist of a minimum of three nodes (Brandes & Erlebach, 2005). Of course, these areas with a high local density, often regarded as cliques, are believed to contain a high level of trust between actors, which can speed up collaboration efforts (Giurca & Metz, 2018). Cliques of actors are also seen as favourable for knowledge creation due to them forming an epistemic community (Cowan, 2005) with dense connections and their own culture of knowledge transfer that is often more sophisticated in comparison. However, this raises some concerns: while these subgroups may function well by themselves, it can be challenging for outside actors to "get into the club".

Structural Measures

The *modularity* ties in next. With the modularity function (Newman, 2006), clusters of densely connected communities of actors can be identified. The algorithm represents the sum of the number of edges linking nodes of the same clusters minus the expected sum if edges were distributed randomly (Zaidi et al., 2014). Detecting distinct groupings of actors and thus community structures in a knowledge network can yield essential insights into the shared actorial characteristics as well as the delimiting differences between communities (Wanzenböck, Neuländtner, et al., 2020).

Another structural measure is to identify *structural holes* in the network. A structural hole describes the space between nodes with no other nodes in between and no loose relationship between the nodes on the edges of the hole (Easley & Kleinberg, 2010; Labun & Wittek, 2014). Structural holes are used to determine weakly connected areas in the network and can help to examine the reasons for the disconnection.

Therefore, an edge that connects two nodes is a *bridge* if deleting this edge would cause the nodes to lie in two different network components. Removing the edge thus causes the number of components – connected substructures in which all nodes are linked – to grow (Easley & Kleinberg, 2010). For knowledge diffusion in networks, bridges are considered bottlenecks since they limit the possible pathways information can take. On the other side, however, too many connections between nodes can make the knowledge flow inefficient (Broekel & Boschma, 2012; Stegbauer, 2008).

As a result, *gatekeepers* play a decisive role in the network. These nodes link two components, communities, or substructures across structural holes together, thereby holding a unique, controlling position for the diffusion of knowledge (Heller-Schuh et al., 2011). Gatekeepers benefit from gaining access to various knowledge sources without a high degree. For themselves, these nodes also tend to exploit their internal capabilities better than their comparisons (Zaheer & Bell, 2005) and thereby matter more for innovation (Ahuja, 2000; A. Morrison, 2008). Their characteristics can further influence the type of knowledge that flows; for example, an actor with an educational background acts differently and values other forms of information than one with a more public focus. Therefore, a highly functional and efficient network would need gatekeepers with different characteristics to exchange and integrate different types of knowledge (Cassi et al., 2008) while not growing too dependent on their functionality simultaneously (Stegbauer & Häußling, 2010). On a similar note, *hubs*, nodes with a vastly higher number of connections than the average, are to be named and lead into the different methods to calculate when a node is central for a network and why.

Centrality Measures

Centrality is one of the most studied concepts in network theory. Identifying the key actors of a network can yield valuable insights into its characteristics and help understand knowledge diffusion mechanics (Protogerou et al., 2010b) since with their hub-position usually comes an important distributive function (Jansen, 2003). Understanding them better can indeed result in understanding the network better. Central actors have a greater responsibility in coordination and are also associated with higher levels of influence, control, prestige, prominence, and decision-making (Nunes & Abreu, 2020), thus also affecting social capital (Sorenson et al., 2010). Especially for bioeconomy, it is considered reasonable to look into who is at the frontline of developing the concept further in Europe during funded projects. The distinct centrality models are based on assumptions about how knowledge flows inside the network, leading to different perspectives on when an actor is considered central (Wanzenböck et al., 2014).

Degree centrality is the most straightforward concept: the node with the most connections (edges) to other nodes is central, thus holding a particular prominence and power (Protogerou et al., 2010b) and holding a solid collaborative experience as well as direct access to diverse information (Heller-Schuh et al., 2011). *Betweenness centrality*, in comparison, sees an actor who is most often on the shortest route between two actors in the network as central, disregarding his otherwise eventually relatively weak connections. For betweenness, these actors control the flow of information, thereby acting as mediators and frequently gatekeepers of communication in the network with a controlling influence (Labun & Wittek, 2014; Wanzenböck, Neuländtner, et al., 2020). *Closeness centrality* again disregards the degree of an actor and emphasizes that the actor with the shortest distance to all other actors is the most central. Due to that, these actors are believed to have the fastest access to information and also diffuse gathered knowledge quickly (Heller-Schuh et al., 2011; Labun & Wittek, 2014). Lastly, *eigenvector centrality* takes the degree of a node into account again and combines it with a measure of the quality of its connections – weighing linkages to influential actors with a high degree heavier. Therefore, the actor with the best connections is central and acts as a hub for knowledge transmission and diffusion (Labun & Wittek, 2014; Wanzenböck et al., 2014).

Derived from these centrality indices, *embeddedness* and *brokerage* can be examined. The embeddedness of an actor describes the extent to which it is connected to another actor by taking the number of common neighbours between two nodes into account. It thereby measures how embedded a node is (Easley & Kleinberg, 2010) and can thus be captured by betweenness and eigenvector centrality (Wasserman & Faust, 2012). Regarding access to new knowledge, being embedded can help a node significantly share its risks more efficiently, leading to more remarkable survival and trust (J. Scott, 2011a). Having access to different actors also means a greater flow of knowledge and ideas for the actor, hence the importance of embeddedness for innovation practices. On the other hand, Brokerage describes the absence of edges between neighbours, for example, when two or more nodes are connected to another node but not to another. Brokers are often positioned between structural holes and tie more distant nodes together (Hart et al., 2019). Brokerage can promote disseminating new information and ideas between and across subgroups or cliques, thus spanning distances, tieing distant actors together, and providing otherwise hard-to-achieve knowledge to connections. By combining both embeddedness and brokerage, one rather complex outcome (Balland et al., 2013) can be the creation of distinct *social capital* – "the set of social resources embedded in relationships" (Tsai & Ghoshal, 1998, p.464) – which in turn boosts the ability to connect and cooperate.

These different measures – descriptive, structural, and centralistic – can be combined into an analytical framework for the analysis of this work (Fig. 3.3).

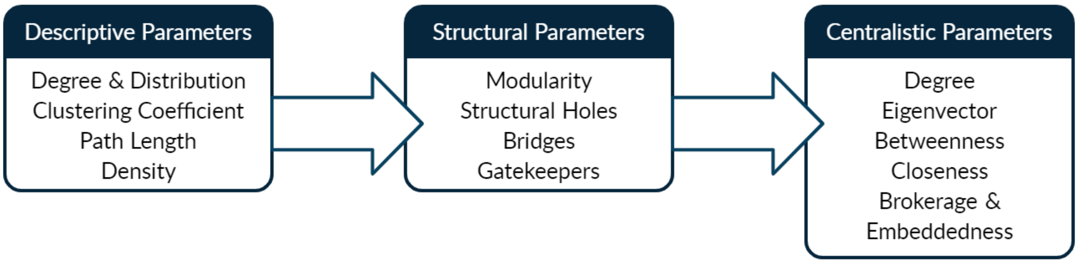


Figure 3.3: Analytical framework

Later in this work, the measures of this outline will be used to shed light on the internal characteristics and be used as criteria to evaluate the network's and its actors' performance regarding knowledge diffusion.

3.2.5 Network Analysis in the Bioeconomy: Issues and a Possible Solution

After the detailed discussion of relevant network theory and parameters, the following section examines recent literature on networks in bioeconomy. It discusses apparent specialties and gaps in the research field before formulating the substantial operationalisation effort needed for tackling these issues in the later analysis. By doing so, challenges and needs are revealed, and potential ways to solve them are shown.

Approaches to network analysis in bioeconomy are still early. The most recent ones follow similar patterns of either blending bibliometric analysis with a shallow (social) network analysis (Bauer et al., 2018; Ben Fradj et al., 2020; Bugge et al., 2016; Muizniece et al., 2020; Paletto et al., 2020; Sanz-Hernández et al., 2019), using qualitative data, e.g. interviews of only a specific sector or country (Giurca, 2020; Giurca & Metz, 2018; Korhonen et al., 2018; López Hernández & Schanz, 2019) or using project data, but again offering only a limited view of one specific sector (Lovrić et al., 2020). Surprisingly, forest- or wood-based bioeconomy seems to dominate the works: Besides Bauer et al. (2018), Giurca and Metz (2018) and Lovrić et al. (2020) focus on this specific sector. Nevertheless, a few key challenges are apparent by looking at these recent examples. First, the data basis of all recent studies consists exclusively of rather narrow excerpts. Focusing on a specific sector or set of actors does not help the bioeconomy with one of its main hurdles: figuring out a standardised understanding of the holistic concept. Furthermore, bibliometric analysis and interviews have difficulties providing a complete overview of a concept as broad as bioeconomy. Formulating the network boundaries is difficult, especially with only tiny or lacking data like a limited response rate and an underrepresentation of certain actors due to an online survey (Korhonen et al., 2018).

The literature does, however, suggest concrete recommendations for further research at a few points. Various authors conclude the need for a more holistic approach. Giurca (2020, p.2-8) note that "only few of these studies have touched upon issues related to actor networks, interests and strategies [and] [...] for a deeper understanding of the nature of such cooperation forms, both mapping the contours of networks and analysing the network discourse can be valuable" and that "future studies on bioeconomy should thus consider a broader spectrum of stakeholders that go beyond recently formed, government-supported bioeconomy clusters [...] [while] a richer interpretation of the network may be gained if both central and more peripheral actors are interrogated". Korhonen et al. (2018, p.15) conclude that "the network analysis presented [...] is far from exhaustive", while Sanz-Hernández et al. (2019, p.115) state that the "field of bioeconomy lacks mixed methodological designs and needs multidisciplinary research [...] [while] studies lack a holistic and multidisciplinary vision that can account for such a multidimensional and complex reality".

The most promising work so far has been done by Lovrić et al. (2020): by mapping research activity based on projects from EU framework programmes and utilising project data from the CORDIS database, they did vital groundlaying work for this study. As stated above, however, they also focused on the forest-based bioeconomy, supposedly due to a more clear-cut definition for this particular sector. Albeit this focus, they end by underlining a lack of research on holistic bioeconomy networks: "It cannot be stated to which extent the forest-based bioeconomy research network is integrated in the overall bioeconomy network, as such a study does not yet exist"(Lovrić et al., 2020, p.10) and thus directly underpinning the vastness of the research field. Seeing "the greatest potential scientific contribution of the study is in its potential to be replicated in the overall bioeconomy field, where longitudinal analysis of all its segments could provide a new perspective on which factors foster and impede the development of research and innovation of such an emerging field" (Lovrić et al., 2020, pp.10-11), which acts as an even greater invitation for this work. It therefore also contributes to the Bioeconomy Strategy's Action Plan of the European Commission. The social network analysis conducted in the literature mentioned above can, thus, be considered as lacking in providing valuable findings that help with the overall course the bioeconomic research field needs.

One of the main hurdles authors seem to face with a holistic approach to bioeconomy networks is the need to demarcate which parts of their data basis can be seen as bioeconomic and which cannot. It does not help that bioeconomy is seen as multifaceted in its breadth and its depth (Bugge et al., 2016) and is regarded as an influential global metadiscourse that seems to only exist in academia and policy circles; that there are many different understandings of what bioeconomy networks mean and that the discourse is still in flux, and that, in the end, a shared identity is missing (Giurca, 2020). The diffuse nature of this evolving concept is, therefore, frequently the most challenging obstacle to overcome. For this work, which aims to solve at least one of these problems by operationalising a definitional approach, the concept needs to be roughly delimited to build upon in the following; a starting point needs to be set. Discussions about existing definitions for bioeconomy occur in various disciplines (López Hernández & Schanz, 2019) and are manifold and, most importantly, frequently tiring due to their fuzziness. Hence, Birchs' critical view of the bioeconomy as a vital neoliberal project (Birch, 2019), combined with the findings of Paletto et al. (2020), who analysed primary definitions on bioeconomy and concluded their work in the two key points (1) *the concept of sustainability as the theoretical foundation* and (2) *the innovation and knowledge processes as the engine* of the bioeconomy (Paletto et al., 2020), as well as the criteria catalogue constructed earlier in this work (Chapter 2.4), are used as this basis. In the following, this delimitation acts as the starting point for the empirical process.

To conclude, operationalising a definitional approach, identifying projects and actors on that basis, and disseminating and analysing the resulting purpose-oriented project network is believed to yield essential results by filling an apparent gap in research on bioeconomy. Furthermore, shedding light on the networks' structural properties, knowledge diffusion characteristics, and actorial parameters with the help of social network analysis is vital for examining the European bioeconomy.

3.3 Data and Methodology

Provan et al. (2005) describe network analysis as a method of collecting and analysing data from multiple individuals or organisations that may interact with one another, focusing on the relationship and not the organisation itself. It thus examines and compares relationships between organisations, clusters or cliques, and the network's actors. Therefore, to substantially describe networks' properties, a profound set of relational data is needed, which contains information on a network's elements, relationships, and nature as a whole (Curtin, 2016). For this set of data, some requirements exist. Analysing entire networks rather than single components is desirable and should be preferred whenever possible (de Nooy et al., 2018). Simultaneously, data demarcation is frequently considered a problem

(Jansen, 2003; Protogerou et al., 2010b). While working on the data, a certain degree of diligence and persistencere is also necessary, and performing social network analysis on primary data is undoubtedly the statistically most robust procedure (Ter Wal & Boschma, 2009).

In light of these statements, primary data based on the CORDIS project database was believed to be the best fit. However, processing raw network data into a usable form can be a complicated, lengthy, and to some extent, challenging process; hence, a more detailed step-by-step approach was chosen for the description of the data basis this study builds upon. Therefore, the processes applied for retrieving, cleaning, and preparing the data are presented in the following.

3.3.1 Description of the Data

The CORDIS database is run by a subcontractor who receives all kinds of project-related data from different General Directorates and incorporates it into a collective database (Heller-Schuh et al., 2011). This study's dataset contains projects and related organisations funded by the European Union under the Horizon 2020 (H2020) framework programme for research and innovation from 2014 to 2020, including completed and ongoing projects. H2020 itself is sectorally divided into three pillars and two specific objectives corresponding to its main priorities (European Commission, 2020b):

1. "Excellent Science"
2. "Industrial Leadership"
3. "Societal Challenges"

- *Specific objective* "Spreading excellence & widening participation"
- *Specific objective* "Science with and for society"

These main priorities are further subdivided into programmes and their subsections. Fig. 3.4 provides an overview of the leading programmes of H2020, while a complete list of all 277 programmes and their subdivisions would go beyond the scope[1].

The data itself[2] is split upon various datasets, the most important ones for this study being *H2020organisations*, which includes variables for all organisations that are part of funded projects and further information, for example, role in the project, type, or address, and *H2020projects*, including mainly public grant information for each project and information regarding the programme a project was funded in, the topic, the title, the call ID, and all participating organisations working in the project. These two datasets formed this study's initial raw data source, consisting of 35 970 organisations in 32 454 projects (retrieved on

[1] accessible at: https://data.europa.eu/euodp/en/data/dataset/cordisref-data
[2] available to download: https://data.europa.eu/euodp/en/data/dataset/cordisH2020projects

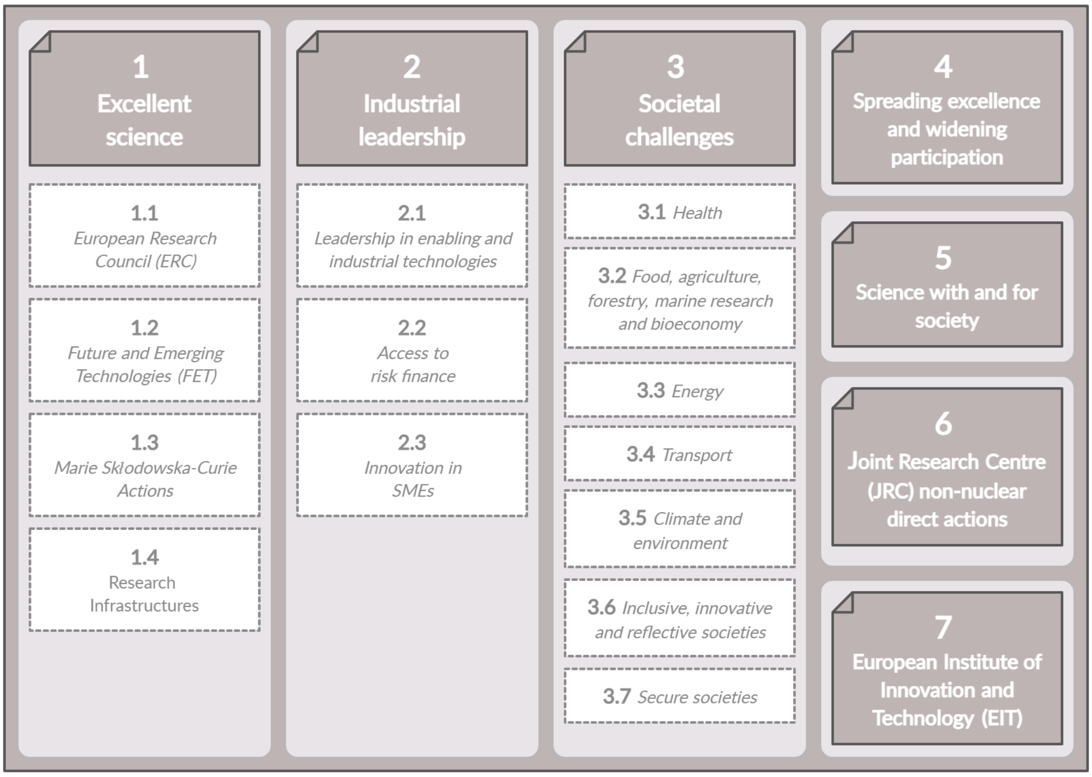


Figure 3.4: Horizon 2020 Framework Programmes

19.04.2021). Fig. 3.5 provides an overview of the data structure and applied methods for a more precise visualisation. Boxes in dark blue symbolise utilised H2020 databases, while light blue illustrates filtered intermediate results and green parts relevant to bioeconomy.

3.3.2 Data Preparation

Retrieving and cleaning CORDIS data is regarded as "cumbersome" because the information is not immediately available or processable, can change over time, and is frequently not complete or inconsistent (Heller-Schuh et al., 2011, p.21). Furthermore, as outlined in section 3.2.5, the conceptual framing of bioeconomy is frequently regarded as a challenge for quantitative approaches. The data certainly includes all funded projects but lacks entirely an unambiguous allocation variable that allows to filter out strictly which projects follow bioeconomic concepts and can thus be seen as bioeconomy-related. This fact, again, is not a novelty in the research field; bioeconomy's demarcation problem hinders more holistic and general research approaches (Sanz-Hernández et al., 2019). Because of these factors, the datasets' initial situation, and the delimitation problem, a novel standardisation method was needed. Thus, an alternative approach was created, with an overarching aim to conduct as few judgement calls on what bioeconomy entails as possible and base the results on exclusively secondary data. Therefore, the procedure shown in Fig. 3.5 was designed. Its elements are discussed below.

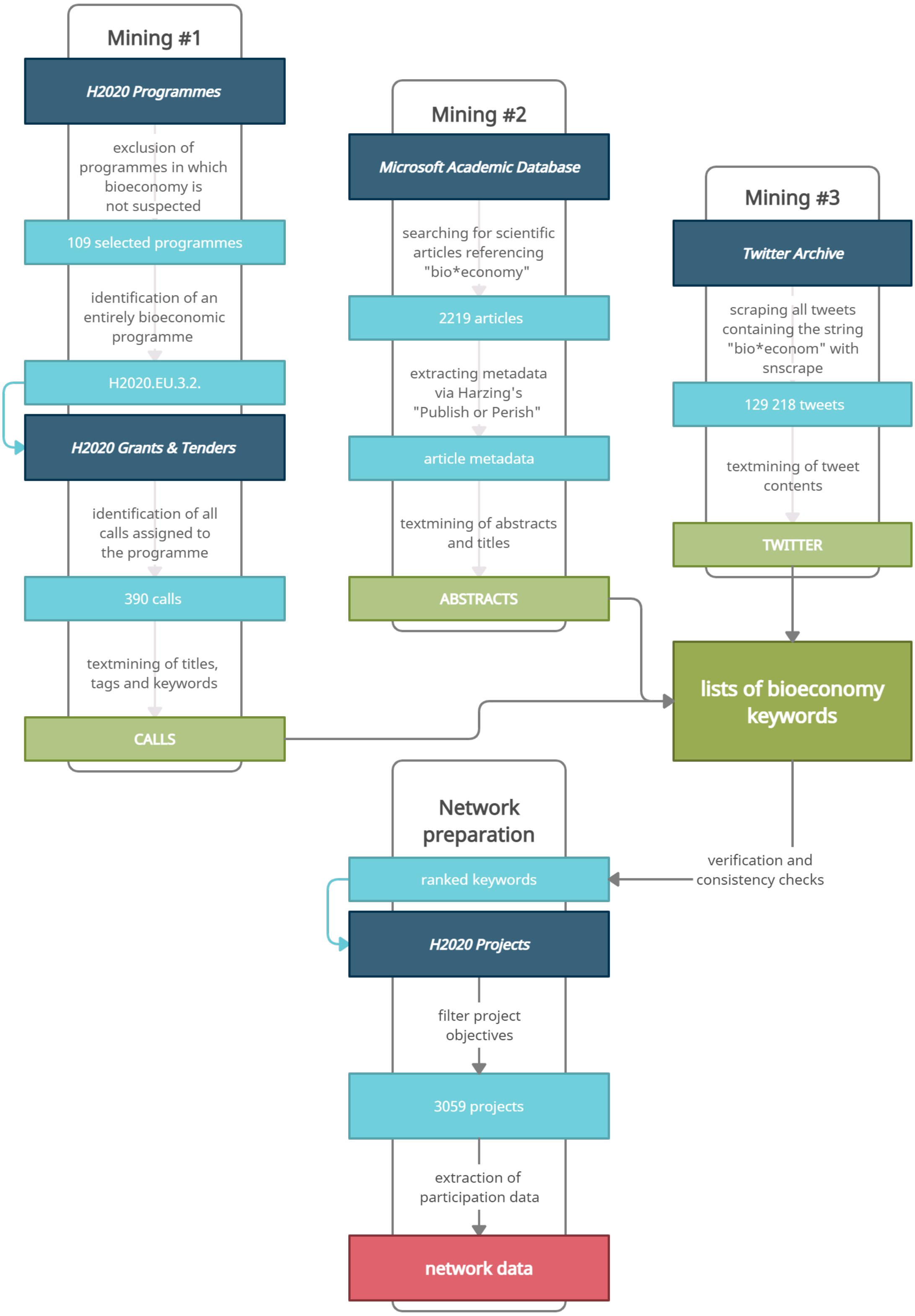


Figure 3.5: Structure and method used for data preparation (own graphic)

Projects that could be undoubtedly assigned the trait ‘bioeconomic’ needed to be identified. However, both datasets lack such an indicating variable; only the (sub-)programme, or subdivision, in which the individual project was funded, is categorised. Even though ‘Bioeconomy’ appears as a section of the ‘Societal Challenges’ programme, more sections that could potentially be regarded as bioeconomic were immediately found on closer inspection (Appendix 3.A). Not only would identifying them by hand result in an enormous undertaking, but the identification process itself would also be, due to the diffuse nature of bioeconomy, an exceptionally rough and complex process in itself. Therefore, it was not believed feasible to filter by the (sub-)programme to yield a comprehensive result, as the categorisation would be too narrow and too exclusive. Instead, an extensive list of keywords that strongly hint towards the bioeconomy to identify projects and their participants via text mining was believed to result in a real-world dataset with higher quality. For bioeconomy, a concept permeating different areas – political, academic, and also non-academic – it would furthermore be severely negligent to incorporate only one of those areas as a source. As outlined before, too many assumptions are made in nowadays bioeconomy. Therefore, looking at already judged secondary data seems a desirable idea, and an approach that examines the understanding of bieconomy from differing angles is seen as favourable.

Therefore, three text minings on different sources were carried out to receive these lists of keywords (Fig. 3.5), which point towards the bioeconomy. Initially, the titles, tags, and keywords of calls under programmes in which bioeconomy is assumed were mined. Then, to gather a more research-oriented point of view, abstracts of publications were looked at. These, however, lack the non-academic public opinion, which informal communications are needed to paint a complete picture. Thus, social media data was regarded to fill this gap, and an extensive scraping of Twitter data was carried out and later also examined. These three mining efforts are described in more detail in the following sections.

Textmining of H2020 Calls

As an initial step, a rather general cleaning of the H2020 programmes was needed. Therefore, the titles of programs, directly considering the concept of the bioeconomy as defined in section 3.2.5., were examined. Whenever the concept is suspected of not playing a role in a programme, the programme is excluded. Table 3.2 gives an overview of programmes where bioeconomy is assumed to play a role. All subprogrammes to the shown programmes are included for a total of 109[3]. Applying this initially rough selection can be seen as desirable not to overlook more ambiguous programmes.

As a next step, the detailed descriptions of these programmes were consulted to narrow the selection further, aiming, in contrast to before, to identify programmes undoubtedly

[3] a more detailed list can be found in Appendix 3.A

Progr.	Title or Short Title
EU.2.1.3	INDUSTRIAL LEADERSHIP - Leadership in enabling and industrial technologies - Advanced materials
EU.2.1.4.	INDUSTRIAL LEADERSHIP - Leadership in enabling and industrial technologies - Biotechnology
EU.2.1.5.	INDUSTRIAL LEADERSHIP - Leadership in enabling and industrial technologies - Advanced manufacturing and processing
EU.3.1.7.	Innovative Medicines Initiative 2 (IMI2)
EU.3.2.	SOCIETAL CHALLENGES - Food security, sustainable agriculture and forestry, marine, maritime and inland water research, and the bioeconomy
EU.3.3.	SOCIETAL CHALLENGES - Secure, clean and efficient energy
EU.3.5.	SOCIETAL CHALLENGES - Climate action, Environment, Resource Efficiency and Raw Materials
EU.5.c.	Integrate society in science and innovation issues, policies and activities in order to integrate citizens' interests and values and to increase the quality, relevance, social acceptability and sustainability of research and innovation outcomes in various fields of activity from social innovation to areas such as biotechnology and nanotechnology
EU.5.d.	Encourage citizens to engage in science through formal and informal science education, and promote the diffusion of science-based activities, namely in science centres and through other appropriate channels
EU.5.f.	Develop the governance for the advancement of responsible research and innovation by all stakeholders, which is sensitive to society needs and demands and promote an ethics framework for research and innovation
EU.5.g.	Take due and proportional precautions in research and innovation activities by anticipating and assessing potential environmental, health and safety impacts

Table 3.2: Programmes where bioeconomy is assumed

pointing towards the bioeconomy. Out of the programmes mentioned in Table 3.3, only *EU.3.2.*, including its subprogrammes (see Table 3.3), fulfils this requirement.

This selection acts as a starting point for the first text mining, intended to extract a set of keywords that hint at bioeconomy in publically funded projects. However, neither the H2020projects nor the H2020organisations dataset contains a usable corpus of text data. While the *H2020projects* dataset contains a variable for the programme(s) a project runs under, using the above list as given as a filter variable is entirely unfeasible, as described in the overview of this section, as it would create an impure dataset by assuming that only projects in EU.3.2. are bioeconomic and therefore disregarding any other potential fitting programmes.

As mentioned, projects in H2020 follow specific calls in which they are funded. In contrast to the two datasets *H2020organisations* and *H2020projects*, there is no downloadable database with sufficient information on these calls. Instead, a searchable online portal is the only accessible option. This portal lists further data on grants, tenders, and funding of these calls and lists tags and keywords. These were seen as a stark opportunity to function as a corpus of text ready to be mined to receive a list of keywords related to bioeconomy.

Progr.	Title or Short Title
EU.3.2.	SOCIETAL CHALLENGES - Food security, sustainable agriculture and forestry, marine, maritime and inland water research, and the bioeconomy
EU.3.2.1.	Sustainable agriculture and forestry
EU.3.2.1.1.	Increasing production efficiency and coping with climate change, while ensuring sustainability and resilience
EU.3.2.1.2.	Providing ecosystems services and public goods
EU.3.2.1.3.	Empowerment of rural areas, support to policies and rural innovation
EU.3.2.1.4.	Sustainable forestry
EU.3.2.2.	Sustainable and competitive agri-food sector for a safe and healthy diet
EU.3.2.2.1.	Informed consumer choices
EU.3.2.2.2.	Healthy and safe foods and diets for all
EU.3.2.2.3.	A sustainable and competitive agri-food industry
EU.3.2.3.	Unlocking the potential of aquatic living resources
EU.3.2.3.1.	Developing sustainable and environmentally-friendly fisheries
EU.3.2.3.2.	Developing competitive and environmentally-friendly European aquaculture
EU.3.2.3.3.	Boosting marine and maritime innovation through biotechnology
EU.3.2.4.	Sustainable and competitive bio-based industries and supporting the development of a European bioeconomy
EU.3.2.4.1.	Fostering the bio-economy for bio-based industries
EU.3.2.4.2.	Developing integrated biorefineries
EU.3.2.4.3.	Supporting market development for bio-based products and processes
EU.3.2.5.	Cross-cutting marine and maritime research
EU.3.2.5.1.	Climate change impact on marine ecosystems and maritime economy
EU.3.2.5.2.	Develop the potential of marine resources through an integrated approach
EU.3.2.5.3.	Cross-cutting concepts and technologies enabling maritime growth
EU.3.2.6.	Bio-based Industries Joint Technology Initiative (BBI-JTI)
EU.3.2.6.1.	Sustainable and competitive bio-based industries and supporting the development of a European bio-economy
EU.3.2.6.2.	Fostering the bio-economy for bio-based industries
EU.3.2.6.3.	Sustainable biorefineries

Table 3.3: Programme EU.3.2. with its subprogrammes

Fortunately, the portal's data was accessible via an Application Programming Interface (API). While the service runs in pilot mode and may undergo modifications and future service enhancements, it passed an initial test for completeness by cross-checking 40 examples of the downloaded API data with the portal's information, which did not reveal any flaws. The .json-formatted data was then grabbed via a basic request, providing a list of all 5 459 calls, with related metadata on tags and keywords. Following transposing into a wide format, the dataset was filtered by the programmes depicted in 3.3, resulting in 390 calls believed to include bioeconomic characteristics. The textual contents of their titles, tags, and keywords were then, after cleaning the most common stopwords, unnested into single words and their occurrence counted (Fig. 3.6).

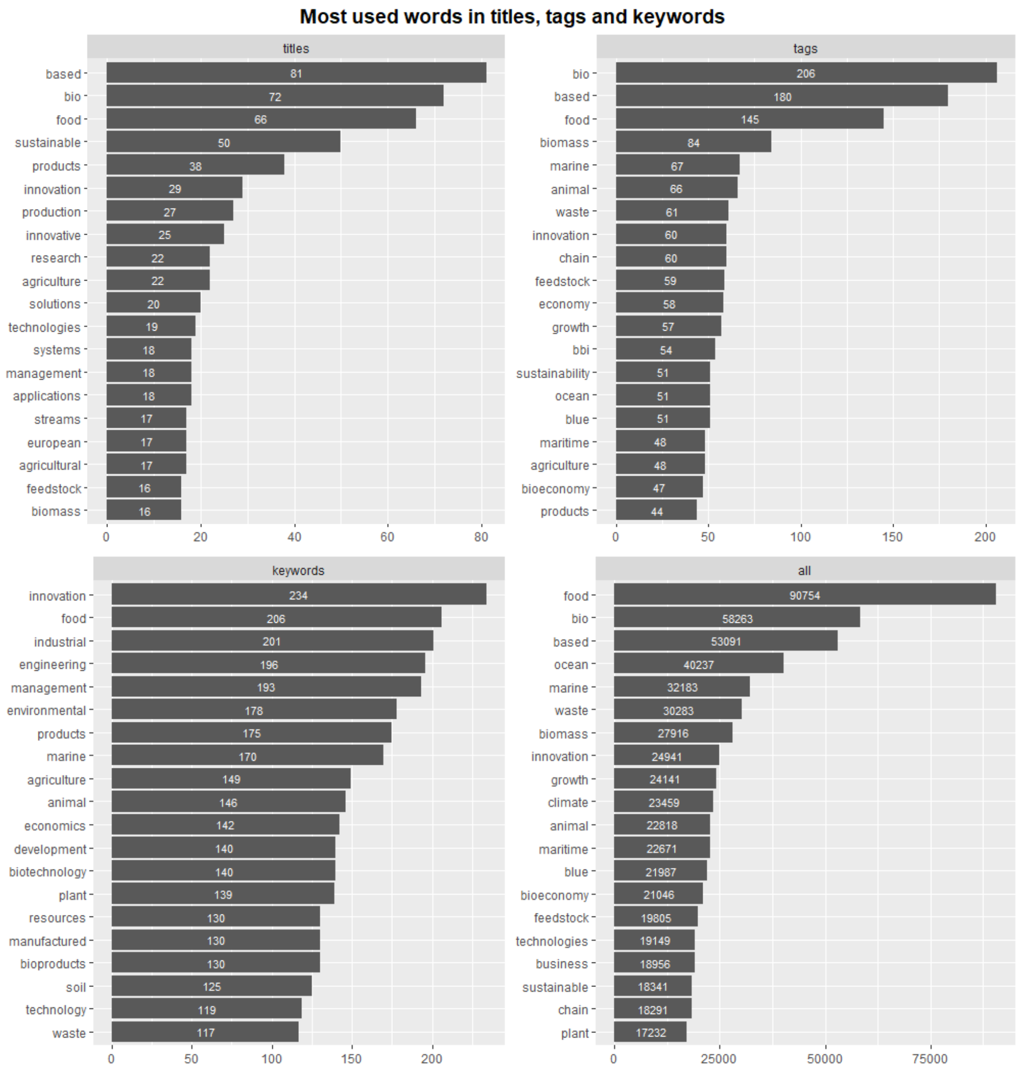


Figure 3.6: Textmining of 3.2. calls

The rankings of the words “bio” and “based” strongly hint toward bigrams, pairs of consecutively occurring words, in the text corpus. Fig. 3.7 shows the most frequent ones, underlining this initial suspicion.

By examining n-grams, the relationship between words can get more apparent. However, n-grams typically only check whether two words frequently occur next to each other and frequently overlap (Silge & Robinson, 2017). Therefore, bigrams like “based industry”, “bioproducts products”, or “technologies industrial” need to be disregarded when taking the list into further consideration.

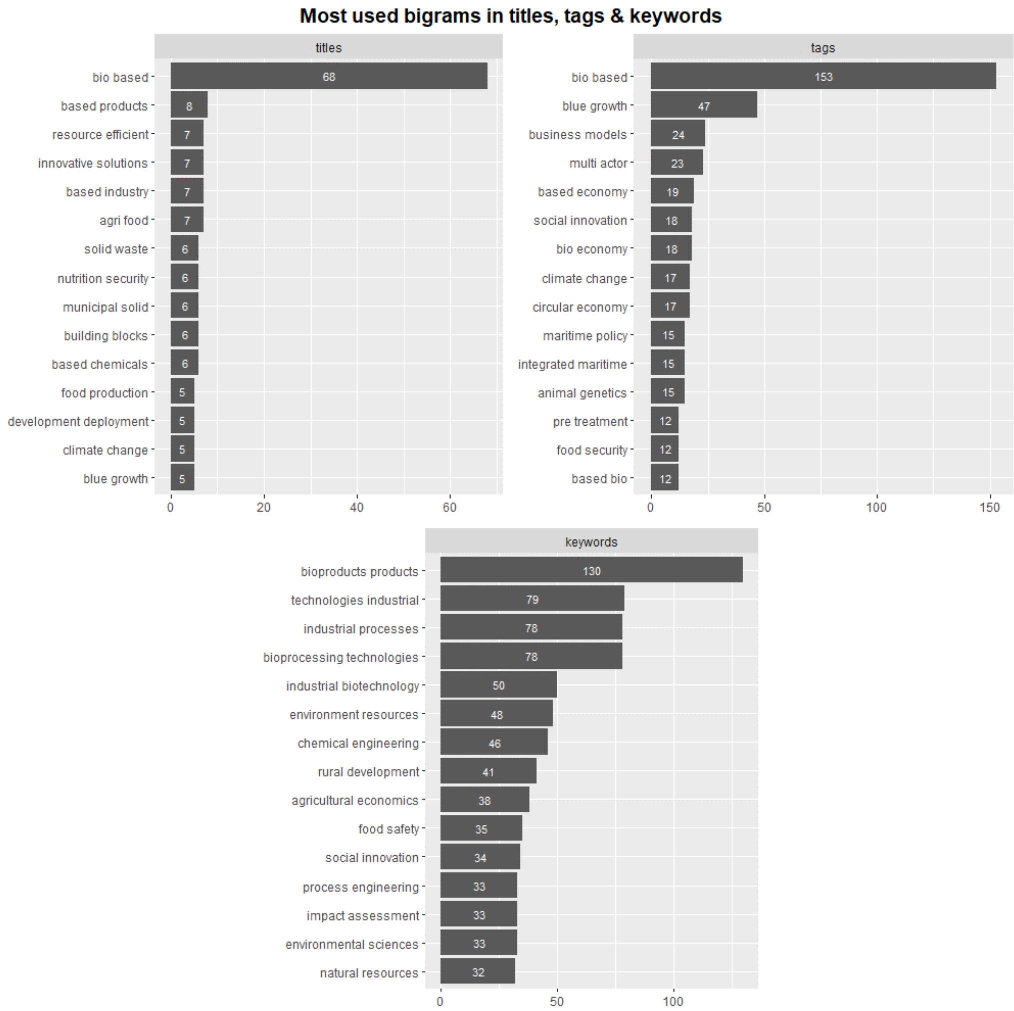


Figure 3.7: Bigrams in 3.2. calls

Textmining of Abstracts

As outlined before, applying text mining to the abstracts of scientific articles that touch upon the topic of bieconomy is seen as an excellent way to cover the merits of the scientific side of the concept. To search for publications, *"Publish or Perish 7"* was used with the search string ‹"*bioeconomy*" OR "*bio economy*" OR "*bio-economy*"›to crawl the Microsoft Academic Research database. Typically, when searching for scientific articles, the gold standard is usually Google Scholar (Martín-Martín et al., 2020); however, crawling is limited and restricted to only a short overview of the abstract instead of the complete one. When complete data is needed, like a complete corpus of text like in this study, the extensive comparison study of Martín-Martín et al. (2020) recommends Microsoft Academic Research over Scopus, Web of Science and Dimensions. Hence, due to this recommendation, crawling with the API yielded 2 219 publications' metadata, which again was fed into R for text mining (Fig. 3.8).

For larger, coherent corpi of text, unnesting trigrams can offer a more detailed view.

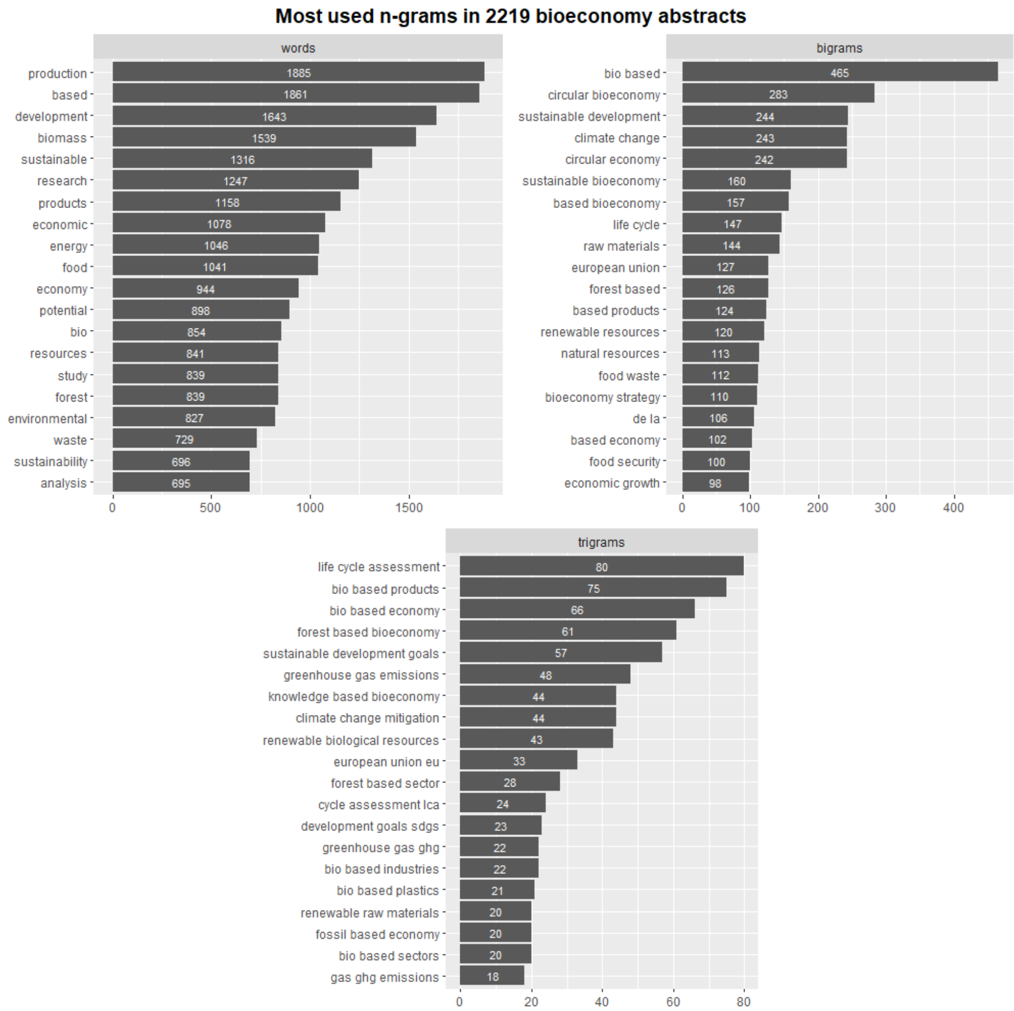


Figure 3.8: N-grams in abstracts

Trigrams in Fig. 3.8, for example, draw a slightly different picture than bigrams, thus leading to a better understanding of the contents of the textual data.

Textmining of Tweets

At last, an exhaustive scraping of Twitter data was carried out to extract a list of keywords the social sphere users use for the concept. For that, the open-source scraping script “snscrape”[4] was used. Snscrape scrapes various social networking services by elaborate search strings and obtains detailed metadata. It uses Python and is licensed under the GNU General Public License v3.0. For this study, the entirety of every tweet sent since the launch of Twitter in 2007 up until April 2021 was searched for “*bio*economy*”. The asterisk functions as a wildcard to hit all appearances of “bioeconomy”, “bio-economy”, as well as “bio economy”. The search resulted in 129 218 found tweets[5] and their relevant

[4]available at https://github.com/JustAnotherArchivist/snscrape
[5]retweets are excluded; retweets older than seven days cannot be scraped (at this time)

metadata. Their contents were then, using the same method as before, handled and mined in R.

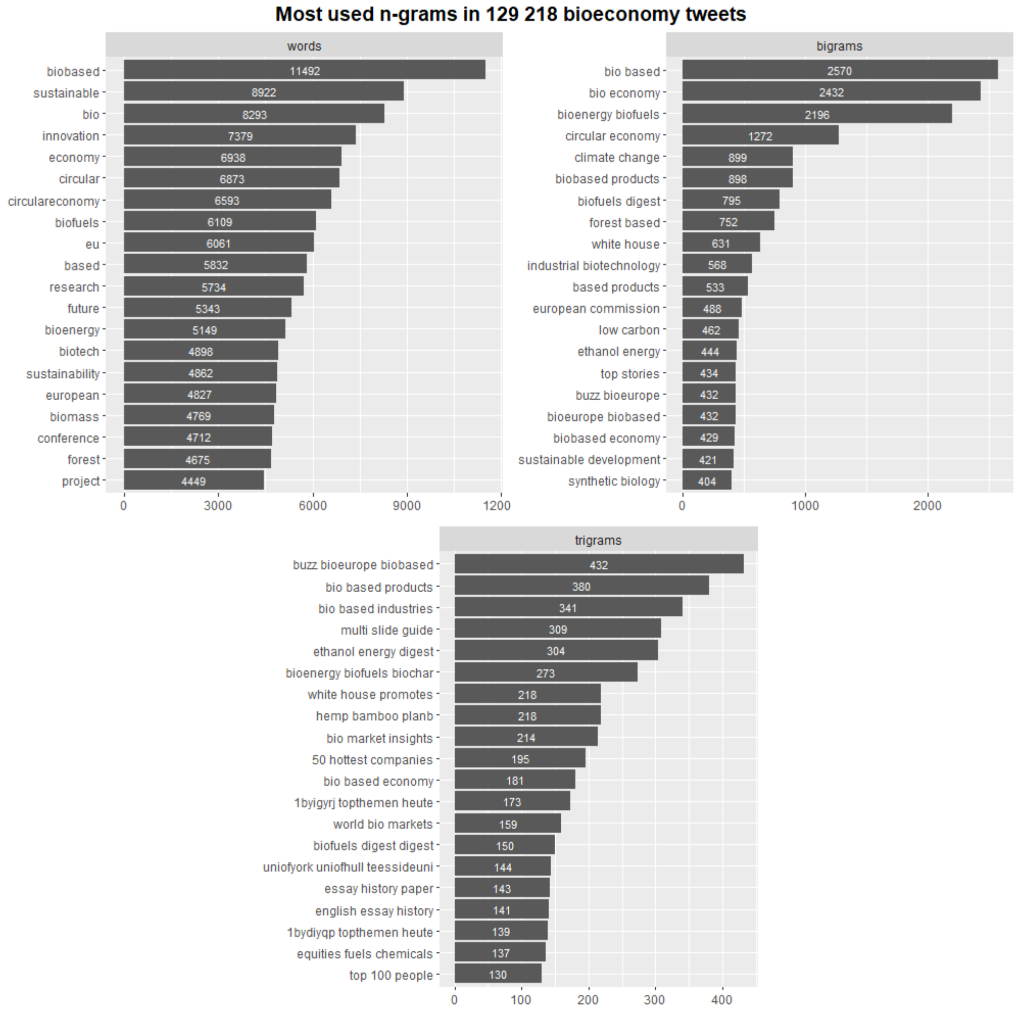


Figure 3.9: N-grams in tweets

3.3.3 Assembling a Keyword List

After these three initial mining efforts, a keyword list to filter all projects needed to be created. Also, in text mining, calculating the tf-idf (term frequency - inverse document frequency) is often used to identify important words that do not frequently occur in a collection of documents (Silge & Robinson, 2017). However, it is seen as favourable to incorporate besides counts of words the tf-idf, since it can achieve a simple weighting of terms and thus provides yet another point of view. Fig. 3.10 shows the tf-idf for words and bigrams of the three different mining sets.[6]

Next, before a final keyword list could be generated, the ranks of the words were checked

[6] Calculating tf-idf works best when analysing document corpi of roughly the same size. The datasets varied widely in their size; therefore, only the top 500 words of each mining result were considered.

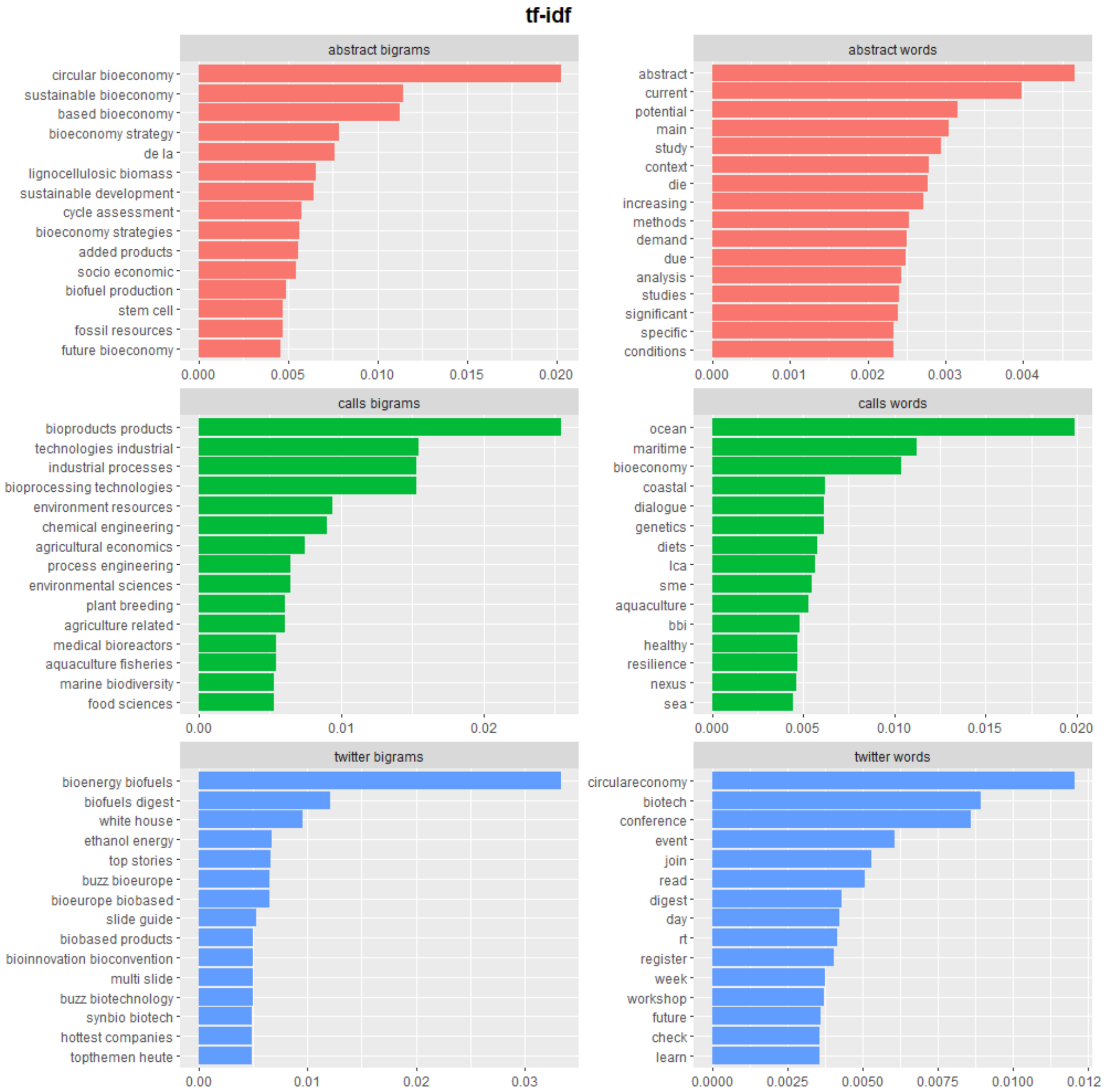


Figure 3.10: Highest tf-idf words and bigrams in each of the three minings

for correlation to examine whether it is a reasonable approach to combine them in that way. Consistency across the three lists, despite their different sources, can be believed based on the findings so far and is thereby checked if the concept of bioeconomy implies equal matter in the three examined areas.

Fig. 3.11 shows, although only a slight, positive correlation between the words' ranks, thus combining them can be justified. Only the top 500 words are considered because of the different lengths of the lists and because creating the final set of keywords is done by examining only the top-ranked words. As shown in Fig. 3.5, all the mining efforts are now getting combined into a set of keywords by considering their rank across the three minings and evaluating their prominence, resulting in two separate sets of keywords: one, in which words can hint toward bioeconomy on their own, and another, which contains terms less decisive in their scope, but able to act as keywords in combination with other

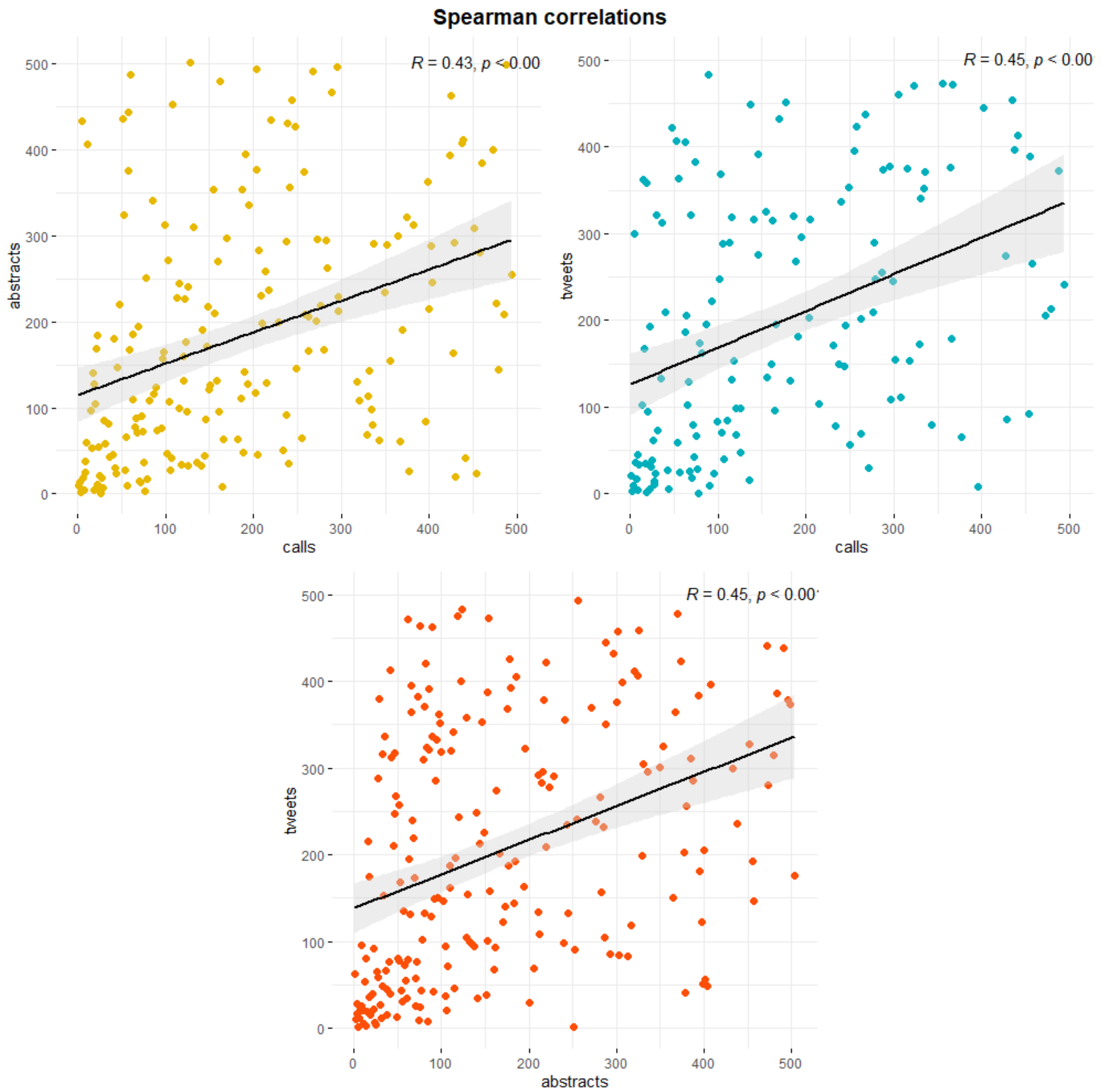


Figure 3.11: Rank correlations of the top 500 words

words of this set. To test an initial set of 14 direct and 19 indirect keywords and their variations for its accuracy, the sets are applied by the same method as described below to projects strongly associated with bioeconomy: those running under the programme 3.2.4.: "*Sustainable and competitive bio-based industries and supporting the development of a European bioeconomy*". Application is made by filtering for keywords in the objective or title of each project in the *H2020projects* dataset. In 3.2.4., 219 projects are funded. Of these, the initial set of keywords identified 87 projects. As a next step, the 132 not identified ones were extracted, and their title and objective were evaluated regarding bioeconomic principles following the concept outlined in Section 3.2.5. Seven more were considered bioeconomic, 11 as rather bioeconomic, and 114 as non-bioeconomic. As a result of this initial test run, one word would be added to the list of words strongly referring to bioeconomy ("bio*mass"), and eleven words were added to the second set, which concludes the final keyword list (Table 3.4).

Keywords depicted in the table below are formatted for regular expression filtering. One cell thereby resembles one contiguous keyword phrase with all its possible combinations.

<table>
<tr><th>Set I</th><th>Set II</th></tr>
<tr><td>((biomass)|(bio-mass))</td><td>(natural resources)</td></tr>
<tr><td>(agricultural waste)</td><td>(wood|forest)</td></tr>
<tr><td>((bioeconom)|(bio[-]econom))</td><td>(plant breeding)</td></tr>
<tr><td>((bio[-]technolog)|(biotechnolog))</td><td>(ocean|maritime|marine|aquacultur)</td></tr>
<tr><td>((biobased)|(bio([-](based))))</td><td>(feedstock)</td></tr>
<tr><td>(biorefine)</td><td>(resource efficien)</td></tr>
<tr><td>(bioenerg(etic|ies|y))</td><td>(biodivers)</td></tr>
<tr><td>(biofuel)</td><td>(rural development)</td></tr>
<tr><td>(bioplastic)</td><td>(innovati)</td></tr>
<tr><td>(food waste)</td><td>(sustainab)</td></tr>
<tr><td>((bio |biological)raw material)</td><td>(cascad)</td></tr>
<tr><td>(sustainable agriculture)</td><td>(raw materials)</td></tr>
<tr><td>(circular economy)</td><td>(renewable resource)</td></tr>
<tr><td>((bio[-]material)|(biomaterial))</td><td>(renewable energ)</td></tr>
<tr><td>(agricultural waste)</td><td>(bioprocess)</td></tr>
<tr><td></td><td>(low carbon)</td></tr>
<tr><td></td><td>(valuechain|value-chain|value chain)</td></tr>
<tr><td></td><td>(residues)</td></tr>
<tr><td></td><td>(blue growth)</td></tr>
<tr><td></td><td>(biotech|bio-tech|bio tech)</td></tr>
<tr><td></td><td>(by-products|by products|biproducts)</td></tr>
<tr><td></td><td>(biomech|bio-mech|bio mech)</td></tr>
<tr><td></td><td>(biofertil)</td></tr>
<tr><td></td><td>(residue)</td></tr>
<tr><td></td><td>(reuse|re-use|re use|reusag|re-usag|re usag)</td></tr>
<tr><td></td><td>(side-product|side product|sideproduct)</td></tr>
<tr><td></td><td>(bioethan)</td></tr>
<tr><td></td><td>(waste)</td></tr>
<tr><td></td><td>(recycl)</td></tr>
<tr><td></td><td>(food safety)</td></tr>
</table>

Table 3.4: List of keywords referencing the bioeconomy

The final filtering process was carried out in R in two steps. First, titles and objectives of all projects in *H2020projects* were searched with

$$\mathbf{filter}(\mathbf{str\_detect}(objective, regex([SetI])))$$

and

$$\mathbf{filter}(\mathbf{str\_detect}(title, regex([SetI]))).$$

Therefore, if one of the keywords of Set I is found in either title or the objective of a project, this project is directly flagged. For the words of Set II, which do not directly point towards bioeconomy on their own, another approach was devised: For each of the 30 strings in Set II, code that follows the outline of

$$\begin{aligned}\mathbf{mutate}(w1 = \mathbf{if\_else}(\mathbf{str\_detect}(objective, regex("(natural\ resources)"))|\\ \mathbf{str\_detect}(title, regex("(natural\ resources)")), 1, 0)\end{aligned}$$

was prepared. The above example for the first string "$(naturalresources)$" creates a new column "$w1$" and fills this column with either a 1 or a 0 if the string is found in either the objective or "|" the title of the project. This is done for every string so that 30 new columns are eventually created. Afterwards, the amount of 1's is counted across these columns, and a project is considered bioeconomic whenever any distinct combination of three words of Set II is identified. The arbitrary cutoff of three words was chosen after testing multiple other variants; three words were found to find the best balance between being too strict and too loose. Finally, Set I was able to identify 1 774 projects and Set II 1 972. The filtered *H2020projects* database, now consisting of only projects assumed as bioeconomy projects, includes 3 054 out of the 32 453 total projects and sets a base layer for the following network analysis.

3.3.4 Data Formatting for Network Analysis

As the last step, the prepared data needs to be formatted in a certain way to "build" the network. Since this study focuses on project networks – one-mode undirected networks – the data needs to be prepared either in the form of an adjacency matrix or an edgelist that follows the structure of:

source	**target**
Partner A	Partner B
Partner A	Partner C
Partner B	Partner C

For Fig. 3.2 the mathematically correct adjacency matrix would look like this:

	A	B	C	D	E
A	0	1	1	0	0
B	1	0	1	0	0
C	1	1	0	1	1
D	0	0	1	0	1
E	0	0	1	1	0

Therefore, two separate datasets, *Nodes*, possessing information about every organisation in the network, and *Edges*, revealing all organisations that have participated in each project and following one of the above structures, needed to be prepared (using R).

Nodes were extracted from the *H2020organisations* dataset, resulting in 9 432 organisations involved in the 3 054 projects. The dataset also includes spatial data for every organisation (*street, city, postcode*), which was considered extremely useful for receiving spatial information. Modern SNA software, however, has specific requirements for visualising spatial data. Therefore, latitudinal and longitudinal coordinates needed to be prepared, and it was considered an unfeasible solution to pinpoint coordinates for 9 432 individual organisations by hand. The process of matching address data to their corresponding geographical coordinates, geocoding, was picked. Sophisticated science, data sets, and algorithms underlie this process, while numerous algorithms are used to match an input address to an address stored in a reference database. However, the variability in algorithms, addresses, and databases can lead to many errors in the geocoded results; this process's accuracy can, therefore, range vastly (McDonald et al., 2017). The address data in *H2020organisations* was inconsistent and far from clean; therefore, for this study, the best method was exploiting Google's Geocoding Service in combination with the R package ggmaps/tidygeocode (David Kahle & Hadley Wickham, 2013). At the start of the process, a private API key needed to be created to access Google's cloud computing engine. After preparing both the *H2020organisations* dataset and the personal API key, the code initially creates a request object and a request based on Google's Geocoding API. It then sends the request to Google's server before creating a Document Object Model, reading the XML results from the request, and grabbing the status node's value before "selecting" a case (read: output) for every request. This way, the address data of 9 410 organisations were geocoded into coordinates; 120 errors were corrected afterwards by altering the address data by hand. As a next step, 40 organisations were randomly picked from the dataset and reviewed for accuracy, resulting in no mislocations, thus allowing for the impression of high accuracy.

As a next step, both datasets, *nodes*, and *edges* needed to be cleaned, restructured, and eventually prepared for network analysis. The data in *nodes* only contain information from *H2020organisations* and coordinates from the geocoding in an already usable form, resulting in just a few decluttering steps to receive the following structure for all organisations that partook in bioeconomy projects in Horizon 2020:

ID/label	city	activityType	country	lat	long
1TO3 CAPITAL BV	AMSTERDAM	PRC	NL	52.3508082	4.8634128
2B Srl	Mogliano Veneto	PRC	IT	45.5856912	12.2196902
UNIVERSITEIT GENT	Gent	HES	BE	51.024929	3.727205
...	...	...	...	...	...

Table 3.5: Exemplified structure of the final dataset "nodes"

For *edges*, however, the process was not as straightforward. As mentioned above, the critical feature of *edges* has to be either an adjacency matrix or an edgelist. Problematically, *H2020organisations* were certainly filtered correctly and only contained bioeconomy projects; however, its structure was present in a wide format but needed to be long. To achieve this, the filtered *H2020organisations* dataset was again reformatted in R, resulting in a complete edge list (Table 3.6).

Source	Target
ENISYST GMBH	ACCADEMIA EUROPEA DI BOLZANO
lLOUC HOLDING BV	MICROGANIC GMBH
...	...

Table 3.6: Exemplified structure of the final dataset "edges"

Undoubtedly, an enormous emphasis was placed on clarifying the materials and methodology used for data preparation and processing. However, this is needed to ensure reproducibility because the procedure involves many different steps. Now, social network analysis can be carried out on top of this minutely edited data.

3.3.5 Social Network Analysis as a Method

On top of "standard" network analysis in R, a second approach to the data using Gephi was considered fruitful. Exploratory Data Analysis does not follow a pre-emptively structured methodology but emphasizes the importance of curiosity and serendipity in data analysis (Heymann & Le Grand, 2013). It does not set any a priori constraints on estimating factors to be extracted (Toral et al., 2011), thus focusing first on describing measures before exploring significant aspects of the network and its actors. Exploratory Social Network Analysis is an inherently deductive task (Perer, 2008), and for a long time, the research community struggled to create software that combines statistical and visualisation analysis (Heymann & Le Grand, 2013). While KrackPlot, Pajek, UCINET, and visone focus on statistical analysis and only support limited visualisations, systems like NetDraw and Tom Sawyer concentrate their visualisation efforts but lack many statistical algorithms

(Perer & Shneiderman, 2008). Gephi, an open-source network exploration and manipulation software that uses a 3D render engine to display networks in real-time, was developed to combine a visualisation engine that uses modern computing power to fair use and deal with large networks and statistical computations. An active developing community and general code modularity keep Gephi supplied with various add-ons, and it is nowadays used to a great extent in various disciplines (Bastian et al., 2009; Jacomy et al., 2014). Complex data sets often produce overwhelming visualisations and statistics; analysis tools that tightly integrate these facets, like Gephi, are beneficial for Explorative Data Analysis (Perer & Shneiderman, 2008). Gephi's key is to ease the interaction with the network, as the visualisation happens simultaneously, allowing the researcher to experiment with various visual configurations with immediate visual feedback, thanks to its multi-threading architecture using the GPU as a renderer (Heymann & Le Grand, 2013). Current datasets are increasingly complex, and static visualisations drastically decrease comprehensibility, making interactive techniques like Exploratory Data Analysis more necessary (Perer & Shneiderman, 2008). The visual analysis follows the mantra of "Overview First, Zoom and Filter, Details-on-Demand" to reveal outstanding elements and saliences, allowing for a more profound analysis process and challenging current hypotheses and raising questions (Heymann & Le Grand, 2013). Therefore, presenting data through visualisation is considered an effective way to utilise human perceptual systems (Perer, 2008). Further, fully explorative SNA has never been easier to implement than today, thanks to the computational progress in recent years and superior software solutions (Cherven, 2015). It is seen as not feasible to use these new techniques and technology only to compute but not to visualise, interpret, and analyse substantively (J. Scott, 2011a).

3.4 Analysis of the European Bioeconomy Network

Following the analytical framework presented in Fig. 3.3, the descriptive statistics and parameters of the network, its actors and joint projects that influence knowledge distribution will be examined first. Then, the structural features of the bioeconomy network as a whole and its actorial cooperations are being looked at before different centrality measures are being calculated and the most central actors in the network identified. Finally, structural changes during its lifecycle are looked at by shedding light on the dynamic evolution of the network over the whole runtime of Horizon 2020.

3.4.1 Description of the final Dataset

First, the dataset will be looked at in more detail. As the previous section concluded, 9 432 organisations partook in a total of 3 054 projects associated with the bioeconomic concept. Table 3.7 lists some initial descriptive statistics of the bioeconomy dataset, while Table 3.8 depicts the difference in relation to the complete H2020 data.

Organisations		Projects	
Number of Organisations	9 432	Number of Projects	3 054
Avg. Projects per Organisation	10.44	Avg. Participants per Project	6.89
Standard Deviation	40.18	Standard Deviation	8.56
Median Projects per Organisation	2	Median Number of Organisations	1

Table 3.7: Descriptive statistics for the dataset

	H2020 complete	H2020 bioeconomy
Number of Projects	32 453	3 054
Avg. Number of Participants	4.43	6.89
Number of Organisations	36 970	9 432
Avg. Number of Projects per Organisation	4.11	10.44

Table 3.8: Comparison of the bioeconomy network and H2020

Tables 3.7 and 3.8 show that nearly 10% of projects funded under Horizon 2020 can be identified as bioeconomic, while bioeconomy projects also consist of more participants on average. Looking at the organisational side, this trend continues: roughly a quarter of all organisations participated in at least one bioeconomic project during H2020s runtime, and the average count of projects these organisations handle is higher than the complete average. The standard deviation of the number of projects per organisation is also noticeable and hints toward a high amplitude of the number of participants per project. Identifying the types of organisations is also crucial for interpretation purposes. In the data set, *$activityType* hints at the sector the organisation are working in, with the European Commission distinguishing between five types and describing them as follows:

- **Private Sector**
  Private, for-profit entities, including small or medium-sized enterprises and excluding Universities and Higher or Secondary Education Establishments.
- **Public Body**
  Any legal entity established as a public body by national law or an international organisation. Excludes Research Organisations and Higher or Secondary Education Establishments.
- **Research Organisation**
  A legal entity that is established as a non-profit organisation and whose main objective is carrying out research or technological development.
- **University**
  A legal entity that is recognised by its national education system as a University or Higher or Secondary Education Establishment. It can be a public or a private body.
- **Other**
  Any entity not falling into one of the other four categories.

Sector	**organisations**	**share of total**	**overall proj. participation**	**share of participation**
PRC – *Private sector*	5 795	61.5	20 089	20.4
PUB – *Public body*	589	6.2	3 820	3.9
REC – *Research organisation*	1 065	11.3	24 319	24.7
HES – *University*	991	10.5	45 992	46.7
OTH – *Other*	981	10.4	4 209	4.3
NA	11	0.1	11	0.01
	9 432	100	98 440	100

Table 3.9: Sectoral identity of organisations in the network

Table 3.9 shows the distribution of the organisations in the network in these sectors.

The high number of organisations working in the private sector is initially striking. However, a significant dominance of the research-oriented sectors REC and HES is apparent when looking at the overall project participation. While single companies account for nearly two-thirds of unique organisations, their impact is far more negligible when looking at the complete structure in which *Universities* and *Research organisations* take the lead.

Subsequently, Fig. 3.12 shows the geographical extent of the unique organisations and their sectoral identity. Blue shows the private sector, brown public bodies, green research, and magenta universities. 669 organisations are omitted since their location is not in Europe.

Especially noticeable is the clustering of companies and research organisations in western European countries, while public bodies often appear in eastern and southern Europe. This can be further underlined by shedding light on where the project coordinators are located (Fig. 3.13) and the distribution of types per country (Fig. 3.14).

A discrepancy between east- and west Europe, as well as the core and periphery regarding the coordinator's location, becomes apparent. The particular focus lies on Spain, Germany, France, Italy, and the United Kingdom.

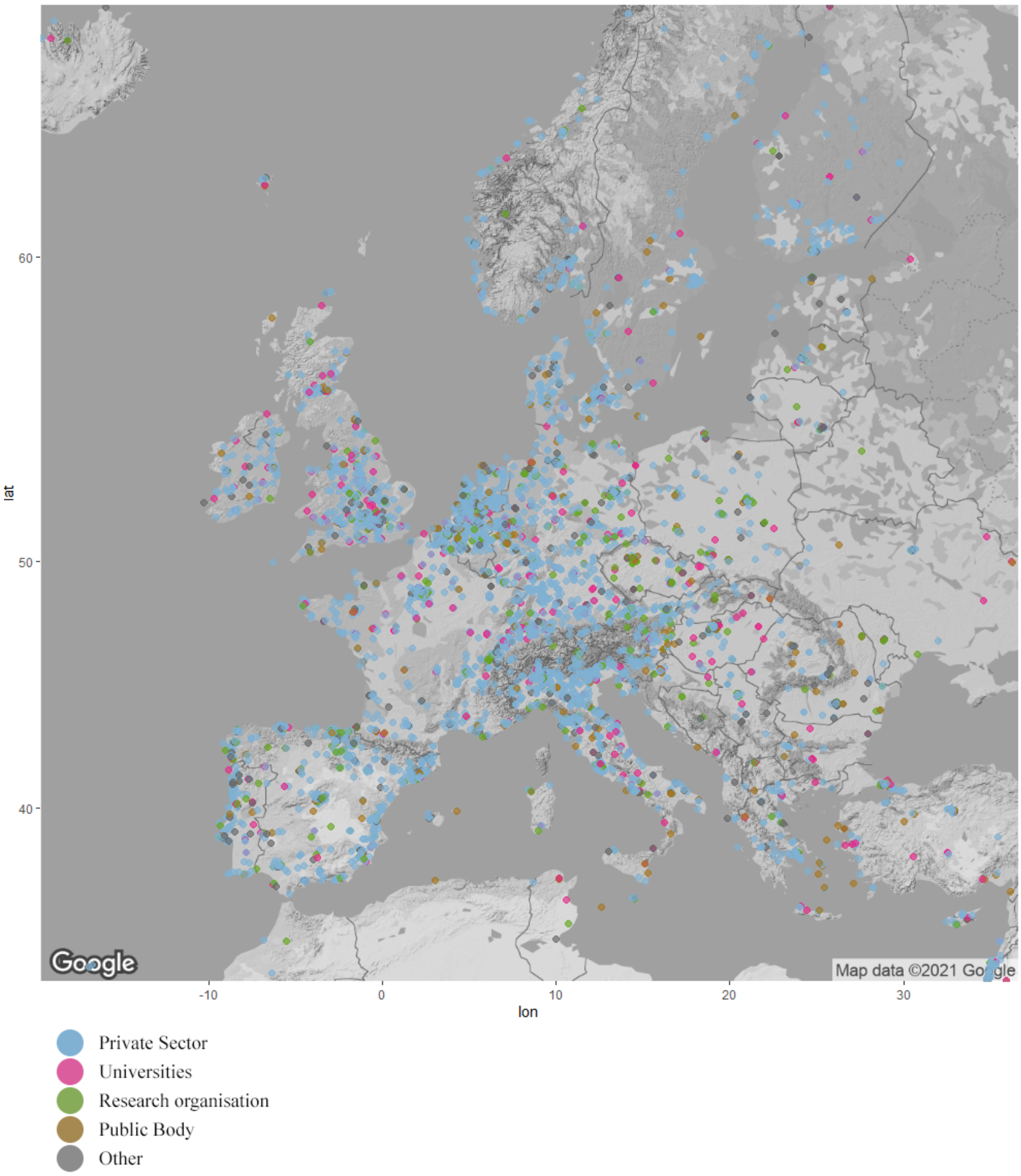


Figure 3.12: Organisations in bioeconomy projects

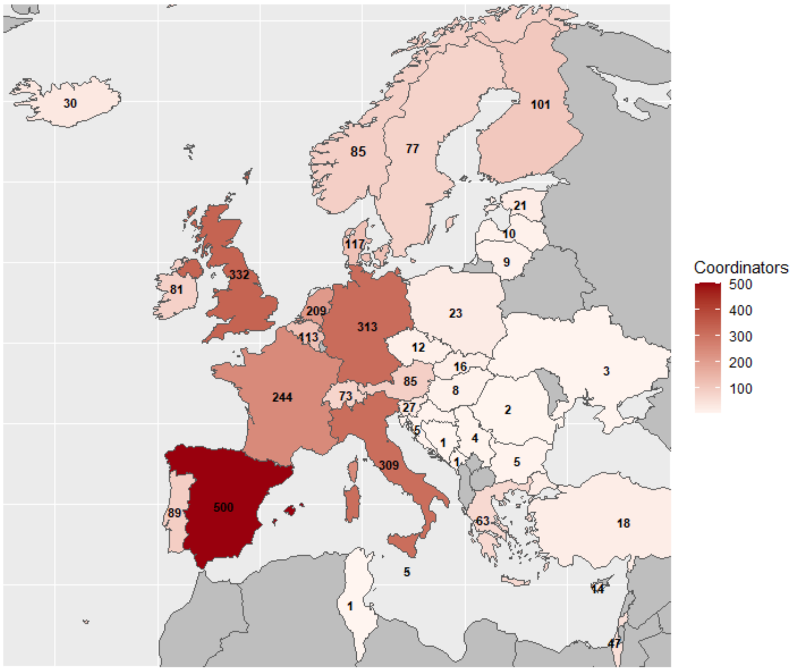


Figure 3.13: Origins of coordinators of bioeconomy projects

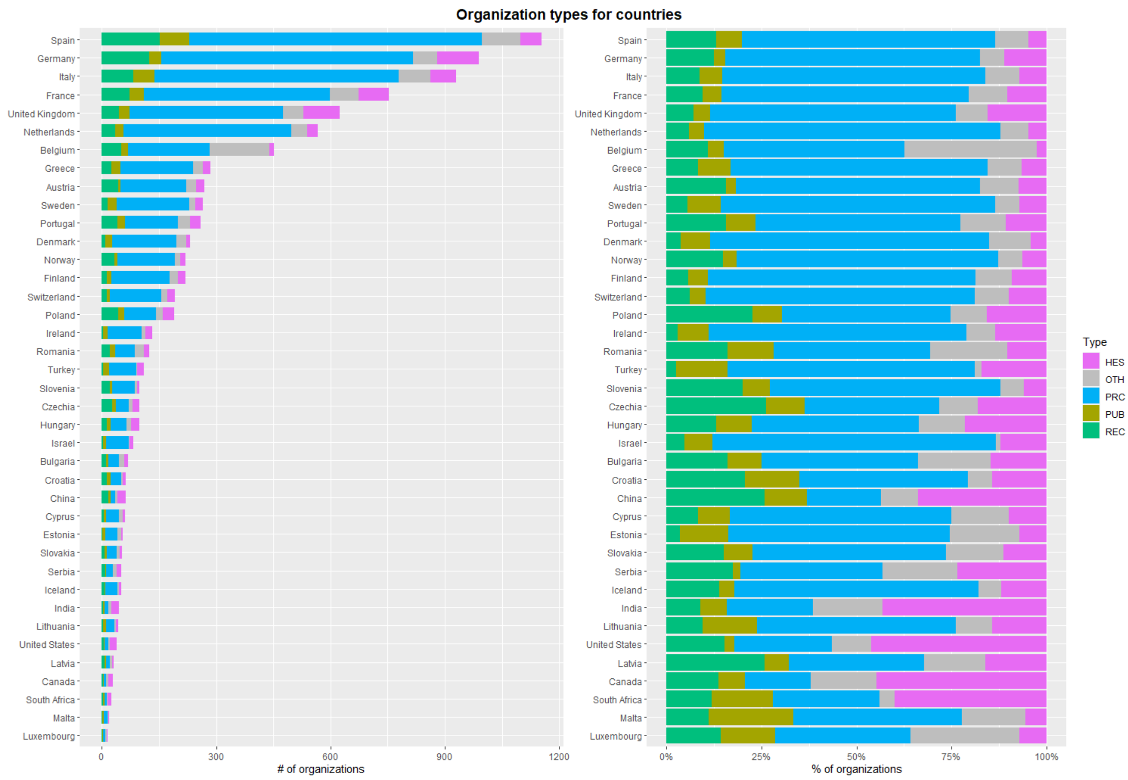


Figure 3.14: Distribution of organisation types

3.4.2 Further preliminary Considerations

Visualisation algorithms, per definition, pursue the central objective of revealing the structure inherent in the data set. In general, it must be noticed that every visualisation is a falsification since it is always the projection of a multidimensional reality into a 2- or 3-dimensional visualisation (Pfeffer, 2010). In order to minimise this distortion of the projection, various layout algorithms will be described during the analysis; however, every following visualisation needs to be observed with caution. Light was already shed on social network analysis as a descriptive method for promoting knowledge exchange in innovation processes that examine network actors' positions, structures, and connections. Interpretive, thus mainly qualitative approaches, focus on these aspects of social reality. Their defining feature lies in understanding meaning while also aiming to reconstruct it systematically (Hollstein, 2011). Qualitative, descriptive studies mainly explore new or unexplored networks, while the underlying understanding and presentation for practical use do not always remain purely descriptive (Stegbauer & Häußling, 2010). These works create the foundation for quantitative, hypothesis-testing forms of investigation. Exploratory social network analysis is thus followed by quantitative designs (Hollstein, 2011).

In this study, affiliation data builds the foundation for analysis. Consisting of two sets of binary relationships between members of two sets of items, affiliation networks have some specificities that need to be addressed (Borgatti & Halgin, 2011). The two sets of items here are organisations and projects; the binary relation that connects them is the "participation" in a funded project. It is to be kept in mind that transforming two-mode bipartite data into one-mode creates some challenges for interpreting the results. A direct tie in a derived one-mode network is easy to interpret: it indicates that two organisations are participating in joint projects. The absence of a direct tie implies that two organisations do not share a project (de Nooy et al., 2018). However, the interpretation of subgroups consisting of three or more nodes is far more complicated in derived one-mode networks (de Nooy et al., 2018), which must be kept in mind.

The process of the explorative analysis for social networks follows the initial structure of the framework depicted in Fig. 3.3 and is furthermore based roughly on earlier examinations (Cherven, 2015; Heller-Schuh et al., 2011; Holladay et al., 2017; Klärner et al., 2020; Liu et al., 2019; Nunes & Abreu, 2020; Prem Sankar et al., 2015; Protogerou et al., 2010b; Provan et al., 2005; Stegbauer, 2008; Stegbauer & Häußling, 2010; Toral et al., 2011; Wanzenböck, Neuländtner, et al., 2020), combined under the context of bioeconomy and the unique features of the dataset. Initially, the whole network's measures, metrics, statistics, and parameters get descriptively reviewed. Afterwards, substructures like clusters, components, subgroups, and cliques are explored before analysis for the node level – actors – and thus, centralisation measures are carried out. Then, the network's unique features are examined, and light is shed on gatekeepers, the robustness of the network, and its small world nature. Lastly, the network's dynamic over Horizon 2020's runtime is analysed. If not declared otherwise, all calculations are done on the complete network and include all projects that ran from 2014 – 2021. As primary tools, the packages "sna" (Butts, 2008b),"network" (Butts, 2008a), "igraph" (Csárdi G. & Nepusz T., 2006), and "statnet" (Handcock et al., 2008) for R were used, while for the visualisation and further data-exploration, Gephi was found a powerful tool.

3.4.3 Descriptive Statistics of the Network

Table 3.10 depicts some general, descriptive characteristics and properties of the complete network that can be derived without visual inspection. As the network contains several organisations that only ever received funding on their own, without being part of a project with more than one participant, the descriptives include "self-loops", edges in which the source and target are the same organisation, and counting as an edge towards the total amount.

	H2020	**Bioeconomy**
Organisations (= nodes)	34 390	9 432
Projects	32 454	3 054
Edges	1 096 453	175 448
Avg. degree	63.77	37.21
Median degree	17	19
Min. degree	1	1
Max. degree	16 134	2 508
Std. dev. degree	281	85.27
Network density	0.0018	0.002
Network diameter	7	6
Avg. path length	2.78	2.77
Avg. clustering coefficient	0.127	0.197

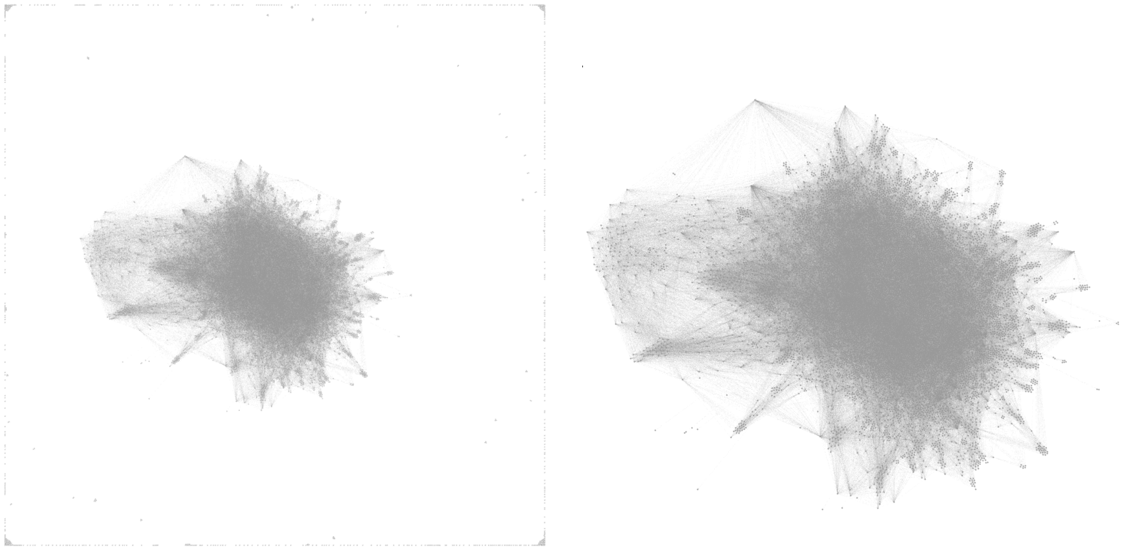
Table 3.10: Descriptive Statistics for the H2020 bioeconomy network

Whenever calculations on the network were carried out, these loops were taken into account. When looking at the broad degree range (1 – 2 508), the low density, and the average clustering coefficient, some questions also arise. First of all, a degree 1 can imply that an organisation is connected either to precisely one other organisation or to itself due to the loops mentioned earlier. As said, these loops are taken into consideration whenever possible. Furthermore, due to the network's one-mode structure, a degree of 1 is also possible if an organisation is the only organisation in multiple projects. Therefore, an edge only resembles that connected nodes participated in a project, and degree is to be seen as a measure of activity. This is, again, due to the transformation of two-mode into one-mode data, as described in Section 3.2.3. Therefore, out of the 3 054 projects, only 1 505 were worked on by more than one participant, picturing a fractured network. In comparison, the maximum degree of 2 508, taken by "Fraunhofer Gesellschaft zur Förderung der angewandten Forschung", stands out on the other end spectrum. It is Europe's largest application-oriented research organisation and plays a vital role in scientific and technological policy. It is also believed that it may represent smaller sub-institutions and has such high participation because it functions as a distributor for EU funding for its various research facilities, institutions, and centres.

After filtering out all organisations that were never connected to other actors, 8 820 organisations remain. Due to its nature as an affiliation/participation network, its low density comes as no surprise. Density – the proportion of potential links that have been observed (Protogerou et al., 2010b) – is a good indicator of the connectedness of a network's members. Here, members are only ever connected if they participate in the same project, which results in an expected low connectedness. However, the organisations' social distance can also be measured by the size of the giant component and geodesic distance (Protogerou et al., 2010b). The giant component, a maximal subset of organisations that can "reach" one another through n-paths but have no connections outside, covers slightly less than the above stated 8 820, namely 8 630 organisations (91.50%), and nearly all, 174 538 (99.48%) of the edges. While the network is quite extensive, which a diameter of 6 suggests, it is still more interconnected than anticipated. Therefore, the organisations participating in EU-funded projects are, directly or indirectly, tightly interconnected by their collaborations (Protogerou et al., 2010b), underlined by an average path length of 2.77. However, the large number of projects focusing on single organisations instead of collaboration remains to be discussed further.

Visualising the network for the following steps is beneficial to receive immediate visual feedback. Initially, the network is tough to distinguish without any layout algorithm applied due to its vast number of edges. In R, plotting a readable graph is nearly impossible; luckily, Gephi includes various algorithms to reposition nodes in the graph to improve its readability and general aesthetics. The ForceAtlas2 algorithm is a comprehensive solution and functions as a starting point. ForceAtlas2, a force-directed layout, simulates a physical system to spatialise the network. Nodes thereby repulse each other, and edges attract nodes like springs. These forces work until a balanced state is achieved (Jacomy et al., 2014). The square around Fig. 3.15a depicts the organisations not connected to the entire network. Filtering them out, Fig. 3.15b, the giant component, remains. Immediately, the dense inner part of the network and various clustered structures become apparent. The latter differ in size and the number of connected nodes. This filtered network (n = 8 630) now forms the basis for subsequent examinations.

With the giant component's help, the number of connected components is 1, meaning that the network depicted in Fig. 3.15b is fully connected. Next, the substructures of the network will be looked at. In Fig. 3.15b, early hints of clustering are visible. The average clustering coefficient calculates the number of closed triads relative to the potential number available in the network, ranging from 0 to 1 and emphasizing local cliques (Cherven, 2015), with values closer to 1 hinting at closer relationships (Holladay et al., 2017). H2020s bioeconomy network has an average clustering coefficient of 0.197,



(a) Network after application of ForceAtlas2 (b) Giant component of the network

Figure 3.15: Network visualisations

indicating relatively low transitivity. To further investigate, modularity was calculated, which places nodes into an aggregated cluster based on shared characteristics (Fig. 3.16): the modularity of 0.51 described a total of 21 communities.

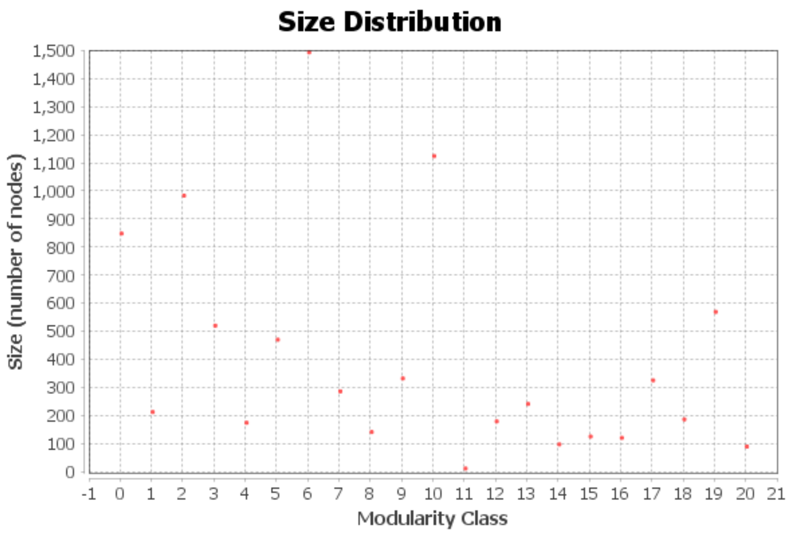


Figure 3.16: Network modularity

Nodes were coloured in the visualisation according to their modularity class (Fig. 3.17). Predominantly blue (Modularity class 6), orange (10), green (2), pink (0), and brown (19) stand out. These five classes consist of 5 510 nodes, thus 58.42% of the complete network, indicating greater relevance than the other classes. The visual impression supports this statement and will be further tackled in the subsequent discussion focusing on the structural parameters of the network. Also noticeable are some key nodes having large degrees and seemingly function as distributors. The roles these actors play are determined

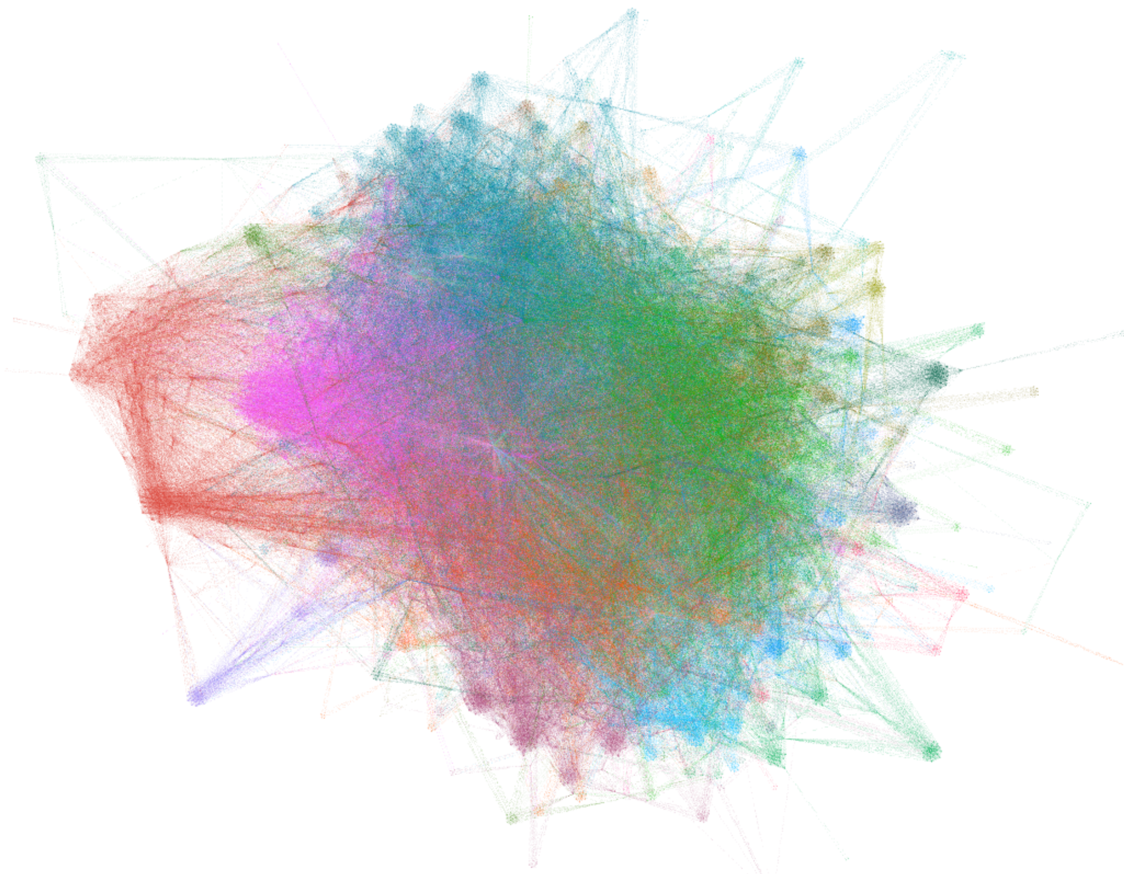


Figure 3.17: Modularity classes

by analysing and inspecting centrality measures. The degree distribution yields an initial overview of the network's spread (Fig. 3.18). While there are single nodes at large values over 1 000, most nodes fall into categories ranging from 1 to 39, with almost all of them in 10 – 29 (Table 3.11).

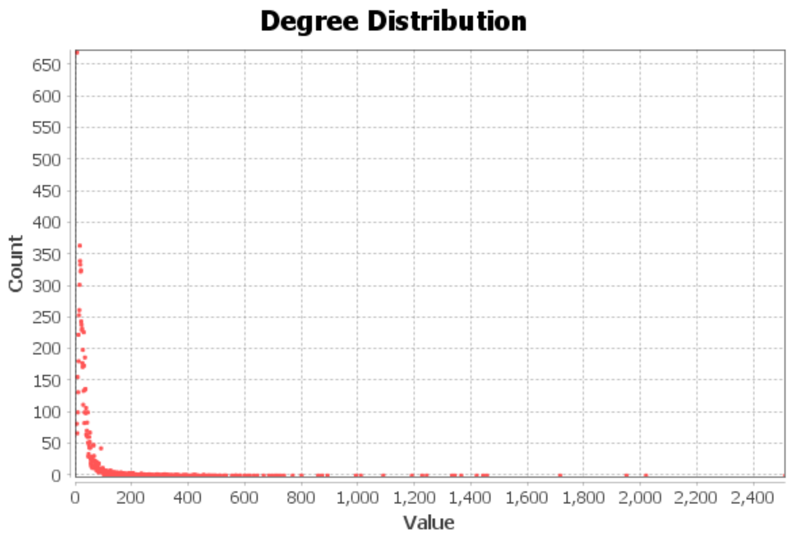


Figure 3.18: Degree distribution for the network

node degree	Organisations	% of complete network
self-loop	612	6.49
1 – 4	367	3.90
5 – 9	895	9.49
10 – 19	2 973	31.52
20 – 29	1 622	17.18
30 – 39	1 021	10.82
40 – 49	545	5.78
50 – 99	830	8.80
100 – 199	342	3.63
200 – 299	98	1.04
300 – 499	83	0.88
500 – 999	29	0.31
1 000 – 1 999	13	0.14
> 2 000	2	0.02
	9 432	100

Table 3.11: Exemplified structure of the final dataset “edges”

Nearly a third of all organisations in the H2020 bioeconomy network have a degree of 10 – 19, meaning they are connected by participation in projects to 10 – 19 other organisations. 612 projects only include a single organisation. After a node degree larger than 19, the amount of organisations drop significantly, resulting in the majority (79.40%) of organisations being linked to 39 or fewer; thus, the network's fragmentation is acknowledged. Some actors also seem to occupy a central position for the general connectedness when considering their individual degrees. For example, looking at Fig. 3.19, in which the node size is calculated by the degree, extensive involvement in relations with other actors is suspected for actors with a high degree, thus allowing for more knowledge generation and spread. Usually, these central actors have greater access and control over resources as well as knowledge and are likely to be associated with innovative activity (Protogerou et al., 2010b). Fig. 3.19 and Table 3.12 illustrate nodes with the most considerable degree.

Again, the focus on western and southern Europe can be seen, and the fact that especially research organisations form the actors with the highest degrees. The expectation of a particular knowledge-intensive actorial structure for the central players of the network is intensified.

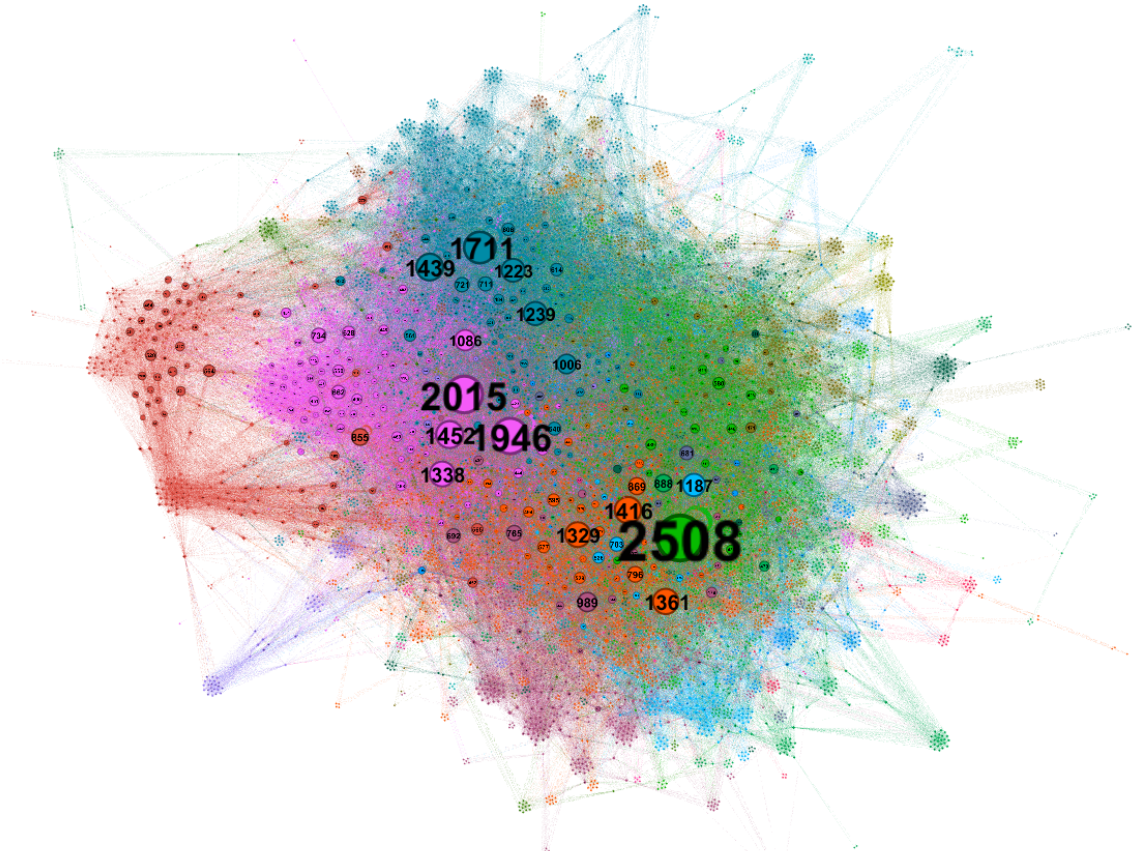


Figure 3.19: Nodes highlighted by their degree

node	country	category	degree
Fraunhofer	Germany	Research	2 508
Gesellschaft zur Förderung der angewandten Forschung			
CSIC	Spain	Research	2 015
Consejo Superior de Investigaciones Científicas			
CNR	Italy	Research	1 946
Consiglio Nazionale delle Ricerche			
Stichting Wageningen Research	Netherlands	Research	1 711
Danmarks Tekniske Universitet	Denmark	University	1 452
INRAE	France	Research	1 439
Institut national de recherche pour l'agriculture, l'alimentation et l'environnement			
VTT	Finland	Research	1 416
Technical Research Center of Finland			
Tecnalia Research and Innovation	Spain	Research	1 361
CNRS	France	Research	1 338
Centre national de la recherche scientifique			
CEA	France	Research	1 329
Commissariat à l'énergie atomique et aux énergies alternatives			

Table 3.12: Top 10 nodes by degree

3.4.4 Measuring Centrality

Connection and degree data are used to measure centrality, doubling down on the importance and role of specific nodes in and for the network (Heller-Schuh et al., 2011; Wanzenböck, Neuländtner, et al., 2020; Wanzenböck et al., 2014). Concepts of the centrality of actors assume that the actor, who is involved in many relationships in the network, is "visible" in the network and is thus used to quantify the degree of interconnectedness of nodes (Prem Sankar et al., 2015). This is, again, based on the assumption that such prominent actors have access to network resources, control, and information. Centrality concepts only presuppose undirected relationships and have initially been developed with them in mind (Jansen, 2003). There are various measures; however, degree, closeness, betweenness, and eigenvector, which were already described shortly in section 3.2.4, are the most prominent ones. While each quantifies how close each node is to the (imaginary) central position of the network, the concept of how they are central is differently defined for each measure (Prem Sankar et al., 2015). Table 3.12 and Fig. 3.19 above already depict the simplest, *degree centrality*, which measures the number of ties a single actor has with other actors. *Eigenvector centrality* is a more sophisticated version of degree centrality since it addresses the quality of the connections – connections to actors, who are also well connected and thus more influential (Protogerou et al., 2010b). *Closeness* takes each node's distance to every other node into account, with a greater value representing shorter distances and thus points towards actors who can reach other nodes faster, while *betweenness* measures the number of times an actor is located on the path between two actors, thus functions as a briding through which information flows (Jansen, 2003; Prem Sankar et al., 2015; Protogerou et al., 2010a, 2010b). The above indices were calculated for all nodes to identify the central actors in the bioeconomy network, resulting in Tables 3.13, 3.14, and 3.15. The scale for all indices ranges was normalised from $0 - 1$, with 1 indicating the highest centrality level. In order to circumvent distortions, the calculations excluded not-connected nodes, and thus were done again on the giant component.

node	**country**	**category**	**eigenvector**
CSIC	Spain	Research Organisation	**1**
Fraunhofer	Germany	Research Organisation	**0.8499**
CNR	Italy	Research Organisation	**0.8426**
CNRS	France	Research Organisation	**0.7335**
Danmarks Tekniske Universitet	Denmark	University	**0.7145**
Stichting Wageningen Research	Netherlands	Research Organisation	**0.7020**
INRAE	France	Research Organisation	**0.6293**
VTT	Finland	Research Organisation	**0.5820**
Wageningen University	Netherlands	University	**0.5484**
CEA	France	Research Organisation	**0.5431**

Table 3.13: Top 10 nodes by eigenvector centrality

node	country	category	closeness
Fraunhofer	Germany	Research Organisation	**0.5479**
CNR	Italy	Research Organisation	**0.5360**
CSIC	Spain	Research Organisation	**0.5296**
Stichting Wageningen Research	Netherlands	Research Organisation	**0.5238**
VTT	Finland	Research Organisation	**0.5188**
Tecnalia Research and Innovation	Spain	Research Organisation	**0.5185**
Danmarks Tekniske Universitet	Denmark	University	**0.5182**
CEA	France	Research Organisation	**0.5141**
INRAE	France	Research Organisation	**0.5128**
Technical University of Athens	Greece	University	**0.5126**

Table 3.14: Top 10 nodes by closeness centrality

node	country	category	betweeness
Fraunhofer	Germany	Research Organisation	**0.1293**
CNR	Italy	Research Organisation	**0.0696**
CSIC	Spain	Research Organisation	**0.0591**
Stichting Wageningen Research	Netherlands	Research Organisation	**0.0520**
Tecnalia Research and Innovation	Spain	Research Organisation	**0.0425**
VTT	Finland	Research Organisation	**0.0422**
Technical University of Athens	Greece	University	**0.0419**
CEA	France	Research Organisation	**0.0393**
Danmarks Tekniske Universitet	Denmark	University	**0.0352**
Universita di Bologna	Italy	University	**0.0340**

Table 3.15: Top 10 nodes by betweeness centrality

With the help of a synthetic index based on the sum of the joint rankings of organisations in terms of the four centrality measurements, a ranking of the ten most central actors across all centrality measures in the network was performed (Table 3.16).

rank	node	country	category	index
1	***Fraunhofer***	Germany	Research Organisation	**5**
2	***CNR***	Italy	Research Organisation	**9**
3	***CSIC***	Spain	Research Organisation	**10**
4	***Stichting Wageningen Research***	Netherlands	Research Organisation	**18**
5	***Danmarks Tekniske Universitet***	Denmark	University	**26**
6	***VTT***	Finland	Research Organisation	**26**
7	***Tecnalia Research and Innovation***	Spain	Research Organisation	**33**
8	***CNRS***	France	Research Organisation	**35**
9	***INRAE***	France	Research Organisation	**35**
9	***CEA***	France	Research Organisation	**36**

Table 3.16: Top 10 central nodes in the bioeconomy network

Spearman's rank correlation coefficient was calculated to validate the synthetic ranking used in Table 3.16 to determine the relationship between the centrality measures and if combining them is feasible (Table 3.17), resulting in a strong, positive monotonic correlation between them, with a nearly perfect monotonic correlation between closeness and eigenvector centrality.

	degree c.	**closeness c.**	**betweeness c.**	**eigenvector**
degree c.	1	0.748***	0.674***	0.823***
closeness c.		1	0.603***	0.957***
betweeness c.			1	0.615***
eigenvector				1

*** correlation is significant at 0.01 level

Table 3.17: Rank correlation (Spearman rho) between centrality indices

Finally, Fig. 3.20 visualises the location of the ten central actors in the network, with node sizes again displaying degree centrality and their respective labels, while ForceAtlas 2 was used as a layout algorithm again.

Fig. 3.20 and Table 3.16 further underline the impression that research organisations are located dominantly in central positions in the network. As discussed in Section 3.2.4, actors can be seen as central because they are embedded in a closely-knit group of associates or linked to other well-connected actors. At the same time, organisations in brokerage positions are central because they bridge societies that would otherwise be disconnected (Radil & Walther, 2019), thereby fulfilling a much sought-after trait for knowledge transition in a network. Understanding how an actor is embedded in its neighbourhood helps detect power, influence, and dependency effects structures. Therefore, the algorithm was tasked to dissuade hubs instead of centring them to help visualise actors on brokerage positions (Fig. 3.21).

Looking at Fig. 3.21, the graph immediately appears sparser. Most noticeably, six out of the ten most central actors hold evident gatekeeper characteristics; especially CEA, VTT, and Tecnalia are put in a more peripheral position than before, while Fraunhofer, Wageningen, and INRAE hold their relative positions. In these positions, they help link more distant actors to the centre of the network, thus playing a vital role in spreading more distant knowledge. CSIC, DTU, CNR, and CNRS are keeping their position as highly connected, central nodes, emphasising their power to influence the network. Kleinberg (1999) proposed a valuable model to examine further knowledge dynamics: the Hyperlink-Induced Topic Search (HITS). It calculates two separate values for each node: Authority, measuring how valuable information stored by a given node is, and Hub, an indicator of the links' quality and from a node (Cherven, 2015). To visualise this, node size was calculated based on both authority and hub, and the ForceAtlas2 algorithm was applied once again (Fig. 3.22). Interestingly, the top 10 central actors are slightly reshuffled in the top 10 of the HITS calculation, with Wageningen University taking the place of Tecnalia, which dropped to rank 17 (Table 3.18). Moreover, a spatially exact distribution becomes

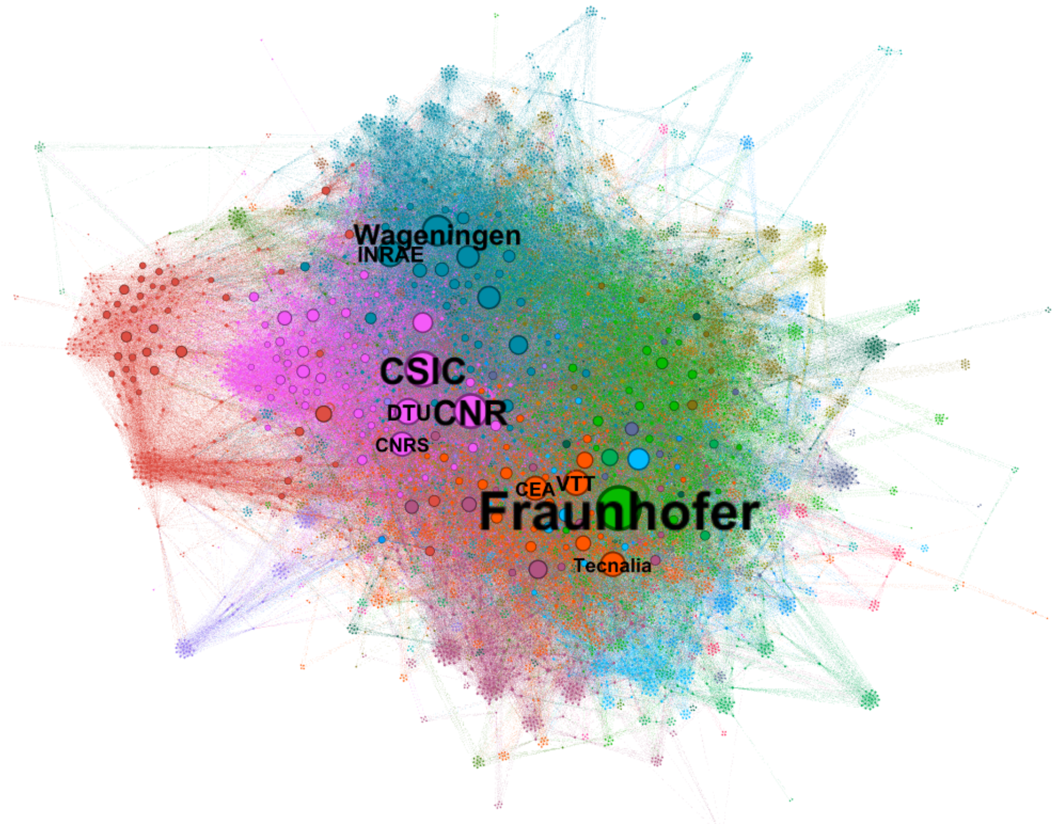


Figure 3.20: Central actors in the H2020 bioeconomy network

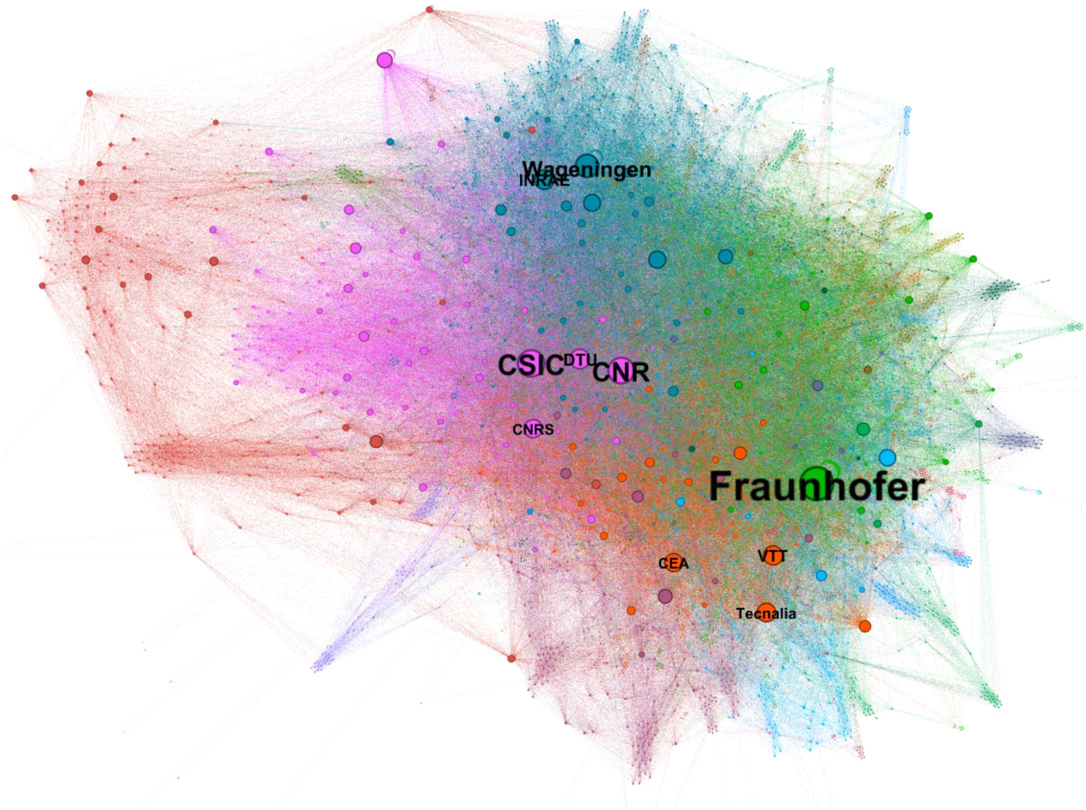


Figure 3.21: Brokerage and embeddedness of actors

apparent, with the purple modularity class mainly occupying the centre, sprinkled with blue from the north and orange and green from the east, while terracotta spreads to the west and light blue as well as berry to the south-east.

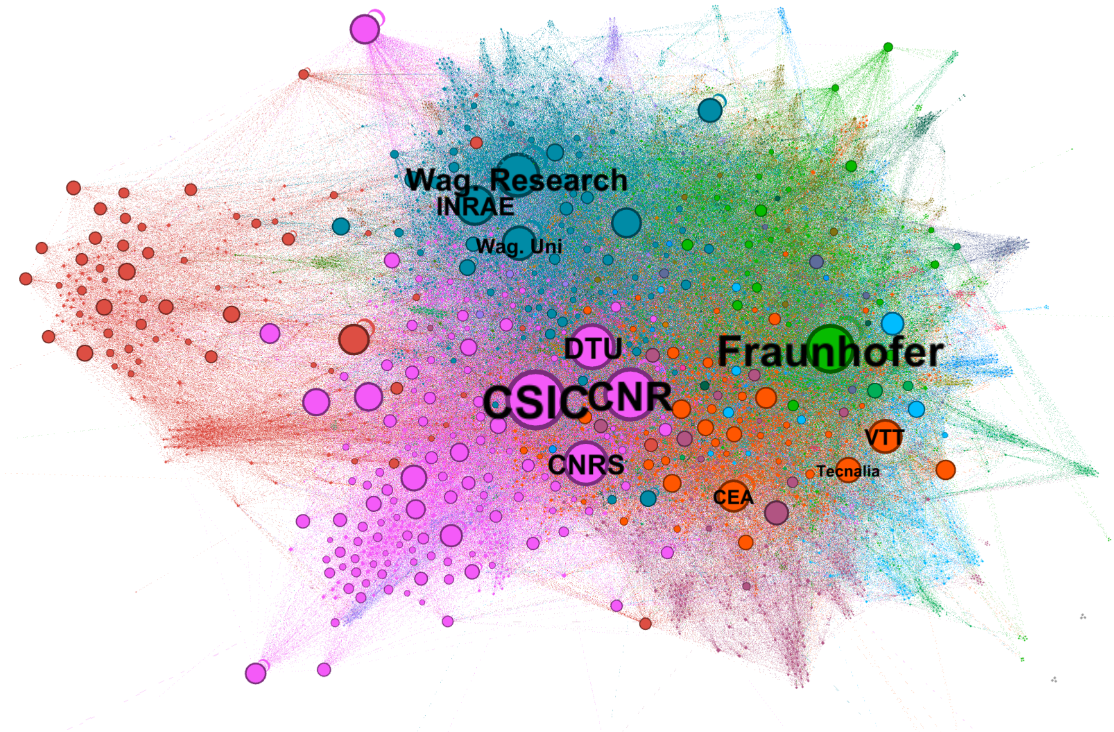


Figure 3.22: HITS-based network

node	country	category	authority
CSIC	Spain	Research Organisation	**0.2467**
CNR	Italy	Research Organisation	**0.2189**
Fraunhofer	Germany	Research Organisation	**0.1996**
Danmarks Tekniske Universitet	Denmark	University	**0.1890**
CNRS	France	Research Organisation	**0.1845**
Stichting Wageningen Research	Netherlands	Research Organisation	**0.1819**
INRAE	France	Research Organisation	**0.1631**
Wageningen University	Netherlands	University	**0.1407**
VTT	Finland	Research Organisation	**0.1387**
CEA	France	Research Organisation	**0.1306**

Table 3.18: Top 10 HITS by authority

Calculating the network's k-core and subsequent filtering and recalculating the organisations' positions makes this spatial distribution clearer. K-cores in undirected graphs are connected, maximal-induced subgraphs with a minimum degree greater than or equal to k. K-cores are not necessarily cohesive subsets, but they identify areas of the graph containing clique like-structures (Leech et al., 2014). Thus, they can be an excellent tool to filter noise out of the network while highlighting related organisations and their relative position and spreading capabilities and power positions. Applying a k of 60, the following network depiction was achieved 3.23.

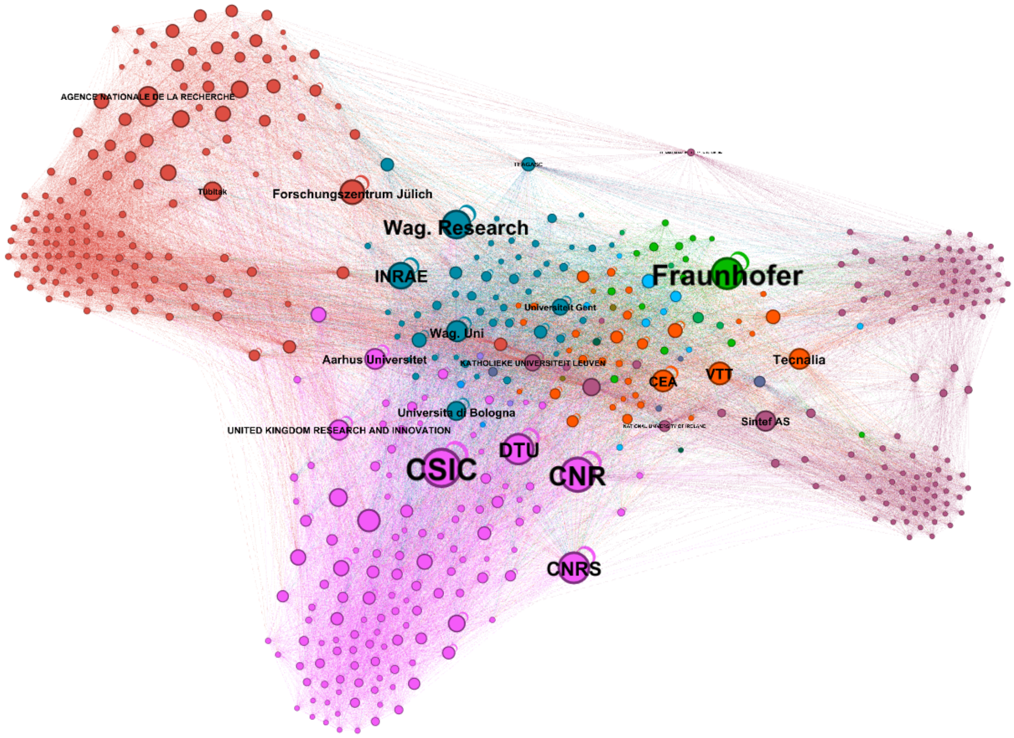


Figure 3.23: K-core of the filtered network (k=60)

The spatial, functional, and categorical distribution is now more evident, with Forschungszentrum Jülich, CNRS, Fraunhofer, Wageningen Research, and INRAE holding bridging positions to the outer parts of the network. At the same time, an eastern and western subgroup with the same modularity class is noticeable. CSIC, DTU, CNR connect the southern wing. Wageningen University, Universita di Bologna and Universiteit Gent can be considered the central core, with CEA, VTT, and Tecnalia holding bridging positions to the eastern subgroup.

At the beginning of the analysis, a dense and well-connected network was assumed. After analysing various centrality indices, the question of the robustness of the network arises. The robustness of the network can be checked by excluding the most central actors. The synthetic centrality index and the HITS calculation were used to eradicate the eleven central nodes from the network (filtered network) before the result was compared to the measures of the complete network (Table 3.19).

Table 3.19 points out a lack of robustness of the complete network. The average degree and the average path length drop without the eleven most central nodes. Also, the filtered network is less clustered. Therefore, the filtered, central actors also fulfil an essential

	filtered network	complete network
nodes	9 421	9 432
edges	160 877	175 448
avg. degree	34.16	37.21
network diameter	6	6
graph density	0.00179	0.00195
avg. path length	2.90	2.77
avg. clustering coefficient	0.24	0.197

Table 3.19: Robustness comparison

connecting role for the network, stitching together nodes that would otherwise be left unconnected. To confirm the performance of the initial network regarding transmissiveness, the small-world property can be calculated. This is done using the average path length L and the average clustering coefficient C and comparing them with the values of a randomly generated network with roughly the same number of nodes and edges. The random graph was calculated using the Erdos-Renyi model (Erdős & Rényi, 1964) with the help of the R package igraph.

L_{actual}	2.77
L_{random}	2.86
C_{actual}	0.19
C_{random}	0.004

Table 3.20: Small-world property of the network

Table 3.20 shows:

$$\lambda \approx 1 \qquad \text{for} \quad \lambda = \frac{L_{actual}}{L_{random}}$$

and

$$\gamma > 1 \qquad \text{for} \quad \gamma = \frac{C_{actual}}{C_{random}}$$

The conditions a small-world network needs to fulfil are as follows:

$$C_{actual} \gg C_{random} \quad \text{and} \quad L_{actual} \approx L_{random}$$

Therefore, the small-world property can be assumed valid for the European bioeconomy network. Furthermore, the higher clustering coefficient indicates that the small-world network has some spatial organisation. On the other hand, random networks lack structure and have a lower clustering coefficient. Also, small-world networks are seen as more efficient in communication than spatial networks and thus have a smaller average path length (Ansmann & Lehnertz, 2011).

As the last step, the modularised network can be mapped using a mercatorial projection with the geocoded latitudes and longitudes, illustrating the Horizon 2020 bioeconomy network (Fig. 3.24 and 3.25). As a ranking operator for node size, authority is used, while the modularity classes of the nodes assign the colours.

Figure 3.24: European H2020 bioeconomy network

Thanks to the many organisations present, border structures (Fig. 3.24) are immediately visible even without a background map. Attention is drawn toward western Europe, again (Fig. 3.25). A high degree of clustering in Benelux countries is visible, and the importance of organisations in modularity class pink holding key positions for connectivity to more peripheral regions can be noted. Interestingly, compared to the pink class, the dark blue one is more clustered in locations where it occurs, while Fraunhofer dominates green, without other class organisations visible.

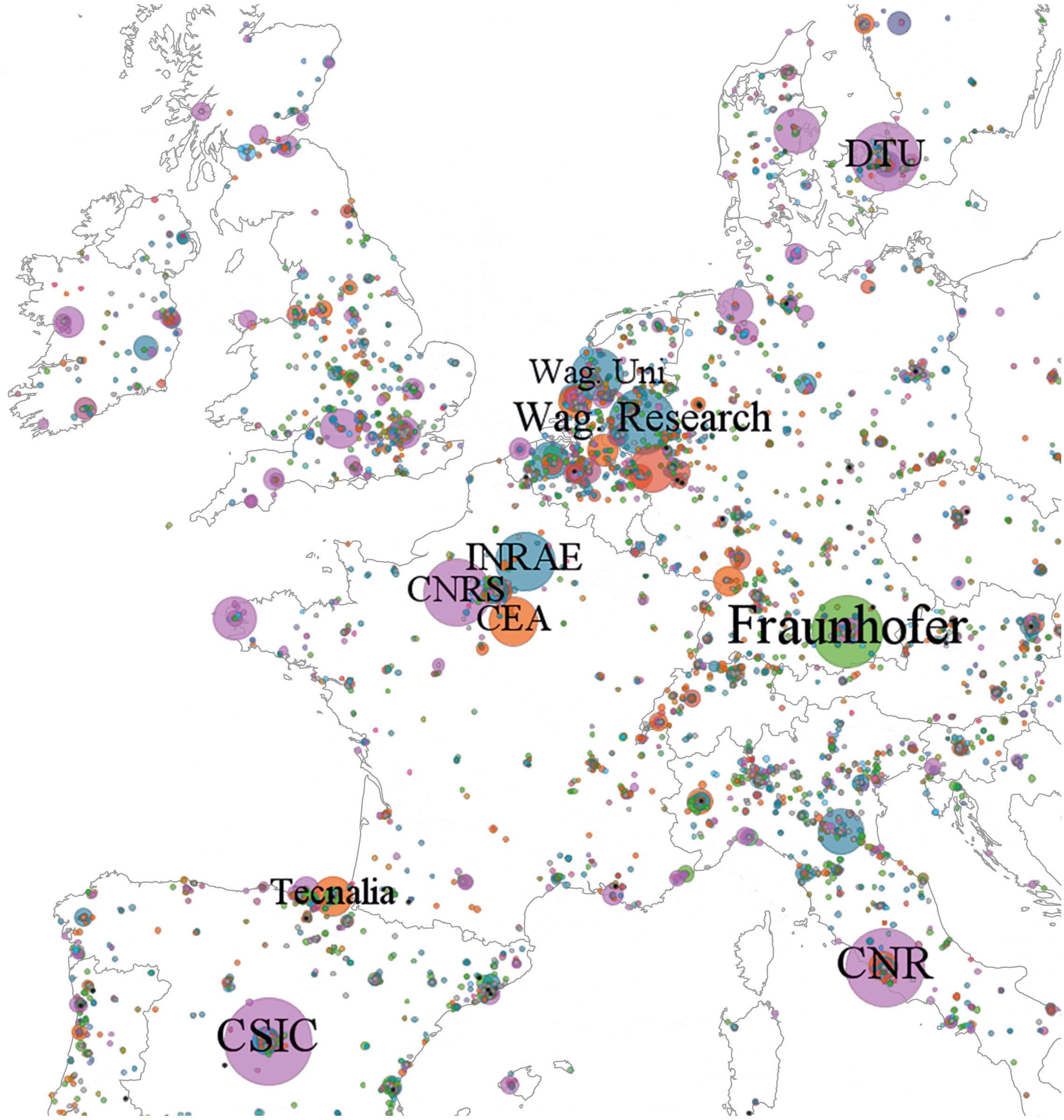


Figure 3.25: European H2020 bioeconomy network (zoomed)

3.4.5 Network Dynamics

All calculations until now were done for the complete network over the entire running time of the framework programme H2020. The analysis was carried out based on the assumption that links once established stay in place over the years. To review the dynamic evolution of the network, it was sliced into snapshots with a yearly frequency to gather information on how it and its actors changed over the years, how it evolved, and which implications these results may yield. These snapshots were created by identifying all projects active on the 31st December of every year. Data preparation was done in R by first transforming an interval variable (duration) from each project's startDate and endDate values and filtering for the snapshot date within every project's duration column. By that, a subnetwork was built for each of the years 2014 – 2020. Table 3.21 shows network statistics for each year, while Fig. 3.26 visualises the essential aspects of the table.

	2014	2015	2016	2017	2018	2019	2020
Organisations	98	1 937	3 420	4 709	5 391	5 966	6 483
Projects	24	383	712	985	1 155	1 256	1 351
Edges	709	22 320	48 701	74 276	89 467	107 730	121 074
Avg. degree	14.47	23	28.48	31.55	33.19	36.11	37.35
Median degree	12	15	17	18	19	20	20
Min. degree	1	1	1	1	1	1	1
Max. degree	34	345	721	1 126	1 200	1 337	1 537
Std. dev. degree	10.61	27.79	42.58	54.20	60.20	65.98	70.40
Network density	0.1462	0.0119	0.0083	0.0067	0.0062	0.0061	0.0058
Network diameter	2	6	6	6	7	5	5
Avg. path length	1.30	2.96	2.87	2.83	2.80	2.76	2.75
Avg. clustering coefficient	0.98	0.50	0.36	0.28	0.26	0.26	0.24
Efficiency	0.3152	0.9871	0.9916	0.9935	0.9941	0.9942	0.9946
Connectedness	0.2089	0.8522	0.8909	0.9258	0.9300	0.9270	0.9515

Table 3.21: Network descriptives for yearly subnetworks

2014 was left out on purpose since it marks the initiation of the framework programme. The increase in size per year is immediately noticeable. The number of projects and organisations increases annually, with the most considerable increment in the years after H2020s initiation in 2014. Therefore, all degree parameters also experience linear growth. While the network grows in size, it is less dense and clustered. At the same time, its efficiency, connectedness, and average path length decrease from year to year. Butts (2008b) suggests connectedness and efficiency shed light on a network's hierarchical structures on a scale from 0 to 1, with values closer to 1 resembling more weakly connected networks. Thus, while experiencing significant growth over H2020s runtime, the network loses connectedness. This is not a big surprise and is somewhat expected for project-based networks this large of size since accumulation effects take place over the years and projects differ in runtime.

Further importance lies in observing the central actors over the years to identify changes in their position. Only data from 2015, 2017, and 2020 were compared. Since the medium duration of projects is three years, 2015 was regarded as a good starting point, as the snapshot would include projects started since the initiation, while 2017 forms the midway point and 2020 provides insights into the late stages of H2020s runtime. The subnetworks for these years were imported into Gephi, filtered by their biggest component, and visualised with the ForceAtlas 2 algorithm while hubs were dissuaded. Node sizes are calculated by degree, and the colour scale resembles the authority ranking of each node from white to dark red; Figures 3.27a, 3.27b, and 3.27c depict these subnetworks.

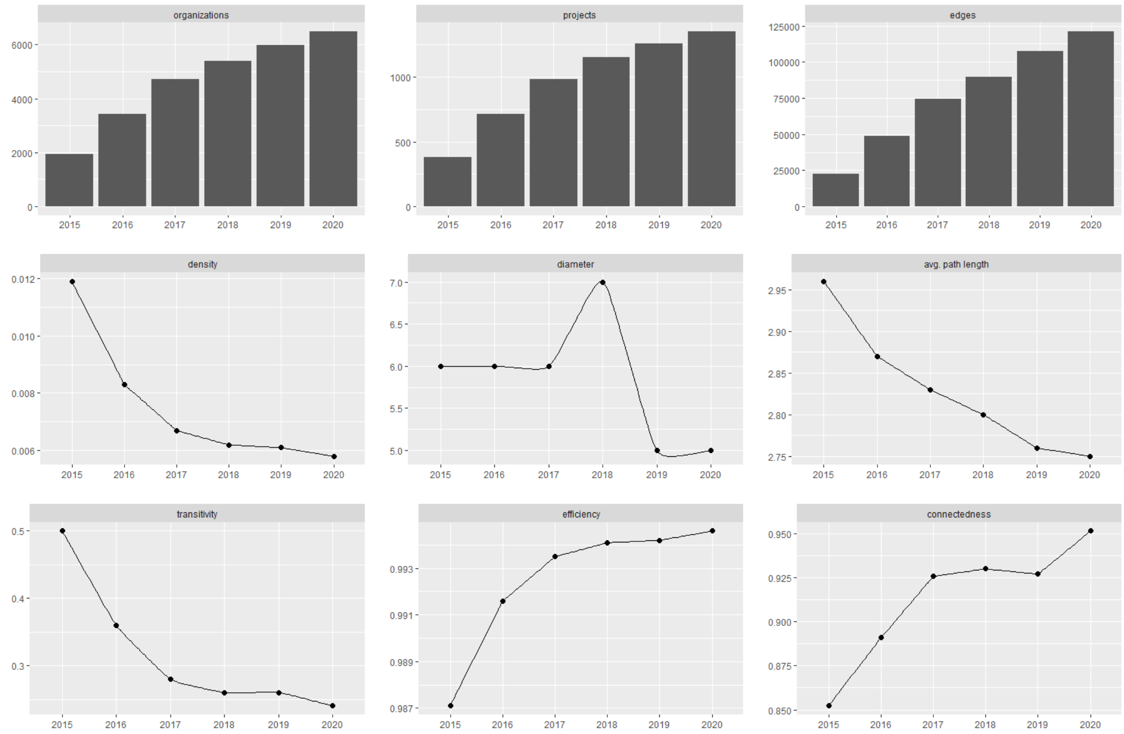


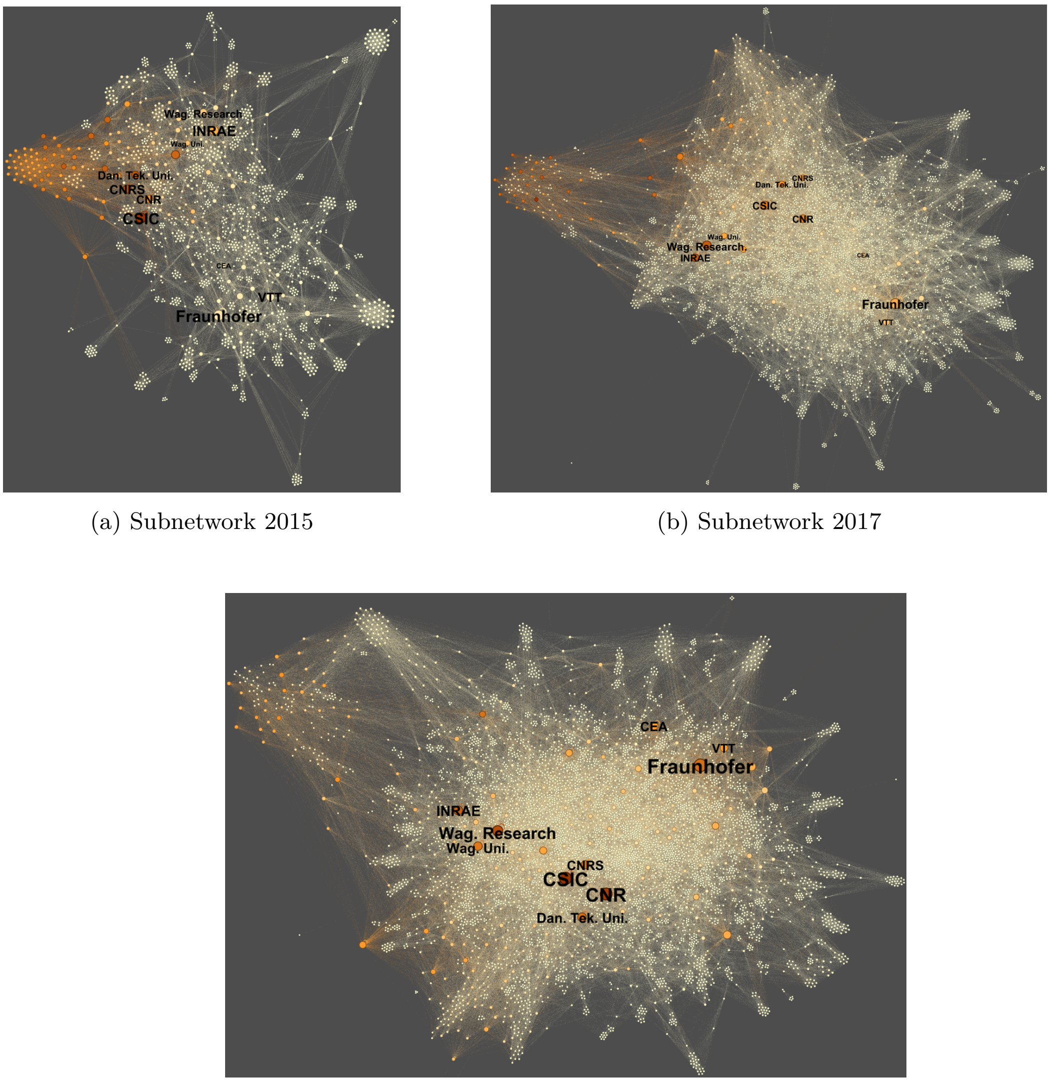
Figure 3.26: Network descriptives for yearly subnetworks

Examining the three visualisations, some positional changes become apparent. First, the ten most central actors (see Table 18) form three subgroups, which spatial positions have remained the same over the years:

- G1: INRAE, Wageningen Research, Wageningen University
- G2: CNRS, CSIC, CNR, Danmarks Tekniske Universitet
- G3: Fraunhofer, VTT, CEA

The distance between the organisations inside these groups also persists with slight alterations. Attention can also be drawn to the groups' positions in each subnetwork. While all groups shift places over the years, the most significant change can be observed in G2's position. Initially, in 2015, G2 held a close connection to the strongly connected western subgroup of the network, mainly consisting of research organisations with, apparently, a strong bond already in place before H2020s initiation, which may explain their high authority scores and spatial proximity. In 2017, a disconnection of G2 from this subgroup can be noticed, with G2 moving towards the north and centre of the network, with their final position being the most central one in 2020. Their role of connecting the western subgroup to the rest of the network was taken over by G1 in 2017, which did not leave this position afterwards.

Interestingly, the western subgroup dissipates over the years, with organisations moving either inwards or along the outer rims of the network. Their authority and hub character



(a) Subnetwork 2015

(b) Subnetwork 2017

(c) Subnetwork 2020

Figure 3.27: Subnetwork visualisations (in years)

also weaken over the years. An explanation for this dissipation can be found in connecting the subgroups' organisations to a higher number of organisations that occupy more central positions. It may thus also give room for the impression that the network can include organisations with already tight bonds in place, which, if true, is an excellent achievement in itself. G3, at last, rallies its HITS index significantly over the years and ends in an essential connecting position in 2020, with all its members having a higher authority and hub character than they did in 2015 and now fulfilling important bridging characteristics. The subnetworks further underline the impression that the spread of knowledge in the network relies on central actors, which contain essential connectivity properties. However, the dynamic analysis also sheds light on the networks' ability to connect actors from highly connected subgroups to the more expansive network, thus dissolving bonds. Nevertheless, in contrast, bonds between central actors tend to stay in place, if not strengthen over the years, which manifests into an essential fact for the bioeconomy network: central actors and their connectedness to one another are of significant importance for the networks' performance but help lesser connected actors to benefit from their capabilities.

3.5 Discussion

The data collection and analysis offered various results for the European bioeconomy and its (dynamic) subnetworks. The filtered project data revealed an overrepresentation of project leaders in western European countries, which, combined with the observation that all of the project networks' most central actors are also located in western Europe, bolster the impression that bioeconomy projects running under Horizon 2020, and thereby the concept itself, are mainly managed and driven by large research organisations in Germany, France, Spain, Italy and the Benelux countries. This is underlined by the various descriptive, structural, and centralistic parameters (see Fig. 3.3, Analytical Framework) of the network and its actors.

First, the broad degree range, and thereby the discrepancy in project participation between a very active top group – organisations with a degree larger than 500 (44 organisations, 0.47% of the network) – and the less well-connected rest of the actors, can be mentioned. Many actors are very weakly connected with the network, primarily to a few other, mainly central, nodes. Most actors have a degree of up to 39, resulting in a sparse graph and a greater focus on more central actors. This top group of actors with a high average degree is well connected to the rest of the network, especially to other actors in this group, and consists almost exclusively of research organisations and, to a lesser extent, universities. More knowledge is not only brokered faster in this group than outside of it but, due to their prominent position, information stemming from this centre can reach the outskirts of the network faster on a shorter path (Bogner, 2019a; Giurca & Metz, 2018). Due to the spillover being enhanced in this way, the knowledge created and shared by this group can be believed to play a dominant role in what bioeconomy entails and how bioeconomy projects are conducted in Horizon 2020.

Due to the relatively high density of the network, its short average path length, and the occurrence of well-connected clusters, information can diffuse quickly (Wanzenböck et al., 2014). By calculating modularity, groups of densely connected communities were identified, in which, in turn, a certain level of trust can be assumed. This trust can lead to an even faster spread of knowledge (Medeiros et al., 2016) while also increasing the chance of subsequent collaboration and the occurrence of cliques – epistemic communities, which are also favourable for knowledge creation (J. Scott, 2011b).

The structural features of the network underline this argument about the influence of a central group of actors. Looking at the k-core of the network, its structural holes, hubs, and gatekeeper characteristics became even more evident. Certain bridging positions connecting the network's core to its periphery can be seen as a bottleneck for the flow of knowledge and thereby apply a particular filter to the information transferred through them (Heller-Schuh et al., 2011). In the Horizon 2020 network, at least in the k-core, the structural holes appear around another central group of actors. However, this central group does not consist of the well-connected subgroup of high-degree research organisations and universities; instead, the latter frequently occupy the connecting bridging positions to the outer parts. Due to their controlling position for the diffusion of knowledge inside the network, they also act as gatekeepers for this flow: Information that is spread through the network has to go through them, therefore, a particular influence on the composition of the transferred information can be assumed (Cassi et al., 2008). They play an important role in brokering knowledge by linking distant actors together and providing various information to many organisations in the network, thus also holding a significant social capital and trust in their relationships (Tsai & Ghoshal, 1998).

In a perfect network, actors in these positions would need to be as diverse as possible regarding their type in order for the information passing through to be influenced by not only one but many different knowledge bases (Wanzenböck et al., 2014; Wasserman & Faust, 2012). In the Horizon 2020 bioeconomy network, that is not the case. No organisations or public bodies (apart from state-funded research organisations) hold a central position or bridging/gatekeeper characteristics; they play a minor role in influencing the information flow inside the network. This is even more apparent when looking at the four calculated centrality parameters – while the ranks of the actors shift slightly between them, the top group of mainly research organisations does not. That means that these organisations have prominence, power, and collaboration experience and thus more direct access to new information (degree centrality), control the flow of information by acting as mediators and gatekeepers (betweenness), have the fastest access to new, high-level knowledge while also diffusing gathered knowledge more quickly (closeness) and are, lastly, also linked to other influential and dominant actors with a high degree, therefore clearly entailing a considerable authority and hub character for the network (eigenvector). Due to this central, dominant position, they are also tightly embedded in the network and could potentially have the most diverse linkages to other actors. Varied connections to different actor types are strongly associated with driving the creation of new knowledge and, therefore, innovation (Balland et al., 2013; Nieto & Santamaría, 2007) – but have to be regarded critical here. While the central group of actors is tightly embedded in the network, the preferred connections are not towards organisations and diverse actors but rather other research organisations and universities. While actors from the private sector are, at least numbers-wise, represented in the network, they are almost exclusively in non-influential positions. Furthermore, many calls for projects require the leading actor to include businesses in their project outline, which may lead to placeholder participation with little to no influence on the project itself or its contributions.

The dominance of research-oriented actors in a research-oriented network is not entirely surprising since these institutions already rely heavily on funding. That is, however, not always positively connotated. Relying solely on funding is directly connected with being pressured into applying for funding, which otherwise would not necessarily be the case – an unfavourable outcome, especially against the backdrop of the bioeconomy. Bioeconomy, as a concept, is already highly fuzzy; incorporating the need for scientific actors to broaden it further to receive much-needed and sought-after funding does not help with its most significant weakness of being non-tangible and still on a meta-scale. Furthermore, the relatively high number of private sector actors in the network but not in the projects is also more or less expected but must again be seen critical in the light of a network representing the bioeconomy. Bioeconomy, which implications and mindset depend on a broad spread throughout the private sector as well, but especially the low-tech sector, does not achieve its goal with a network centred nearly exclusively around research and academia and that – apparently – still clings to the concept of the KBBE.

Due to the asymmetric power relations inside the network, the central group appears in a locked-in state concerning the power and influence they hold, which may also result in a stark Matthew effect: success in obtaining funds directly enhances the ability to raise more money in the future (Protogerou et al., 2010b), which leads to a feedback loop, a self-reinforcing effect, and thereby the twofold problem of "rich getting richer" and "picking out winners" in the initiation stage of funding (Easley & Kleinberg, 2010). During the funding application, the EU promotes the process as being open-bid; however, picking out winners can never be completely ruled out and can be assumed in this case, especially when considering their dominance. Problematic network characteristics do not necessarily follow a core of strong, central actors; however, the network relies heavily on this core, which became apparent when analysing the troubling robustness at the latest. Degree, closeness, betweenness, eigenvector, and the HITS calculation underlined, with some variance, this effect. Undoubtedly, the network's clustering coefficient and average path length lead to the assumption that it holds small-world structures; however, these are primarily driven by the gatekeeping, brokering, and embedded positions the central organisations occupy. Also, the small-world property itself faces some problems and needs to be discussed. Smallworldness, as an indicating measure, must be seen critical. It seems to be a trait of many, if not all, empirical networks; therefore, testing for it may be seen as redundant (Ansmann & Lehnertz, 2011). Testing for it is also not robust to measurement errors (Bialonski et al., 2010), and thus the result should be taken with a grain of salt. It does not say how the mean shortest path scales with the network size since there can not be an utterly comparable network with a different number of nodes.

Nevertheless, of course, the diffusion of knowledge, thus information, inside the network can be considered fast and reliable, and a certain degree of innovativeness can be assumed; however, this impression is only superficial and reveals shortcomings on closer inspection. Due to the locked-in state of powerful actors, the most apparent implication is that no new knowledge might enter the network (Ter Wal & Boschma, 2009) since there is no renewal of structures, but the opposite happens with the described effects. Due to their power and influence, powerful actors might also dictate the narrative innovation-wise, and information has to flow through them to reach many other subgroups and components. They do, nonetheless, keep the network connected. Without them, the network would lose much of its well-connectedness, and thus the possibility of knowledge flow would be diminished. Furthermore, in light of the dynamic analysis results, the tie-formation for central actors seems to follow stark homophilic tendencies. Homophily describes a strong willingness of actors to form bonds with actors of similar characteristics, thus directly affecting the formation of clusters (Giurca & Metz, 2018) – in combination with the above-mentioned Matthew effect, this must be regarded as a potential shortfall of the network. This, again, counters innovative prospects since the central actors, which have a considerable impact on the network, tend to favour collaborations with other well-known, central actors instead of searching for more diverse actors with other types, e.g. from the private sector (Bröring et al., 2020).

Further analysis of the dynamic nature of the network also showed increasing interest in the topic, which, again, does not come as a surprise. The importance of central actors was further bolstered, while a new network capability came to attention: its inclusive ability. Some actors that initially had strong ties to organisations of another subgroup lost their connections over the years and traded them for a more central position. This must, however, be seen in relative terms with the character of the network as a whole. Connections between organisations mean that they were participating in a funded project. It does not resemble in any way a proven collaboration between them. But this effect has to be connotated positively alone for the possibility the network structure has in weakening initially strong bonds and connecting actors to a broader range of different actors. Then again, it is assumed that organisations with a higher degree, thus more connections, contain a greater possibility of inducing impacts, but it is by no means a proven fact that they indeed do in reality. However, in the end, collaborations, even if only in the context of funded projects, remain to be seen as a healthy thing for the bioeconomy. Intra-industry collaborations often suffer from limited novelty (Nieto & Santamaría, 2007), which, again, can be seen as a driver for the development of the concept. Besides being more expensive financially, more diverse pairings and cooperations are harder to achieve, initiate, and keep up. Thus, the approach is built on good soil but still needs improvement to bear fruit. Companies need to play a more central as well as bridging role, and the focus needs to shift away from ample research facilities and towards a more comprehensive and diverse scenery, which tries to achieve and implement practical outcomes and in the end takes steps to move away from being a fuzzy discussion on a meta-scale. Network analysis, lastly, points out possibilities rather than clear-cut facts (D. Morrison et al., 2022), but it is essential to recognise them and act accordingly.

The study also faced some limitations. While all of them were tackled to the author's best abilities, they still need to be considered. First, the transformation from two-mode into one-mode networks while allowing the study of two-mode networks with the tools and notions for easier-to-analyse one-mode networks has some problems. Information in the bipartite structure might get lost in the transformation, while some properties of the resulting projection may be due to the transformation process instead of the underlying data (Latapy et al., 2008). Latapy further warns that projections after transformation might look denser and more clustered, even if the bipartite base does not resemble this effect. Therefore, all visualisations presented in this study must be regarded with this potential effect. Then, the study also focused on a single network. Typically, the informative value of network analysis grows by incorporating a comparison network. Sadly, this was not regarded as a feasible option due to the project structure, novel methodological approach to the data, and lack of data on the bioeconomy. While great emphasis was put on delimiting the network, the influence of subjective qualitative assessment can not be ruled out completely; as few assumptions as possible were carried out, they can never be completely free of bias. Also, CORDIS-data had a bad reputation in the past for being erroneous in their quality. During the data processing and analysis done in this study, this effect could not be verified; however, there is always the possibility of missing data, which is a known risk, especially for network analysis and the chosen methodology. Of course, CORDIS also does not resemble the complete European research activity on the matter but is the most complete set of bioeconomy network data there is at the time of writing. In addition, the study also briefly touched upon organisations outside of Europe participating in H2020 projects. It would be a possibility to exclude them from the network; however, this was not done, as it was seen as a mistake since they did, in the greater scheme of things, not play a significant role but are still vital connectors and participants in projects and thus, excluding them would mean displaying an even more distorted reality. Of course, shedding light on their actual impact on the network is an interesting question for further research. Finally, all visualisations were affected by the significant obstacle of the lack of resolution and the lost opportunity for the reader to explore the graph by hand.

3.6 Conclusion

In summary, this study focused on achieving two goals:

- *First,* designing a method able to identify funded projects and their participants by applying the concept of bioeconomy, with a minimal amount of assumptions and judgment calls done, and
- *Second,* applying this method to Horizon 2020 data in order to examine and analyse bioeconomy's representation in the EU's latest funding programme, identifying central actors and core network characteristics as well as discussing emerging implications.

Using three exhaustive text minings on data from entirely different perspectives on the bioeconomy, preparing and analysing it afterwards in R, and visualising the results in

Gephi following social network ideas, an innovative approach to descriptive data analysis in the light of the bioeconomy has been carried out. In the end, both goals could be achieved: the methodological approach toward the concept of bioeconomy proved to be valid and robust and was later used to depict the European bioeconomy network and its central actors by performing detailed network analysis. A clear picture of the network was presented by calculating descriptive statistics, visualising essential results, and looking at various network features and measurements. Examining the evolution and dynamic over the years provided yet another angle on the matter. The study contributes significantly to descriptive analysis in human and economic geography, where social network analysis as a tool is still underrepresented. After presenting state-of-the-art theory from a network and geographical perspective, the methodology for gathering and editing the data and social network analysis was presented in great detail. The following analytical considerations profoundly concluded the implications and challenges faced by an EU-funded bioeconomy network as well as that the depiction and analysis of their network structures reveal processes vital for creating knowledge and, further, driving innovation. The work also opens the door for future, subsequent research. It not only underlines the use of descriptive data analysis that incorporates exploration and visual inspection of network structures, but it also offers direct links for further research to the questions asked: What this study did not touch upon, but what is considered one, if not the essential geographic question – spatiality and the regional diffusion of knowledge. The study pointed out the structural focus of the network on central actors. However, in what way these actors influence the spread of knowledge regarding the bioeconomy to regional actors might be crucial for the further development of the concept and also to receive critical information on how to improve funding schemes, especially for the backdrop of bioeconomy, in the EU. Showing light on the real-world influence of a network whose sole purpose is to bring up innovations can function as a saving grace while examining it on the country level might lead to even more exciting results. The study also pointed toward the relatively weak position of companies inside the network; getting more insight into their behaviour with the help of qualitative research might lead to a better understanding of their position, while researching exclusively company-oriented networks is further believed to yield exciting novelties on the matter as well. Then again, figuring out how – and if – they adopt a “bioeconomic” point of view remains another immense research opportunity. Especially for the recent discourse on bioeconomy seems to be seldomly focused on them and even rarer focused on companies from the low-tech sector. However, these are not to be forgotten players in the bioeconomy; against all odds, they are also primary drivers and need a higher quality inclusion in funded, R&D-oriented project networks.

Appendix

3.A Detailed List of Subprogrammes

Table 3.A.1: Subprogrammes

Progr.	**Title or short title**
EU.2.1.3.	INDUSTRIAL LEADERSHIP - Leadership in enabling and industrial technologies - Advanced materials
EU.2.1.3.1.	Cross-cutting and enabling materials technologies
EU.2.1.3.2.	Materials development and transformation
EU.2.1.3.3.	Management of materials components
EU.2.1.3.4.	Materials for a sustainable, resource-efficient and low-emission industry
EU.2.1.3.5.	Materials for creative industries, including heritage
EU.2.1.3.6.	Metrology, characterisation, standardisation and quality control
EU.2.1.3.7.	Optimisation of the use of materials
EU.2.1.4.	INDUSTRIAL LEADERSHIP - Leadership in enabling and industrial technologies – Biotechnology
EU.2.1.4.1.	Boosting cutting-edge biotechnologies as a future innovation driver
EU.2.1.4.2.	Bio-technology based industrial products and processes
EU.2.1.4.3.	Innovative and competitive platform technologies
EU.2.1.5.	INDUSTRIAL LEADERSHIP - Leadership in enabling and industrial technologies - Advanced manufacturing and processing
EU.2.1.5.1.	Technologies for Factories of the Future
EU.2.1.5.2.	Technologies enabling energy-efficient systems and energy-efficient buildings with a low environmental impact
EU.2.1.5.3.	Sustainable, resource-efficient and low-carbon technologies in energy-intensive process industries
EU.2.1.5.4.	New sustainable business models
EU.3.1.7.	Innovative Medicines Initiative 2 (IMI2)
EU.3.1.7.1.	Antimicrobial resistance
EU.3.1.7.10.	Cancer
EU.3.1.7.11.	Rare/Orphan Diseases
EU.3.1.7.12.	Vaccine
EU.3.1.7.13.	Other
EU.3.1.7.2.	Osteoarthritis
EU.3.1.7.3.	Cardiovascular diseases
EU.3.1.7.4.	Diabetes
EU.3.1.7.5.	Neurodegenerative diseases
EU.3.1.7.6.	Psychiatric diseases
EU.3.1.7.7.	Respiratory diseases
EU.3.1.7.8.	Immune-mediated diseases
EU.3.1.7.9.	Ageing-associated diseases
EU.3.2.	SOCIETAL CHALLENGES - Food security, sustainable agriculture and forestry, marine, maritime and inland water research, and the bioeconomy
EU.3.2.1.	Sustainable agriculture and forestry

EU.3.2.1.1.	Increasing production efficiency and coping with climate change, while ensuring sustainability and resilience
EU.3.2.1.2.	Providing ecosystems services and public goods
EU.3.2.1.3.	Empowerment of rural areas, support to policies and rural innovation
EU.3.2.1.4.	Sustainable forestry
EU.3.2.2.	Sustainable and competitive agri-food sector for a safe and healthy diet
EU.3.2.2.1.	Informed consumer choices
EU.3.2.2.2.	Healthy and safe foods and diets for all
EU.3.2.2.3.	A sustainable and competitive agri-food industry
EU.3.2.3.	Unlocking the potential of aquatic living resources
EU.3.2.3.1.	Developing sustainable and environmentally-friendly fisheries
EU.3.2.3.2.	Developing competitive and environmentally-friendly European aquaculture
EU.3.2.3.3.	Boosting marine and maritime innovation through biotechnology
EU.3.2.4.	Sustainable and competitive bio-based industries and supporting the development of a European bioeconomy
EU.3.2.4.1.	Fostering the bio-economy for bio-based industries
EU.3.2.4.2.	Developing integrated biorefineries
EU.3.2.4.3.	Supporting market development for bio-based products and processes
EU.3.2.5.	Cross-cutting marine and maritime research
EU.3.2.5.1.	Climate change impact on marine ecosystems and maritime economy
EU.3.2.5.2.	Develop the potential of marine resources through an integrated approach
EU.3.2.5.3.	Cross-cutting concepts and technologies enabling maritime growth
EU.3.2.6.	Bio-based Industries Joint Technology Initiative (BBI-JTI)
EU.3.2.6.1.	Sustainable and competitive bio-based industries and supporting the development of a European bio-economy
EU.3.2.6.2.	Fostering the bio-economy for bio-based industrie
EU.3.2.6.3.	Sustainable biorefineries
EU.3.3.	SOCIETAL CHALLENGES - Secure, clean and efficient energy
EU.3.3.1.	Reducing energy consumption and carbon foorpint by smart and sustainable use
EU.3.3.1.1.	Bring to mass market technologies and services for a smart and efficient energy use
EU.3.3.1.2.	Unlock the potential of efficient and renewable heating-cooling systems
EU.3.3.1.3.	Foster European Smart cities and Communities
EU.3.3.2.	Low-cost, low-carbon energy supply
EU.3.3.2.1.	Develop the full potential of wind energy
EU.3.3.2.2.	Develop efficient, reliable and cost-competitive solar energy systems
EU.3.3.2.3.	Develop competitive and environmentally safe technologies for CO2 capture, transport, storage and re-use
EU.3.3.2.4.	Develop geothermal, hydro, marine and other renewable energy options
EU.3.3.3.	Alternative fuels and mobile energy sources
EU.3.3.3.1.	Make bio-energy more competitive and sustainable
EU.3.3.3.2.	Reducing time to market for hydrogen and fuel cells technologies
EU.3.3.3.3.	New alternative fuels
EU.3.3.4.	A single, smart European electricity grid
EU.3.3.5.	New knowledge and technologies
EU.3.3.6.	Robust decision making and public engagement
EU.3.3.7.	Market uptake of energy innovation - building on Intelligent Energy Europe
EU.3.3.8.	FCH2 (energy objectives)
EU.3.3.8.1.	Increase the electrical efficiency and the durability of the different fuel cells used for power production to levels which can compete with conventional technologies, while reducing costs
EU.3.3.8.2.	Increase the energy efficiency of production of hydrogen mainly from water electrolysis and renewable sources while reducing operating and capital costs, so that the combined system of the hydrogen production and the conversion using the fuel cell system can compete with the alternatives for electricity production available on the market
EU.3.3.8.3.	Demonstrate on a large scale the feasibility of using hydrogen to support integration of renewable energy sources into the energy systems, including through its use as a competitive energy storage medium for electricity produced from renewable energy sources
EU.3.5.	SOCIETAL CHALLENGES - Climate action, Environment, Resource Efficiency and Raw Materials

EU.3.5.1.	Fighting and adapting to climate change
EU.3.5.1.1.	Improve the understanding of climate change and the provision of reliable climate projections
EU.3.5.1.2.	Assess impacts, vulnerabilities and develop innovative cost-effective adaptation and risk prevention and management measures
EU.3.5.1.3.	Support mitigation policies, including studies that focus on impact from other sectoral policies
EU.3.5.2.	Protection of the environment, sustainable management of natural resources, water, biodiversity and ecosystems
EU.3.5.2.1.	Further our understanding of biodiversity and the functioning of ecosystems, their interactions with social systems and their role in sustaining the economy and human well-being
EU.3.5.2.2.	Developing integrated approaches to address water-related challenges and the transition to sustainable management and use of water resources and services
EU.3.5.2.3.	Provide knowledge and tools for effective decision making and public engagement
EU.3.5.3.	Ensuring the sustainable supply of non-energy and non-agricultural raw materials
EU.3.5.3.1.	Improve the knowledge base on the availability of raw materials
EU.3.5.3.2.	Promote the sustainable supply and use of raw materials, including mineral resources, from land and sea, covering exploration, extraction, processing, re-use, recycling and recovery
EU.3.5.3.3.	Find alternatives for critical raw materials
EU.3.5.3.4.	Improve societal awareness and skills on raw materials
EU.3.5.4.	Enabling the transition towards a green economy and society through eco-innovation
EU.3.5.4.1.	Strengthen eco-innovative technologies, processes, services and products including exploring ways to reduce the quantities of raw materials in production and consumption, and overcoming barriers in this context and boost their market uptake
EU.3.5.4.2.	Support innovative policies and societal changes
EU.3.5.4.3.	Measure and assess progress towards a green economy
EU.3.5.4.4.	Foster resource efficiency through digital systems
EU.3.5.5.	Developing comprehensive and sustained global environmental observation and information systems
EU.3.5.6.	Cultural heritage
EU.3.5.6.1.	Identifying resilience levels via observations, monitoring and modelling
EU.3.5.6.2.	Providing for a better understanding on how communities perceive and respond to climate change and seismic and volcanic hazards
EU.3.5.7.	FCH2 (raw materials objective)
EU.3.5.7.1.	Reduce the use of the EU defined ”Critical raw materials”, for instance through low platinum or platinum free resources and through recycling or reducing or avoiding the use of rare earth elements
EU.5.c.	Integrate society in science and innovation issues, policies and activities in order to integrate citizens’ interests and values and to increase the quality, relevance, social acceptability and sustainability of research and innovation outcomes in various fields of activity from social innovation to areas such as biotechnology and nanotechnology
EU.5.d.	Encourage citizens to engage in science through formal and informal science education, and promote the diffusion of science-based activities, namely in science centres and through other appropriate channels
EU.5.f.	Develop the governance for the advancement of responsible research and innovation by all stakeholders, which is sensitive to society needs and demands and promote an ethics framework for research and innovation
EU.5.g.	Take due and proportional precautions in research and innovation activities by anticipating and assessing potential environmental, health and safety impacts

Chapter 4

Knowledge and Innovation in a Low-Tech, Agri-Food Value Chain

The Role of the Bioeconomy in the Sugar Industry in three European Regions

Abstract

The research field of the bioeconomy is receiving more and more public attention and is being discussed intensely in political and scientific spheres. While playing an essential role in EU politics, the bioeconomy still lacks a coherent understanding across multiple actorial layers. Especially low-tech companies are at risk of getting overlooked by policymakers because of the focus of innovation policy on R&D activities and high-tech innovation. However, long-established companies in traditional sectors can play an essential role in transitioning from a fossil-based economy toward a bio-based one. Against this backdrop, the paper examines how knowledge and innovation in low-tech value chains work and what role bioeconomy plays in innovative activities at the firm level. Sugar industry value-chains in three rural European regions were chosen as an exemplary case. With the help of qualitative content analysis, actor-based perspectives on knowledge creation and innovation are analysed. The study formulates statements regarding knowledge generation, spread, and innovation from an agri-food point of view centred around the sugar industry and reviews which characteristics of bioeconomy find an application and which challenges present themselves. The findings are then set into the context of the broader bioeconomy discourse based on specific barriers and drivers for a bioeconomy transition within low-tech value chains.

Keywords: bioeconomy, innovation, knowledge, value chains, agri-food, sustainability transitions

4.1 Introduction

As interest in the concept of bioeconomy surges across all regulatory layers and its influence is furthermore boosted with – *more or less focused* (Meyer, 2017) – strategies, visions and manuals on the regional, national and international level and momentum is built, the scientific world repeatedly points out its weaknesses — one of them being that the low-tech and especially agri-food sectors are frequently overlooked: The concept faces too little exposure in these areas and is still being discussed mainly on a meta scale (Bauer et al., 2018; Cuerva et al., 2014; Esposito et al., 2020; Mehmood et al., 2021). Paired with the analysis in Chapter 3 that also concluded an under-representation of SMEs in project-based research activities, their potentially weak position in knowledge networks must be assumed. However, these play an essential role in transitioning from a fossil-based economy (Jia, 2021), especially in rural and less populated regions (Kardung et al., 2021) and also in the agri-food industry (Kusi-Sarpong et al., 2019). The transformation is increasingly seen as urgent and irrefutable when considering the often-repeated wicked problems our world will inevitably face (Barrett et al., 2020). For this transition to happen, innovation is repeatedly named as the most dominant factor in pushing the bioeconomy into a position of genuinely competing against fossil-based lock-ins (Birch, 2019; Dabbert et al., 2017; Golembiewski et al., 2015; Jander et al., 2020; Purkus et al., 2018; van Lancker et al., 2016). Combined with the previously mentioned neglection of the low-tech and agri-food sectors, their position must be considered critical, while in-depth studies looking into the innovativeness of low-tech bioeconomic structures are few (Wydra, 2019). That is, although the agri-food sector increasingly shifts its locus of innovation from single firms to the entire value chain (Kühne et al., 2010) and it is believed that sustainable interventions and innovation can boost its competitiveness (Arcese et al., 2015).

Therefore, this work contributes to the ongoing debate on the bioeconomy with a detailed look into innovation activities in a low-tech, agri-food sector to better understand its mechanisms, drivers, and potential hurdles along the way while focusing primarily on the actors involved. The low-tech sector must not be disregarded when painting a bioeconomic future – this study tries to underline this statement based on findings from the sugar value chain and aims to understand its mechanisms of innovation better to start the conversation on possible future pathways. It combines this approach with a value-chain point of view to yield an analytical framework. This allows for deeper insights into cooperation dynamics, governance and specific helpful or harmful configurations for innovative activities and can thus set the scene for transparent, qualitative analysis of concrete, actor-specific factors. Prime examples to further the argument regarding a lack of innovation research into already in-use biomass tend to be long-established, traditional sectors like the sugar industry. While containing positive tendencies towards the bioeconomic principle by focusing on circularity and waste-stream valorisation along the whole chain and possible future use as a platform for bioplastics, sugar still only plays an underrepresented role in research; most of the green innovation literature has taken a more holistic approach, while only a few studies have analysed sectors separately or with a broader focus on low-tech (Cuerva et al., 2014). For this study, however, it is considered a perfect fit as a research case. The sugar industry presents various reasons to answer how innovation is done in a low-tech value chain. The use case processing-wise is, as said, inherently bioeconomic, and the whole chain revolves around a renewable, strictly biological resource. With that, circularity as well as cascading, both key bioeconomy-specific innovation paths, are getting applied. While frequently managed internationally, the value chain is deeply embedded regionally due to long traditions and, therefore, in many cases, faces strong path dependency. On the other hand, it almost always involves the same actor types, making it significantly research-friendly since different case regions can be examined with the same methodology. Comparisons between cases, in order to achieve characteristics typical for the bioeconomy, are thus a possibility, presenting more than one angle on the matter and possibly yielding exciting results about the power of agency of the various actors, especially when considering regionally distinct conditions and dependencies.

To achieve this comparability, a methodology aiming at fine-slicing actorial perspectives and their complex relationships was designed to understand better the complexity of bioeconomy in a low-tech, agri-food sector. Interviews were conducted with identical actor types along the sugar-industry value chain in three rural European cases. Following a deduction from relevant theory, a qualitative research design was chosen as the go-to methodology to gather optimal, in-depth data without striding too far from the contemporary research context. The research questions at the baseline of this study are thereby structured as follows:

1. Which specificities regarding governance, cooperation dynamics, and actorial relationships does a low-tech, agri-food value chain offer, and which differences occur?
2. How does knowledge flow, how are innovations achieved in a low-tech, agri-food value chain, and which factors have an influence?
3. Which characteristics of bioeconomy find application, and in what ways do they influence decision-making in the low-tech value chain of sugar?

The agri-food topics of innovation and knowledge diffusal, value-chain configurations, and the transition towards bioeconomy are central for this study; they will also function as the structural outline context-wise: *first*, the relevant theory behind the three matters will be presented – innovation types and modes in low-tech and agri-food sectors are examined before value chain configurations from a bioeconomic point of view are considered, and an analytical framework is built. *Second*, the overarching case for this work, the sugar industry, is being set. *Third*, based on the theoretical framework, qualitative content analysis methods are described before *fourth*, the results of the interviews are presented, analysed, and finally, *fifth*, a conclusion is drawn.

4.2 Theoretical Framework

4.2.1 Innovation Systems in Agri-Food Sectors

As the agri-food industry is canonically assigned as part of the low-tech sector, it is a good idea to investigate the topic in a broader sense before looking at the specifics. Low-technology, or low-tech, refers to industries which have, in comparison, fewer or no expenditures at all allocated to research and development (R&D). The categorisation follows "R&D intensity", an indicator that measures the ratio of the R&D expenses to the turnover of a firm or the whole industry's output (Hirsch-Kreinsen & Schwinge, 2014). Therefore, following an OECD definition from 1994, low-tech is applied at an R&D intensity under 3%, and the industry is considered not research-intensive (Jacobson et al., 2006). While the classification was updated to a "more realistic" 2.5% (Legler & Frietsch, 2007), it needs to be looked at with care. The categorisation based on the sectors' average share of expenditures on research and development activities (R&D) is seen as rather critical for its narrow-mindedness regarding the single indicator defining innovativeness (R&D intensity) and the oversight of intra-sectoral heterogeneity (Kirner et al., 2009). Looking at the most recent OECD categorisation (NACE Rev. 2), one immediately sees that many industries that fall under the low-tech categorisation are rather traditional and mature ones, and it comes with no surprise that "manufacture of food products" is also one of them. This also applies to the agri-food industry, which has traditionally been viewed as a low-tech sector with slow rates of innovation (Arcese et al., 2015).

Different factors should be considered when looking at innovation in the agri-food area, as new types of fodder, feeding systems, types of packaging, types of conservation, additives, flavours or consumer products are introduced regularly, and new types of logistics in addition to the types of innovations covered by the OECD definition – namely product, process, market, and organisational innovations – find application. As a result, agri-food innovation does not always fit neatly into established conceptual and empirical definitions of innovation (Finco et al., 2018). While the dominant mode is incremental rather than radical innovation, innovation is still an effective tool supporting the transition of the sector, especially in traditional and mature industries (Arcese et al., 2015). Also, the number of intangible components involved in innovation processes in the agri-food industry grew, as did consumer needs and demand for more sustainable production. As a result, the agri-food industry came up with innovation strategies not based simply on R&D, but on learning processes and interaction between actors (Kühne et al., 2010), initially hinting at an innovation regime of *Doing, Using, Interacting (DUI)*. Kafetzopoulos and Skalkos (2019) recently surveyed agri-food firms regarding drivers of innovation. Their results show that Greek agri-food companies across all sizes rely primarily on *quality and process management* as drivers. Managing them purposefully means noticing and avoiding issues, leading to more effective processes and innovation capability. At the same time, *collaborations, knowledge orientation* and *flexibility* (framed as environmental dynamism) are identified but seem to play a subordinate role in the studies context (Kafetzopoulos & Skalkos, 2019). Further, as Jia (2021) showed, underlying *societal factors* also affect the innovation process in the agri-food sector. Following the current global context, Jia identified the urgency to address the above-mentioned *wicked problems*, like the urgency to combat hunger and a growing world population, as another driver. However, decreasing investment in the sector and a social lock-in into fossil-based products led to a decline in productivity and a halt in transitioning to more sustainable solutions (Jia, 2021). The work describes the sector as a complex system that is no longer used simply for production but also for consumption and environmental purposes and is heavily dependent on external actors (Jia, 2021). This complexity was one of the main reasons researchers adopted the *Innovation System* approach for research on innovation in agri-food (Touzard et al., 2015), in order to structure the underlying processes.

While the classic, linear innovation process sees R&D and investments into R&D activities in a leading position for the innovativeness of firms (Kirner et al., 2009), the Innovation System approach, mainly defined by Lundvall et al. (2002), challenges this idea. The innovation system approach regards innovation as a non-linear, complex, collaborative, multi-level process embedded in a systemic setting (Lundvall, 2010). One of the primary, recurring themes in innovation system literature is *knowledge* and its flow between actors present in the system (Bougrain & Haudeville, 2002; Giuliani et al., 2011).

While lagging behind high-tech counterparts in product innovation, agri-food firms (and the processing industry in general) rely heavily on the organisation and innovation of their processes; thus emphasis lies on the quality of these existing ones instead of innovating new products (Kirner et al., 2009). An *interactive learning* mindset revolving around incremental innovation with a focus on learning by doing and tacit knowledge seems fitting (Fu et al., 2013). Along those lines, *absorptive capacity*, the ability of firms to handle and use knowledge, is regarded as an essential factor (Bougrain & Haudeville, 2002) and is built mainly by interaction with research organisations. For agri-food, these hold an even more significant responsibility since the cultivation conditions differ widely between regions and alien technologies need to be adopted for the local settings (Giuliani et al., 2011; Prenzel et al., 2018). A growing emphasis in the literature is thus put on these *interactions* between actors since collaboration can provide access to various external sources of information (Kühne et al., 2010) outside of the chain, strengthening the learning effect for actors involved. Another critical factor in an innovation system is the *policy environment*, which, in the best case, diagnoses and enhances the functionality of the system as a whole instead of its components (Lamprinopoulou et al., 2014). Policymakers can positively influence the agri-food innovation system by being aware of the tradition and culture of innovation in a given field and by helping to improve collective as well as open learning and involving multiple actors (Lamprinopoulou et al., 2014). However, societal demands also have risen, with consumers demanding agriculture that uses fewer pesticides, which, in turn, resulted in a regime of increased regulatory control of the sector (Huyghe et al., 2020).

Agri-food and its socio-technical complexity can be seen as one of the industrial sectors most heavily intertwined with sustainable development goals; therefore, it needs to be discussed on a broader scale, focusing on its pathways of knowledge and collaboration dynamics (Jia, 2021). A closer look at the theory behind green innovation and its interference with bioeconomy is thus taken in the following.

4.2.2 Sustainable Innovation Approaches

Following an increasing global focus on sustainability and international environmental regulations and a shifting consciousness of consumers and customers in the presence of sustainability transitions (Geels, 2010), a greater emphasis is being put in recent years on a more sustainable production regime and a more effective environmental management in corporations (Chen, 2008). With that emphasis, the importance of managing innovations tailored toward sustainability has been growing in research and practice (Schiederig et al., 2012). Besides green innovation, different terms emerge, with eco-, circular-, environmental- and sustainable innovation frequently named in the literature. Over the last 25 years, various authors presented different definitions for these notions of innovation. On a more holistic scale, D'Amato et al. (2017) recently compared circular- with green- and bio-economy in a literature review. The main identified overlaps between the terms are seen in energy, emissions, and the utilisation of natural resources, with eco-efficiency playing a primary role in circular- and green-economy literature. While both circular- and bioeconomy revolve around a particular resource, but with a different focus on urbanisation for the first and rural development for the latter, term-wise, the green economy tends to address all natural processes (D'Amato et al., 2017).

Regarding innovation principles in the various terms mentioned above, Schiederig et al. (2012) concluded that only minor differences are to be identified between them, and thus the terms may be used as somewhat synonymous. Chen (2008) also distinguishes between green product and process innovation, both of which to be involved in counting as green innovation in the reduction of used resources, materials and energy, prevention of pollution, reduction of emissions, waste recycling and general reusability. Schiederig et al. (2012) made an effort to summarise these definitions mentioned above and identified six recurring aspects of "green innovations" – the notion ultimately used on a holistic scale in this work:

1. *The object of innovation is a product, process, service or method;*
2. *the innovation should satisfy needs, solve problems and be competitive on the market;*
3. *has no negative impacts on the environment;*
4. *needs a thorough analysis of the entire life cycle with all input and output factors;*
5. *with its intention for reduction being economical or ecological and*
6. *hopefully sets a new, green standard for the firm.*

These are in line with the bioeconomy-specific innovation types and challenges presented by Bröring et al. (2020). In their work, they propose substitute products, new processes, new products and new behaviour as types of innovation in bioeconomy, with value-chain, resources, innovation capacity and knowledge capacity, market and sustainability as their conflicting challenges (Bröring et al., 2020). With both of these aspect sets being rather unspecific, the work concludes a definitive need for further analysis on the firm level to gather an in-depth look into their practices. Cuerva et al. (2014), who investigate eco-innovation on the small- and medium firm level in the food sector, subdivided the determinants of eco-innovation in an SME context (Fig. 4.2.1) into technological and organisational capabilities acting as a technology push factor, with lagging behind competitors and suppliers also acting as technology push, while increasing product differentiation and shifting customer demands as well as the collaboration with competitors and suppliers are seen as market-pull factors. External influences, such as public subsidies and networks, can work in both directions, push or pull, regulatory-wise (Cuerva et al., 2014).

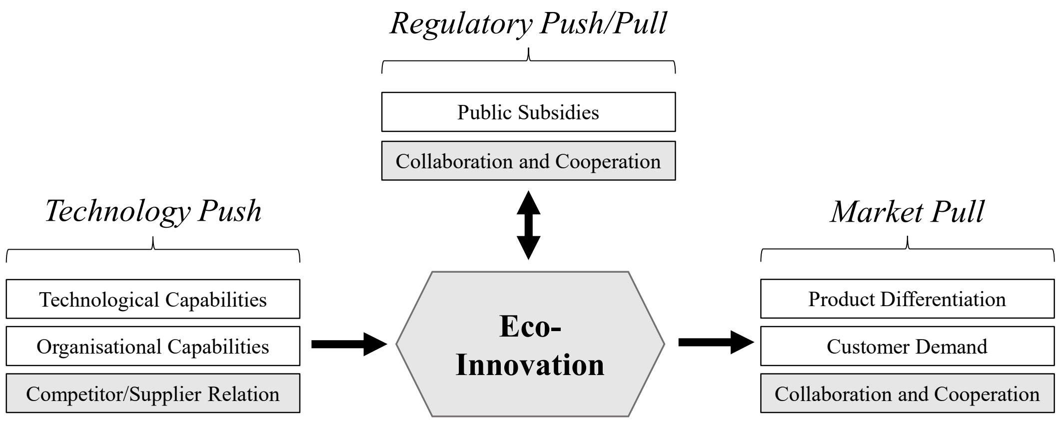


Figure 4.2.1: Determinants of eco-innovation in an SME context (own graphic based on Cuerva et al. (2014))

A significant overlap between the external factors and drivers for innovation in a bioeconomic setting becomes apparent; thus, considering them for the analytical framework is almost necessary. Furthermore, the work of Cuerva et al. (2014) concludes that the need for environmental sustainability brought new concerns and pressures to low-tech firms' innovative activity and underlines that low-tech firms are more prone to innovate in green *processes* rather than *products*, but specific case studies are needed (Cuerva et al., 2014). These findings align with Pacheco et al. (2017), while both works strongly call for more best-practice research in the future – a definite motivation for this work.

In the literature on bioeconomy innovation, the concepts of cascading and circularity are frequently brought up. This is not a surprise since they are part of the European guiding principle on bioeconomy as defined by the Standing Committee of Agricultural Research

(SCAR) (SCAR, 2015). In addition, a recent study explored criteria for sustainable bioeconomy innovations. A crucial finding was that fostering cascade or circular systems is one of the most frequently occurring criteria (Laibach et al., 2019), underlining their importance for the concept of the bioeconomy. Cascading, conceptually, means using resources sequentially for different purposes through multiple material (re-)use phases, before the material, as the last step, is either used for energy extraction or -recovery. At the same time, a consecutive resource circulation achieves efficiency optimally and can result in an elongated and more sustainable lifecycle of the raw material (Campbell-Johnston et al., 2020). Initially, the concept was introduced as a general tool for achieving more sustainability in resource use (Sirkin & ten Houten, 1994) and is still based on improving biomass utilisation through reusing and recycling the material through as many processes as possible before ultimately using it for generating energy (Jarre et al., 2020). Over the years and especially since the introduction and upswing of bioeconomy, increased attention has been put on it, which resulted in three approaches that are discussed extensively by Jarre et al. (2020): Cascading in time, defined by the sequential use of biomass, cascading in value, which puts emphasis on the prioritisation of the most valuable use-case and cascading in function that focuses primarily on co-production and can be seen in modern biorefineries (Jarre et al., 2020). Fig. 4.2.2 visualises these three concepts over time:

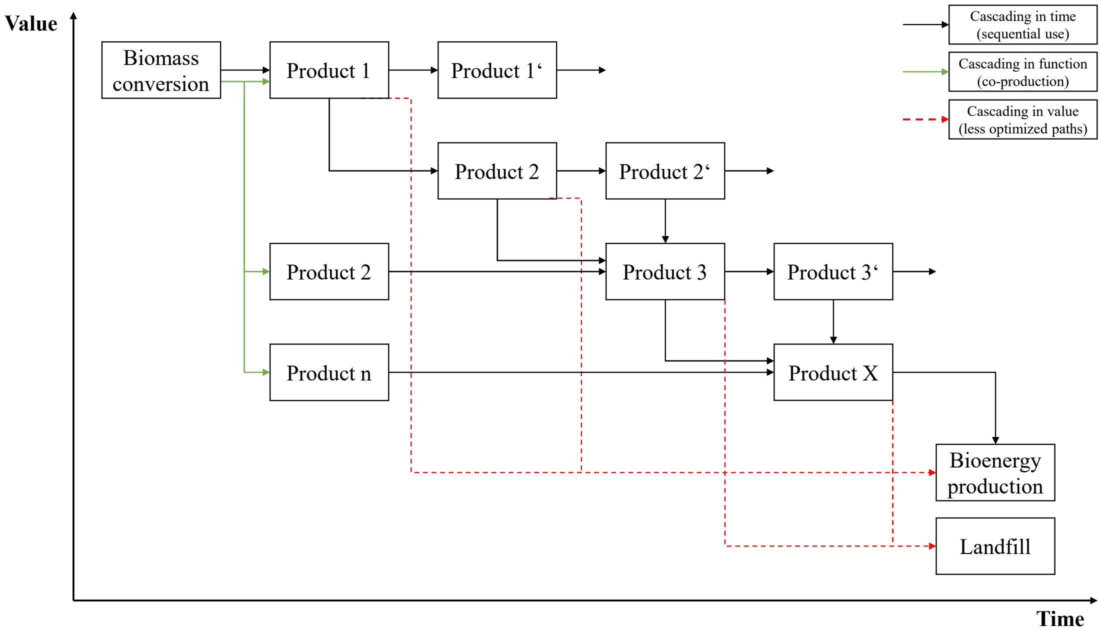


Figure 4.2.2: Cascading approaches (own graphic based on Jarre et al. (2020))

Circular economy, on the other hand, faces the same problem as bioeconomy, for it lacks a distinct definition but is – same as cascading – centred around prolonging resource productivity (Blomsma & Brennan, 2017). The circular economy wants to close resource loops as much as possible in order to be as regenerative and restorative in a material lifecycle as possible. When considering the fact that the R framework – *reduce, reuse,* *recycle* – is often named in combination with the term (Ghisellini et al., 2016), a distinct overlap with not only cascading but also bioeconomy conceptually is apparent. Regarding innovation, these can have a profound impact on entire value chains. Optimising the ecological footprint of a product by applying cascading of biomass or adopting a circular economy approach can increase its value on the one hand while also minimizing resource consumption and waste production on the other and due to the complete value chain being affected, this innovation can have a systemic character (Bröring et al., 2020) and by that having great relevance for bioeconomy in general.

To conclude, on a meta-scale, literature regarding green-, eco-, sustainable- and circular as well as cascading innovation further nurtured the impression of the complexity of innovation in bioeconomy, and the agri-food sector seemed to underline the importance of a broader innovation systems perspective. While, term-wise, green innovation has been chosen to carry along this work, emphasis and focus will be put on cascading as a bioeconomy speciality innovation-wise. Along the lines of green innovation and innovation systems, some authors also see open innovation and the DUI and STI innovation modes as potential approaches to the low-tech industry – and to the bioeconomy.

4.2.3 Open Innovation and Innovation Modes

Medeiros et al. (2016) argue that the challenges in the agri-food sector can be answered with complex and systemic innovations, which in turn can be achieved by adopting an *open innovation approach*, representing a new paradigm for development in the sector (Medeiros et al., 2016) and function as an incremental resource for a rise in competitiveness (Arcese et al., 2015). Open innovation was adopted almost exclusively by high-tech firms initially, but it gradually became a strategic approach for traditional and mature sectors and also moved into the agri-food industry (Chesbrough & Crowther, 2006). In general, open innovation grew to not only become the dominant approach for relationship-based innovation but is also seen by authors as a rationale for innovation development in the bioeconomy (van Lancker et al., 2016) or even an entirely new paradigm for agri-industry innovation (Bogers et al., 2018). By definition, open innovation describes "the use of purposive inflows and outflows of knowledge to accelerate internal innovation and expand the markets for external use of innovation" (Chesbrough, 2012, p.20). These two distinguished kinds, inbound (outside-in) and outbound (inside-out), are driven mainly by *technology- and market-push* elements. The first one revolves around opening up the innovation process to external inputs and contributions, while the latter, certainly the less researched one, requires organisations to allow unused or underutilised ideas and experiences to venture outside (Bogers et al., 2018). This particular configuration holds certain risks, primarily associated with unwanted, outgoing knowledge spillover effects (van Lancker et al., 2016), creating a lack of trust between actors. *Trust*, however, is integral, as the relationships needed for open innovation between firms require mutual trust (Medeiros et al., 2016). Some other prerequisites are also named for open innovation to lead firms to success.

Besides a solid and *supportive organisational culture* regarding the mindset behind open innovation, a convinced and *driven leadership*, the right *resources* and *capacity* for the mechanisms, as well as a specific absorptive capacity to manage a broader knowledge base and the *relational capability* to create and contain inter-organisational relationships are named (van Lancker et al., 2016).

A substantial set of innovation *types* and approaches for agri-food has been investigated. However, specific innovation *modes* need to be discussed as well. On a broader scale, *innovation modes* are incorporated as a sub-part of the literature on innovation systems (Parrilli & Alcalde Heras, 2016), and thereby DUI and STI are seen as "archetypical strategies firms use to innovate" (Parrilli & Radicic, 2021, p.346). They are regarded as ideal types of innovation and learning (Jensen et al., 2007) and are linked to complex mechanisms of knowledge distribution (Kirner et al., 2009). As stated multiple times, knowledge manifests as a primary driver for innovation; differentiating it is thus considered a good idea before presenting modes building upon it. *Elements of knowledge* can be either tacit, explicit, thus readily usable by others, or codified, implicit, and therefore not without further work adoptable. Besides the form of knowledge, one can also distinguish between four types through which learning takes place (Lundvall et al., 2002): know-what, know-how, know-why, and know-who. Now, per definition, STI stands for Science, Technology, and Innovation and is based on the production and use of codified scientific and technical knowledge, while DUI, Doing Using Interacting, describes an experience-based mode of learning (Jensen et al., 2007). While STI sets a high priority on the production of know-why, DUI, in turn, typically provides know-how and know-who (Jensen et al., 2007). To further that: STI is based on high R&D expenditures and supports interactions with the academic world, thus diffusing research, which generates analytical and, to a lesser extent, synthetic knowledge, often resulting in technological innovation (Parrilli & Alcalde Heras, 2016). DUI describes a rather hands-on idea. Stressing the importance of interaction and practice-based innovations, it sees its main drivers in the capacity of a firm to develop and manage internal (informal and formal) but also external exchanges and interactions of knowledge, thus resulting in rather non-technological or radical innovation (Parrilli & Alcalde Heras, 2016). However, firms able to combine both modes in some way are expected to reach a higher degree of innovativeness than firms only doing one (Thomä, 2017).

The dominant mode in the low-tech and agri-food sector is DUI (Isaksen & Nilsson, 2013). Isaksen and Nilsson identified in one of the few works on DUI/STI in the agri-food industry certain hurdles preventing a higher innovation rate in the sector. One of them is a lack of *linkages to the knowledge infrastructure*, e.g. academia or research institutes. The authors lay the problem on the firms' lack of absorptive capacity, which could not absorb the external knowledge. Then, as traditional in the low-tech industry, a focus on incremental instead of radical or systemic innovation prevails. Coupled with small internal R&D activities and the above mentioned lacking absorptive capacity, firms were regarded as especially straggling in the sector (Isaksen & Nilsson, 2013). However, findings from the recent study on DUI and STI by Parrilli and Radicic (2021), which query the traditional homogeneity of the SME segment, show that medium-sized firms can, against all odds, function as leaders of a new local economic development and are potentially able even to drive the competitiveness of locally-based supply chains. Regional development practices can thus be initiated by supporting and getting support from MSEs (micro- and small enterprises), which can also benefit from strong place-based development (Parrilli & Radicic, 2021). These findings have yet to be verified, though, but already demonstrate a potential avenue for bioeconomy as a regional driver from a value chain perspective.

4.2.4 Value Chain Perspectives in Agri-Food and Bioeconomy

Value chains are considered the economic backbone of the world and its central nervous system, managing to transform the global marketplace from trading in goods to trading in networks (Kano, 2018). While the concept of linked activities of an organisation impacting its competitiveness was introduced by Porter in the 1980s (Porter, 1985), it certainly saw much refreshment over the years. One of the significant developments is Gerrefi's global value chain approach. The term goes back to the global commodity chain concept developed by Gereffi (1994). However, unlike related concepts, the value chain approach considers the material and information flow interlinked in the process of value creation and their spatial distribution, as well as the concept of value itself (Gereffi, 1994). Additionally, the approach also focuses on the relationships amongst the actors in the chain, its governance, and categorising the level of explicit coordination and power asymmetries (Gereffi et al., 2005). On a baseline, three modes of governance can be distinguished: (1) setting the parameters (*legislative governance*), (2) supporting actors in their efforts to comply (*executive governance*), and (3) monitoring compliance and sanctioning violations (*judicial governance*) (Kaplinsky & Morris, 2001). This is of great importance since the form of governance hugely impacts the mechanisms of how learning works, and thus knowledge transfers and ultimately innovation takes place inside the value chain (Pietrobelli & Rabellotti, 2011). The style of governance a lead firm of the value chain has depends on how complex the involved information in transactions is and if there is a possibility of codifying that information, as well as the level of competence of the suppliers in the chain (Pietrobelli & Rabellotti, 2011). Thus, a particular focus on the lead firms of a value chain is crucial for research (Kano, 2018) since their actions are mainly responsible for how knowledge is transferred to and between the actors or suppliers (Crescenzi et al., 2014). Gereffi et al. (2005) further distinguish five distinct governance configurations global value chains can have (Fig. 4.2.3).

Therefore, when lead firms enact control over the chain, their specific behaviour forges the chain type, resulting in either centralised or decentralised control. While production decisions in the first are made in a central headquarters based on the materials and demand status of the system, the second type describes a setting in which individual units

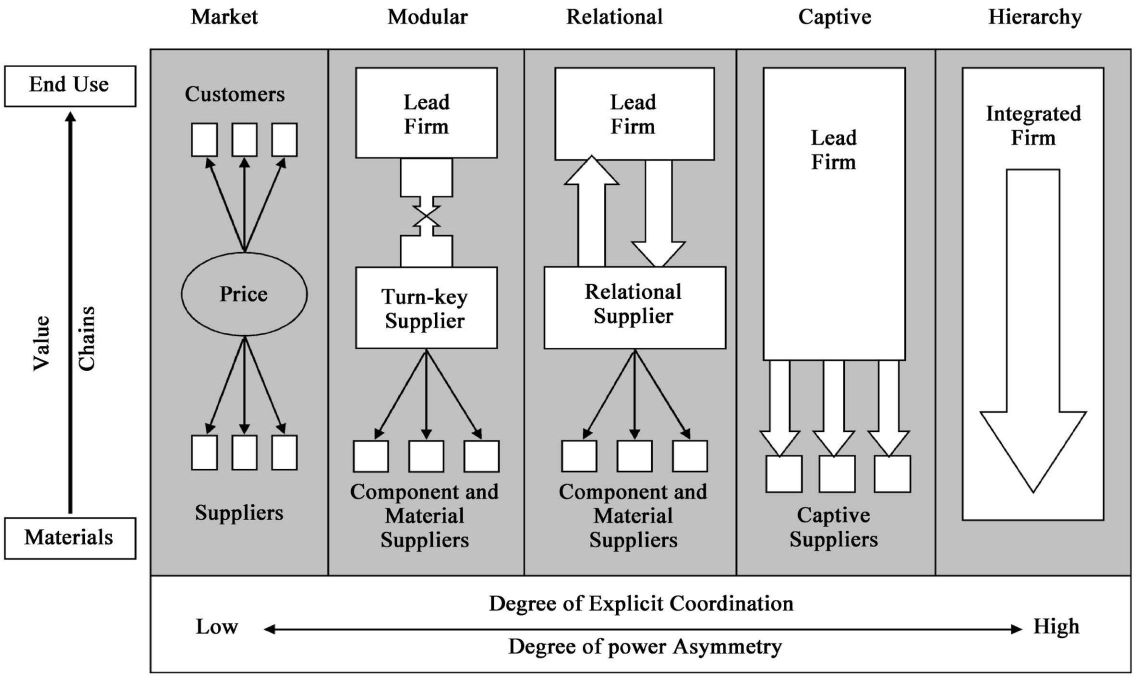


Figure 4.2.3: Governance types in global value chains (Gereffi et al., 2005)

in the chain can make decisions based on more local information (Lee & Billington, 1993). In organisational literature, centralisation is widely established, and different levels can occur, describing a single decision-maker's control over the chain. While higher levels of centralisation help streamline the aims of actors along the chain and reduce adverse effects of unpredictability, low centralisation is believed to increase flexibility, communication, and knowledge generation, thus driving innovation processes (Giannoccaro, 2018). Therefore, an efficient and well-structured innovation system, interacting in a non-linear and endogenous fashion with a value chain, is believed to reduce transaction complexity and increase the capability to deal with complex knowledge, thus supporting the overall value chain performance (Pietrobelli & Rabellotti, 2011). Combining the perspectives of innovation systems and value chains is thus considered beneficial.

Following a value chain perspective, agri-food systems are considered chiefly as "highly decentralised networks of stakeholders independently making decisions that have important economic, environmental, health and social repercussions for others [, which have] deep interdependence among [them]" (Toral et al., 2011, p.974). Regarding their configuration or governance, however, a definite answer strongly depends on the cultured crop, as will be discussed further down the line. It is also believed to consider the researched chain as complete in its scope as possible. Thinking in complete value chains not only represents an essential change in research on relationships among agricultural producers, processors, and consumers (Devaux et al., 2018) but is also considered a necessity by some authors (Lewandowski et al., 2019). Saetta and Caldarelli (2020), for example, notice an increasing interest in the sustainable (environmental), social and economic effects of agri-food value chains and see achieving sustainable growth by focusing on best management practices and improving social and environmental conditions. Subsequently, the term *Sustainable Supply Chain Management (SSCM)* emerged, describing a specific management type of organisational supply chains to (1) *maximise profits*, (2) *increase stakeholders' social well-being* while at the same time (3) *limiting negative environmental consequences* (Hassini et al., 2012), thus following the economic, social and environmental dimensions of sustainability (Ahi & Searcy, 2013) and bioeconomy. Again, not surprisingly, innovation is believed to be an integral and essential part of developing and implementing this kind of supply-chain sustainability (Kusi-Sarpong et al., 2019). Organisations are believed to achieve a truly sustainable value chain revolving around bioeconomic principles by not only integrating the three dimensions but also by going beyond their typical boundaries: strategising supplier operations transparency, having functional risk management, improving stakeholder engagement but also focusing on recycling, reuse and reducing material flows (*R's*) in the chain (Kusi-Sarpong et al., 2019).

This circular but also sustainable perspective was taken by Virchow et al. (2016) and evolved into the concept of *biomass value webs*, incorporating the complexity of bioeconomy by focusing on the cascading use of biomass, which leads to the interlinkage of different value chains, and resulting in a web structure. Its multidimensional framework takes the physical flow of biomass as the basis, aims to understand the interrelations and linkages between several value chains and their governance, and sheds light on the actors involved (Scheiterle et al., 2018). Of course, the idea of a multi-actor network influencing whole sociotechnical regimes is not new and its most prominent representative is certainly Geels, who described one in his seminal work on technological transitions (Geels, 2002); the difference here is the biomass and sustainability focus. Especially for the bioeconomy, a linear, product-focused value chain approach is considered outdated since it fails to incorporate the complex paths – for example, due to cascading or circularity – a biomass resource can take and does not integrate social, economic, and environmental aspects (Virchow et al., 2016). The approach of a biomass-based value web captures all products and sidestreams derived from all typical processing and branching cascading steps of the value chain and can thus help identify potentials and challenges (Virchow et al., 2016). It thereby transforms the approach of utilising value chains in research into a central, broad element instead of a narrative device. Innovation is regarded as a critical element in that approach, integrating the three sustainability dimensions. Therefore, this work combines the value web idea with an innovation system perspective (Scheiterle et al., 2018).

4.2.5 Summarising an Analytical Framework

While the various theories were described above in detail, the leading, recurring concepts are summarised below in an analytical framework structuring the theoretical foundations (Fig. 4.2.4), and with that, the initial research questions will be updated and adjusted.

As investigated, value chains in a low-tech, bioeconomic environment are believed to be not

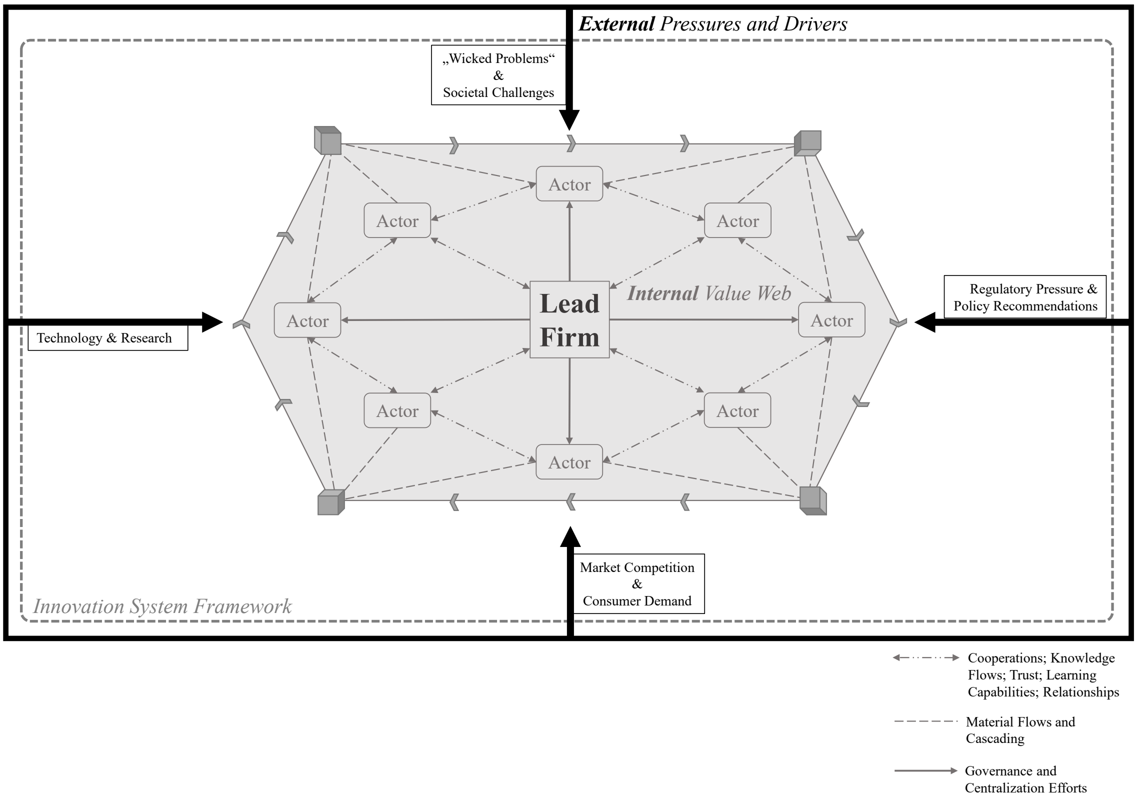


Figure 4.2.4: Analytical framework

configured as linear but as a web instead (*Internal Value Web*) due to adopting approaches following sustainable practices, such as cascading, circularity and the *R*'s (reuse, reduce, recycle) in general. In the framework, especially cascading – due it its concrete and real-world adaptability – is integrated (dashed lines without arrows). A biogenic resource, or biomass, builds the frame of the web and – in a perfect scenario – is used circularly with its different cascades and sidestreams by various actors. A lead firm governs and controls this web, while the actors can take the positions of suppliers, research organisations, public bodies and other stakeholders. However, this lead firm is believed to influence not all actors with the same applied dominance (arrowed lines). Further, the interactions between these actors are of crucial relevance: identifying knowledge flows, learning efforts, trust, and different levels of cooperation is essential to understanding the structure of the underlying innovation system. It is also central to look at the perspective of single actors to identify their absorptive capacity and relational capability; both have importance for the general innovation capability.

Four main external influences could be identified – external pressures and drivers that affect the system, mainly stemming from the green-, eco- and sustainability literature, but also from sustainability transitions (Geels, 2002, 2010; Köhler et al., 2019) and literature on the bioeconomy in general. *Societal challenges and "wicked problems"* gained importance for policymakers during the last 15 years, resulting in their overarching recognition across disciplines and the launch of the Sustainable Development Goals (SDGs) by the United Nations in 2015. Combined with the emergence of an unprecedented global pandemic in recent years that had significant adverse effects on global production networks, these massive social and environmental issues transcend borders, may influence a large part of the global population and thus need to be addressed through collaborative efforts of a wide range of actors (Voegtlin et al., 2022). Mainly due to their multi-dimensional complexity and sheer scope, they are not immediately solvable (Fagerberg & Hutschenreiter, 2020), and while their impact can be direct, their influence on innovation systems, in general, is seen as a rather holistic, ongoing climate that predetermines decision-making for economic processes and policymaking on a larger scale. It can thereby be regarded as a "layered background" for innovation systems.

Regulatory pressure and policies connect seamlessly. Their influence, in comparison, is a lot more direct. Especially for low-tech and agri-food, recent shifts in policy design had a significant impact on the sector. Policies and regulations regarding pest control, use of certain fertilisers, and various EU-wide ordinances – for example, on flower strips – create new incentives and opportunities for some actors but can also function as a hindering factor for others. Whole value chains, or webs, can be involved since regulating cultivation alone significantly affects the continuing chain. Funding for specific crops or processing technologies can be named as incentives. As we will also see later in this work, Germany promoted the production of biogas, which opened an entirely new processing opportunity for sugar factories. *Market and consumer demands* changed significantly with the growing awareness regarding societal challenges. The rise of sustainable, green, environment-protecting and climate-friendly themes in consumer demand across all generations pressures agri-food systems with certain market-pull dynamics, again creating new business opportunities, but greater risks and challenges as well. Switching to organic farming, for example, is associated with high risks for farmers that previously worked conventionally, and steep regulations increase these shift-associated risks. Another important aspect that will be discussed is the changing world market for white sugar and its wide-reaching implications for the whole value web. Lastly, *technology and research*, same as *market and consumers demands*, tend to follow the societal challenges climate, but do also innovate solutions to challenges presented and by that, have a profound influence on the system. Knowledge that is generated by research organisations, which, in turn, cooperate with the lead firm and various actors inside the value web can find its way into practice and can thus drive change inside the innovation system. The closer the cooperation between research and actors, the more knowledge is transferred and the more likely it is to have a positive impact. These external pressures and drivers influence the innovation system environment, where the agri-food value chain is believed to be transformed into a bioeconomic value web. Ultimately, different types and modes of innovation can occur due to the interaction between the unique innovation system shell and the value web core, but also through the internal, bioeconomic configuration.

In summary, the initial set of research questions (1-3) can be updated and complemented with the following sub-questions:

1. Which specificities regarding governance, cooperation dynamics, and actorial relationships does a low-tech, agri-food value chain offer, and which differences occur?
   (a) *Which actors are present, and which capacities and capabilities do they hold?*
   (b) *What kinds of relationships are present between the actors?*
   (c) *Which power has the lead firm in this case, and what kind of governance does it apply to other actors of the value web?*
   (d) *What does the bioeconomic value web look like for the agri-food chain of sugar?*
   (e) *Which of the external factors influence the value web?*
2. How does knowledge flow, how are innovations achieved in a low-tech, agri-food value chain, and which factors have an influence?
   (a) *Which types of knowledge flow in which way between actors?*
   (b) *Which innovation modes and types can be identified?*
   (c) *Which of the external factors influence the innovation system of the sugar industry?*
3. Which characteristics of bioeconomy find application, and in what ways do they influence decision-making in the low-tech value chain of sugar?

These questions will structure the empirical results of this work. Before continuing to answer them, however, the case of sugar needs to be described in more detail, as it is vital to understand its specificities before going into more detail from the case regions afterwards.

4.3 European Beet Sugar Industry

The sugar industry is a prime example of a mature agri-food value chain. The next section briefly sets the scene of the European sugar industry from sugar beet, beginning with a short historical overview. Following the outline of the analytical framework, its inner configuration and structure are described afterward, before external pressures and drivers influencing the system are looked at.

The fact that sugar beet (*Beta vulgaris L.*) contains sugar was first discovered by Oliver de Serres in 1705, the method of extracting sugar from it goes back to Achard in 1799, and shortly after, in 1801, the first sugar beet processing factory was established (Austin, 1928). The beet sugar industry therefore spans over 200 years and is seen as one of the most mature and traditional industries. Over the years, continuous developments and improvements have resulted in sugar beet taking up approximately one-third of the total growing area for sugar crops (Geng & Yang, 2015), while the basic structure of the supply chain mostly stayed the same. Modern sugar beets are biennial crops of temperate and Mediterranean climates and thus have a limited longitudinal maximum; Finland and Sweden are the northernmost countries in Europe in which cultivation happens due to cell death occurring to extensive exposure to temperatures below -5°C (Kaffka & Grantz, 2014). What has to be underlined is that producing sugar is very energy-intensive, especially in the processing phase in the factory (Stevanato et al., 2019). Thus, over the years, the central aim of sugar producers was to make processing as energy-efficient as possible to save costs and fulfil specific regulations (Rajaeifar et al., 2019), further resulting in measures taken to adopt a circular approach (Althoff et al., 2013; Marlander et al., 2003). Cultivating sugar beet nowadays includes sowing specially bred varieties (seeds) and controlling during the growing period via fertilisation, as well as pest and weed control (Cristóbal et al., 2016; Stevanato et al., 2019). After being harvested, the beets are stored near the fields, waiting to be picked up by cleaner loaders – an agricultural machine used for conveniently cleaning and loading beets, especially sugar beets – to be transferred to haulage vehicles, typically lorries, and transported to the nearest sugar factory (Fishpool, 2016). Processing in the factory (Fig. 4.3.1) is also relatively straightforward, with only minor differences occurring between factories. In short, beets are initially cleaned before being sliced into thin slices. Extraction happens with the addition of hot water, which separates the slices into raw juice and beet pulp. The raw juice is then purified using lime into thin juice. Multi-stage evaporation concentrates this thin juice before white sugar (and sugar syrup) are separated by several steps of boiling and crystallization (Lipnizki, 2010).

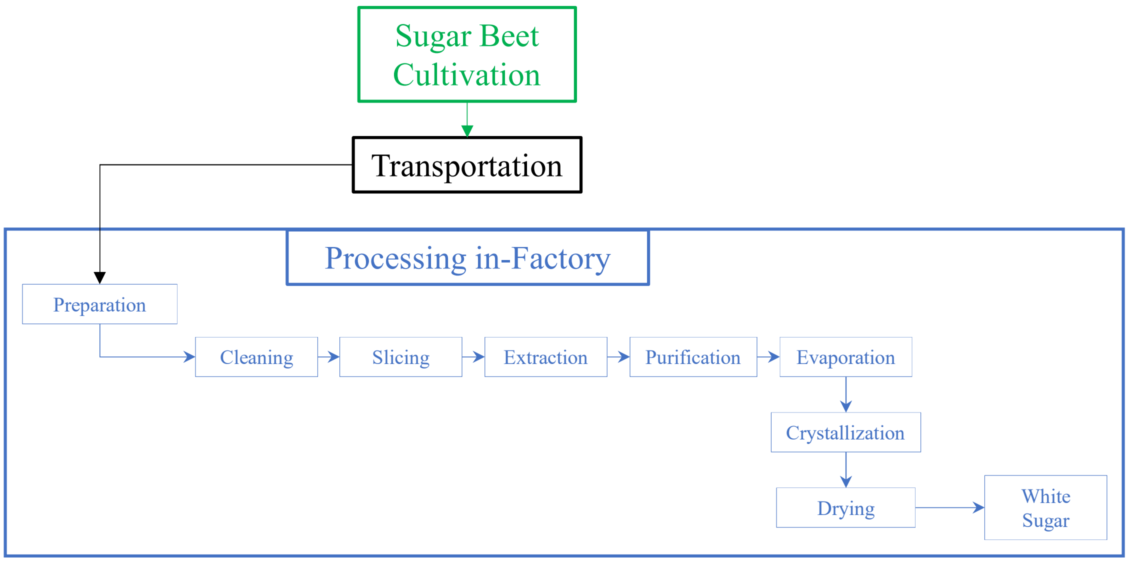


Figure 4.3.1: Simplified processes in sugar production (own graphic based on Stevanato et al. (2019))

The importance of inter-actor relationships and cooperation along the value chain was stated throughout the theoretical considerations. The supply chain of the sugar industry is, in comparison to many other industrial value chains, relatively linear and typically regionally embedded due to the short distance sugar beets can be transported without having to deal with significant losses in quality. This linearity also means that the actor types present in chains of different regions are the same, with only slight variations, thus allowing a standardised approach across all cases. While the essential supply chain is relatively short, for the integrated value web and innovation system perspective, a broader point of view must be applied, including actors not directly involved in the supply chain of sugar beet but having an influence on the chain. The main actors and their interrelations can therefore be put into five broad categories (Fig. 4.3.2). *Farmers* initially cultivate sugar beets, which are transported by a managed logistical operation to the *sugar factory*, where the beet is processed (see Fig. 4.3.1) into mainly white sugar. Furthermore, three other actors occupy relevant positions. First, the *headquarter organisation* is assumed to play a vital role in the chain, applying governing pressure to factories and suppliers further down the line. While in the previous section, agri-food systems were described as highly decentralised, the sugar industry from sugar beet seems to follow a rather unique way, and thus the question regarding how centralised the chain is will be discussed in detail in the results (research question *c.*). *Knowledge providers*, mainly research institutions, tend to give input to multiple actors along the chain and maintain cooperation by transferring various types of knowledge. Lastly, *grower associations* represent the interests of beet farmers in many European countries, conduct negotiations with processing factories, and in many ways play a supportive role for farmers. Finally, while researching and providing seeds used by farmers, seed companies are not a part of the localised, regionally embedded value chain and lack persisting influence on it, hence were not included in this study, but are nevertheless crucial due to their continuous efforts to improve resistance and efficiency of the crop.

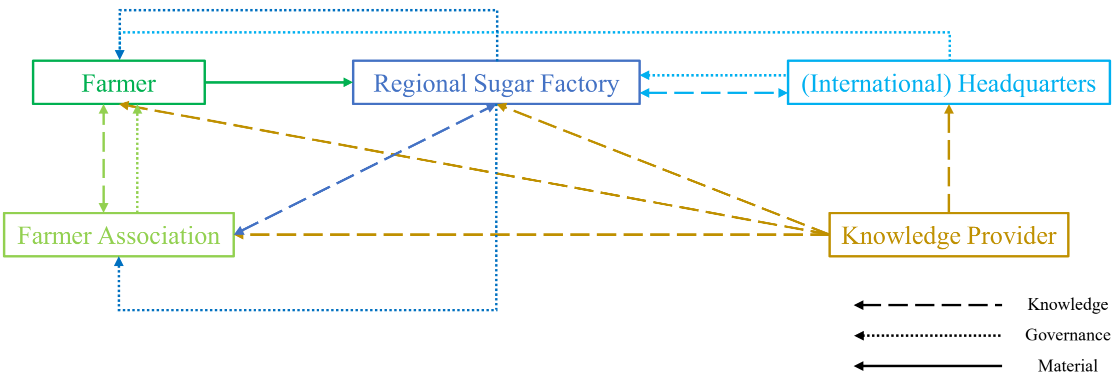


Figure 4.3.2: Essential actor categories in the sugar beet value chain (own graphic)

It has long been a general aim that sustainable development in agriculture has to be done in consideration of economic, ecological and social factors and that modern crop cultivation systems follow environmental goals while ensuring food quality, safety objectives but also competitiveness (Marlander et al., 2003), with sugar beets not being an exception (Stevanato et al., 2019). The increasing yield development and improvements in processing can be primarily attributed to progress in *technology and research*: innovations in breeding – especially crop protection and resistance against pests –, (pre-)fertilisation and weed control, but also improved cultivation and harvest practices, like precision farming – a data, and primarily GPS-driven approach towards farming –, greatly influenced sugar beet cultivation practices (Stevanato et al., 2019). Agricultural research organisations are the primary sources of this knowledge and share it through their interactions with farmers, associations, sugar companies, and their factories.

European sugar manufacturers in 18 countries produced a total of 19.7 million tonnes of sugar in 2017, resulting in a direct contribution to the EU gross domestic product (GDP) of €3.6 billion and accounting for about 1.3% of the food and beverages industry's gross value added (GVA). Including spillover effects, the total GVA effect of the EU sugar manufacturing industry amounted to €15.6 billion, creating 23 700 jobs in primarily rural sugar factories and supporting 166 000 jobs in the agriculture sector through indirect effects. In addition to the jobs directly created by the sugar factories, almost 338 500 indirect and induced jobs along European value chains are supported (Scholz et al., 2019). Germany plays a major role in the EU in sugar beet cultivation, representing around 10% of the global sugar beet production (Alexandri et al., 2019). While a downward trend in the cultivation area can be noticed due to the modernisation of cultivation and cheaper sugar cane production, crop yields steadily increased due to *technology and research* results greatly influencing farming practices.

Looking towards *regulatory pressure & policy recommendations*, the European sugar market recently had to deal with a significant incision. In 2017, the EU restriction on the sugar market ended and resulted in the deregulation and liberalisation of the EU sugar market. This restriction, in its latest instalment, allocated yearly production quotas of 13.5 million tonnes for sugar and 0.7 million tonnes for isoglucose, as well as a minimum purchase price of €26.3 per tonne of sugar beet to EU Member States and then to sugar enterprises, with producers exceeding this quota having to pay a surplus (Rossi, 2018). Now, an enormous challenge presented itself with its abandonment. From 1968 to 2006, the EU sugar regime operated essentially unchanged. The main policy objective of the quota beginning in 1968 was to attain self-sufficiency, successively cut market distortions, and fulfil the EU's international commitments (Rossi, 2018). A study from 2004, not surprisingly, called sugar "one of the most policy distorted of all commodities, and the European Union [...] among the worst offenders" (Mitchell & Bank, 2004, p.3). Mitchell and Bank, among others, saw the protectionist tendencies as a problem, especially for developing countries exporting sugar and not being able to compete, thus recommending reforms. In 2006, the first reform reshaped the quota system and reformed the support measures; however, with its remaining production quota and official prices, the sector was still far from being market-oriented. Instead, a scenario occurred where restricted EU output, governed by quotas, resulted in much higher EU sugar prices than world market prices (Paha et al., 2021). The EU sugar market was immensely concentrated and even monopolistic at times, with only seven alliances (Südzucker, Nordzucker, Tereos, Associated British Foods, Pfeifer and Langen, Royal Cosun, Cristal Union) controlling nearly 90% of the production, while at the same time being protected from imports due to high duties and taxes (Maitah et al., 2016). Therefore, the definitive liberation of the market by ending the quota was believed necessary by October 2017 (Rossi, 2018). Since then, the produced quantities were no longer controlled, allowing actors in the sector to produce as much sugar as they want (Huyghe et al., 2020), while the EU sugar market now also needed to compete globally – crystallised sucrose is reasonably easy to store and to transport (Marlander et al., 2003) – and the market therefore now also had to face market competition and was heavily influenced by that: With third countries increasing their volumes, European sugar producers also increased their margins, which led to excessive price volatility due to surplusses. The EU sugar price dropped significantly, especially compared to sugar processed from sugar cane from third countries, where production is much cheaper, and heavy governmental funding and protection are often provided (Fig. 4.3.3) (Paha et al., 2021).

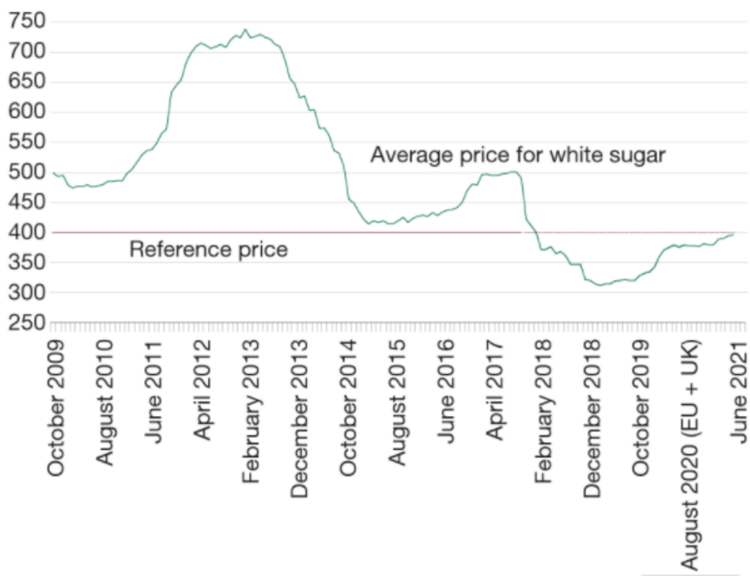


Figure 4.3.3: Average and reference price for white sugar (per tonne) in the EU (in €) (Paha et al., 2021)

While *societal challenges*, as an external pressure, primarily refer to complex problems like climate change, the increasing problem of obesity in western industrialised nations (Stanhope, 2016) certainly influenced *consumer demands*. It led to a significant shift in consumer behaviour in the last 20 years and a significant push for healthier food choices (McCain et al., 2018). Having a better grasp of nutrition in general and sugar specifically, consumers make more considered purchasing choices. Combined with efforts to make nutritional values visible on products, the sugar market was undoubtedly affected. For example, the volume of sugars sold per capita per day from soft drinks declined by 30% in the UK between 2015 and 2018 (Bandy et al., 2020). This shift in the consumer behaviour can also be seen in the recent *"Euromonitor's Voice of the Consumer: Health and Nutrition Survey"*: 53% of respondents see *"Eat less sugar"* as their method of weight loss (Mascaraque, 2021). Of course, consumer behaviour is a very nuanced and complicated topic to touch on, with significant differences between countries. It is therefore difficult to make a generalised statement across national borders; however, a reference to its potential influence is nevertheless indispensable.

From a mere innovative environment or system point of view, these conditions can be considered rather beneficial. The European sugar industry faces a challenging market situation with significant losses, leading to reorganisations, restructurings and plant closings (Huyghe et al., 2020). Such uncertainty can act as a relevant external factor for innovation, especially in a mature industry, where the technology and the general conditions mostly stayed the same over the years, and only incremental, process-oriented change occurred. This rather beneficial "climate" can have a revitalising effect. Combined with a new policy regime changing toward favouring the bioeconomy, the sugar industry in Europe can function as a perfect research case of how innovation in low-tech industries is applied against the backdrop of a bioeconomy. The need for an appropriate innovation agenda that avoids over-exploitation of resources, more efficient use of resources and the valorisation of waste and co-products is one of the challenges of the bioeconomy transition (Dabbert et al., 2017). The sugar industry also seems to have taken notice: in a position paper by the European Association of Sugar Producers (CEFS), the view of *sugar factories as bio-refineries* is established, as well as a (1) *equal treatment of gasoline and biomaterials in material uses,* (2) *more promotion of investment in bioeconomy*, (3) *more promotion of bioeconomy projects themselves* and (4) *a comprehensive review of the political framework demanded* (CEFS EU Sugar, 2019). If and how these positions get implemented across the value web will be answered in the results section of this work.

4.4 Data and Methods

Initially, suitable firms were chosen by purposive sampling (Palinkas et al., 2015). As discussed earlier, the European beet sugar sector is centred around only a few companies (Südzucker, Nordzucker, Tereos, Associated British Foods, Pfeifer and Langen, Royal Cosun, Cristal Union); therefore, the initial identification of key firms was simple. However, as not only the companies themselves but other actors of the value chain were also to be interviewed, the initial set was found to be too large. Therefore, three out of the seven companies that presented the most optimal research conditions were chosen: Cosun Beet Company (former Suiker Unie; NL), Nordzucker (DK/SE) and Pfeifer & Langen (D). With these, two cases in Germany (Mecklenburg-Western Pomerania, Saxony-Anhalt) and one in southern Sweden (Skane) were investigated, with their respective headquarters being located in Denmark (Nordzucker), the Netherlands (Cosun Beet Company) and Germany (Pfeifer & Langen). This selection allowed a comparison of the value chains on the intra- and inter-country level while also shedding light on differences in governing practice of headquarters in three different European countries. Following the essential actor categories presented in 4.3.2 that are believed to have the most significant influence on the sugar beet value web, one case region per company was chosen. As explained in the last section, seed companies were left out on purpose. Instead, specific questions were included to examine how and where stakeholders get the sugar beet seeds and how the relationship is in general. The proximity of the regions played a role as well, as they had to be sufficiently distant from each other not to interfere but not too separated to have a completely different social, economic and climatic setting; comparability needed to be given. The rationale for multiple cases lies in uncovering the flow of information and webs of relations from multiple points of view, shedding light on different configurations and governance structures to gain more in-depth insights (Buciuni & Finotto, 2016). For privacy purposes and the general aim of this work to not only compare cases but to examine how innovation, driven by which forces, occurs, certain pseudonyms will be used for actors (Table 4.4.1).

	Farmer	**Farmers / Growers Association**	**Sugar Factory**	**Knowledge Pr.**	**Head-quarters**
Case A	F-A	V-A	S-A	K-A	H-A
Case B	F-B	V-B / V*-B	S-B	K-B	H-B
Case C	F-C	V-C / V*-C	S-C	K-C	H-C

Table 4.4.1: Pseudonyms for interviewed actors

After the selection, the analytical framework was translated into a semi-directive interview guideline for each actor group to assess their situation and point of view. Interviews were chosen as the data collection method for an in-depth look into the mechanisms described in the analytical framework. While providing consistency in the form of a standardised approach, it also offers the flexibility to double down on interesting conversational paths during the interviews (Lamprinopoulou et al., 2014). While the individual questions between the groups differed, the sets of questions in all five guidelines covered the same categories: *(1) Knowledge and Innovation, (2) Value Chain and By-Products, (3) Cooperation and (4) Bioeconomy* (see Appendix 4.A for the guidelines). In total, 17[1] stakeholder, semi-structured interviews in the three case regions were conducted in a one-wave fashion from June 2018 to July 2020. The interviews lasted between 13 and 110 minutes and were done either face-to-face or by telephone in English or German (Table 4.4.2). All interviews were recorded and fully transcribed in MaxQDA using the simplified transcription system

[1]Interviews V-B and V-C were repeated (V*-B and V*-C) due to an error in planning

by Dresing and Pehl (2018), applying non-disclosure agreements where necessary. When, during the results, cites from German interviews were used, they were first translated into English to ensure anonymity.

Interview	Duration (in min)	Date
K-A	49:35	28.06.2018
S-A	75:59	28.06.2018
F-A	55:22	29.06.2018
H-A	96:20	06.07.2018
S-B	87:09	19.07.2018
V-A	24:05	12.09.2018
V-B	26:22	11.10.2018
F-B	42:08	06.11.2018
V*-B	27:49	10.12.2018
K-B	74:52	14.01.2019
H-B	101:57	10.07.2019
H-C	64:51	17.01.2020
S-C	53:13	17.02.2020
V-C	47:39	20.02.2020
F-C	30:50	25.02.2020
V*-C	55:50	02.07.2020
K-C	13:45	09.07.2020

Table 4.4.2: Interview dates and durations

Qualitative Content Analysis (QCA) provided a perfect fit as the primary analysis method for the transcriptions. QCA can manage large quantities of material with the technical knowledge of the Quantitative Content Analysis but is qualitative-interpretative in its execution, allowing to also grasp latent meanings. Therefore, the procedure is strictly rule-based and highly intersubjectively verifiable (Kuckartz, 2019). Especially in an already fuzzy bioeconomy research area, decluttering plays an important role. In principle, the procedure consists of two steps. First, a criteria system must be created: either inductively on the material or deductively from the analytical framework. Although precise rules of content analysis accompany this process, it remains a qualitative-interpretive act and is referred to as deductive category application. In the second step, coding, the interview transcripts are analysed to determine whether specific categories can be assigned multiple text passages (Gioia et al., 2013). This category-driven approach and the category system are the main instruments of the analysis (Mayring & Fenzl, 2019), with analysis units to be defined in advance. For them, the coding unit determines the minimum text component assigned to a category, the context unit determines the material used for the respective coding, and the evaluation unit defines the text portions that are compared to the category system. For this study, the analysis units are defined as follows (Table 4.4.3).

In this work, the criteria catalogue and its categories were derived deductively from the study's analytical framework and main research questions, creating three distinct categories *(1) innovation and knowledge, (2) bioeconomy characteristics* and *(3) value chain* and their specific sub-categories. The detailed criteria catalogue can be found in Appendix

Coding unit	several words with context, meaningful phrases with regard to the criteria catalogue
Context unit	complete answer text to a question asked
Evaluation unit	all interview transcripts of the study

Table 4.4.3: Analysis units

4.B. Assigning them to text passages of the transcribed interviews (*coding*) was also done in MaxQDA, primarily aimed at finding answers to the formulated research questions (Kuckartz, 2019) while constantly being reanalysed and reassessed. That way, relevant and exciting results could be extracted from the source material.

4.5 Results

In the following, the results of the semi-structured interviews will be presented and structured based on the updated research question as presented on page 114.

4.5.1 Value Chain Configuration

Cultivation and Transport

Before farmers start cultivating sugar beets, they need to obtain the seeds. In all case regions, seeds are bought from the regional sugar factory. Farmers usually have a choice between a range of varieties tailored to the specific climatic conditions of their region, which can differ from year to year. The headquarters decide more (Case A) or less (Case B and C) in cooperation with the sugar factory about which varieties are chosen from which supplier for the year, following prior coordination and contracting with the seed companies (H-A, pos.197). The connection between seed companies and headquarters as well as factories is described by all actor types as a functional and good relationship with mutual interests. For farmers, deciding whether to grow sugar beet or another crop depends on various factors. First and foremost, price is a major driver in this decision for farmers. Growing sugar beet often is "the most profitable" (F-A, pos.65) option in comparison, with a stable yield and only minor fluctuations, thus being calculatable, at least until 2018 (F-C, pos.17). Another reason for cultivating sugar beets is to support crop rotation since sugar beets are leaf crops, not stalk crops like wheat or barley; cultivating them thus breaks up the crop cycle (F-B, pos.24) – which is not only necessary for soil health, but also mandatory by agricultural law in some European countries. Sugar beets can also work as a cleaning (recovery) crop in the rotation since supplied nitrogen is absorbed almost fully by the beets, and nitrate content in the soil is especially low after cultivating them (V-C, pos.77). Another factor playing into this argument is that different plant protections (herbicides, pesticides) are allowed for sugar beet cultivation, which in turn also prepares the soil for the consecutive crop (F-B, pos.24). Farmers also argued for the relatively simple and non-labour intensive cultivation, which in turn freed up time for other practices, such as repairing drainage systems or combating pests (F-B, pos.24). However, these arguments have also to be put into perspective. Sugar beets cannot be grown yearly – as a monoculture – since the soil benefits heavily from crop rotation, and sugar beets do not maintain healthy soils on their own (Bowles et al., 2020). There are also certain risks to the cultivation. The first is, as it is also a problem for other agri-food crops, that the natural factors of weather, precipitation, temperature, and sunshine hours directly affect the yield and, as of yet, cannot be forecasted with accuracy for a growing season. For example, the drought in 2018 left many farmers with a zero-sum yield or even worse (F-C, pos.21). The other predominantly communicated challenge to the farmers lies in storing the beets after harvest in piles near the fields, waiting to get picked up and transported to the sugar factory:

> *"[...] you have quite bigger risks in growing sugar beets compared to wheat, cereals, or all cereals. Because the last delivery of the sugar beets in the mid of January and normally we have the last harvesting time in the mid of November then you have to store them for two months [...]"* (F-A, pos.65)

A typical beet campaign in Northern Europe runs from September until January/February, and not all sugar beets can be picked up simultaneously; the farmer is responsible for shielding the beet against freezing, rot and weather until it is picked up, which can be, depending on the latitude and weather conditions, get increasingly problematic (K-A, pos.76). The date at which the pick-up is scheduled by the sugar factory varies from year to year so that all farmers are treated fairly in a rotating manner (H-C, pos.105). While storage was explicitly stated as a recurring problem by farmers, the rotation was reviewed as fair across the interviewees. Besides the farmers' storage problem, transport and logistics are seen by headquarters and the sugar factories (e.g. S-A, pos.152; H-B, pos.128; S-C, pos.114) as a constant challenge. While historically farmers delivered the beets on their own to their respective factories, nowadays, the sugar factory or headquarters subcontracts transport companies to do the delivery with lorries, as they can cover longer distances and have a larger capacity while also removing harmful uncertainties with being dependent on a delivery organised by farmers themselves. Factories processing sugar from sugar beet must constantly run during the campaign; a constant flow of raw material is crucial. On a typical day during the beet campaign, 700 truck deliveries are scheduled (S-A, pos.160) and even more in some regions, making logistical planning an ongoing challenge but also a vantage point for (process) innovation. The farmers' proximity to the factory also plays a role. Transporting a voluminous raw material like sugar beet is expensive, especially when lorries have to drive long distances; the best setting is to have large farms as close to the factory as possible. That is why a specific "zone" exists around every factory, which demarks the furthest point at which transport is still economically feasible (H-B, pos. 92). In regions with overlapping zones of different factories, competition and attraction around farmers resulted: factories organised acquisition and information events, soliciting the farmers (S-C, pos.40). Of course, that substantially increased the freedom contractual-wise for farmers and provided them with higher flexibility and thus also a more powerful position in the chain.

Actor Characteristics and Linkages

The studied case regions have different models in various contractual relationships, specifying, for example, how many beets are to be delivered, which variety is to be used or when the collection takes place. This brings up the critical topic of interactions and governance, and thereby introduces a pivotal actor present in each of the observed value chains: the growers association; which is not to be confused with the more general farmers association.

> *"The Farmers' Association also works on countless other issues concerning general agricultural and environmental policy. So we are not a political association like the Farmers' Association; we are a professional association, which means we have a very clear professional orientation. The Farmers' Association is not legitimised to negotiate prices and contracts as we do."* (V-C, pos.37)

The growers association represents the sugar beet farmers to the sugar factory and often the headquarters, acting as a direct proxy. It plays a vital role in the chain, as it acts as the main contacting point for the farmers for support and the sugar industry for yearly contract negotiations. Here, two contracts are of importance for farmers. First, the industry agreement regulates the conditions under which the sugar beet can be delivered and includes parameters, such as dirt content, sugar content or remuneration, and dictates the price per tonne. It results from a recurring negotiation between the growers association and the sugar industry and runs from one to three years, differing by region. The cultivation contract, in comparison, refers to an individual agreement between factories and farmers following the industry agreement and regulates the amount of sugar delivered based on the average sugar content of the last few years. Farmers can thereby decide flexibly, depending on their experience and risk affinity (F-B, pos.80). Therefore, the relationship between farmers and growers association is a critical one. Trust plays a major role in that relationship, as they directly decide for them during the negotiations. While farmers can consult the sugar factories' and the seed companies' cultivation advisors, they usually are in much closer contact with the growers association and their respective knowledge organisations. Interestingly, across all case regions, farmers have a positive to very favourable opinion of their regional association:

> *"Well, I think its quite ok. [...] It's quite a strong organisation [...], and they know how it works and what's roughly where you can be in the negotiations. Because otherwise, if I should negotiate with the industry, I think that would not be good at all."* (F-A, pos.97)

"[...] I personally feel well represented by it. [...] And I have just seen this again recently [...] that everyone is saying that the growers association must do more so that we can achieve a better price. But when the world market is [that] competitive, the alternative is that the factory [...] closes down. So [...] I am happy if the growers association manages to keep the factory alive and we farmers also compromise so that we can continue to produce sugar."(F-B, pos. 208)

"The work is good [...]. We negotiate seed prices, beet prices, [...] transport prices and so on, and yes, things have improved in recent years [...] [and] the growers association is doing a good job under these conditions." (F-C, pos.71)

In addition, the growers associations also positively assess the contact with the sugar industry, being aware of the impact of the market liberalisation: Across all case regions, the contractual relationships are valued positively and are also met with understanding for the recent market hardships (e.g. V-A, pos.80). A high level of trust seems to stem from the farmers themselves, which is vital for the functional relationship. Reasons can also be attributed to mutual interest in their practice because they rely heavily on each other, generally for years to come (F-A, pos.179), the long quota history under which this kind of cooperation was initiated and had time to grow, but also the shortness of the supply chain and the fact that only a few actors are involved and that hierarchies between growers associations and farmers are usually rather flat than steep. Trust is therefore hugely favoured between the actors, immensely enhancing their connection capabilities. Another reason for the tight contact between the growers association and the farmers is their role as a direct supporters in situations of need. They organise meetings and sessions focused on helping farmers achieve better results and farming practices and are generally well managed (F-B, pos.224). However, they also are obligated because farmers give up some freedom, and trust must be maintained.

Another important actor in the value web is at least one knowledge provider, giving input to machinery development, cultivation, and general support knowledge-wise. How they are organised and financed differs and can range from research institutes specialised in sugar beet cultivation to more general agricultural research facilities. While the factories and headquarters also have connections to research and, in all cases, an R&D unit, these research organisations function as direct sources of knowledge for farmers and growers associations (K-A, pos.88) and as a link to the scientific world for them. Their connection to the growers associations and farmers differs in each case region. While in some, farmers are approached and cooperated with, in others, interaction lacks completely or is only present for field trials being initiated by the research organisation. Nonetheless, while not occupying a central position in the supply chain, they hold a central position to share knowledge, which will be discussed in more detail in the next section.

Between farmers, close interactions happen. In all interviews with farmers, positive relationships with other farmers were brought up (F-A, pos.175; F-B, pos.172). Reasons for that are the feeling of a shared identity, an already close relationship with the help of the growers association and often the sharing of machinery (F-C, pos.29). The last point is frequently given, as new agricultural machines are expensive and would cost too much for a single farmer to handle, leading to the creation of so-called machinery rings. These can be seen as a possibility for knowledge exchange and a further build-up of trust. However, certain hurdles to interaction with other farmers do exist. First, proximity helps immensely with informal contact; the further away or the more extensive the farm area is, the weaker the direct connection. However, due to organised events and the fact that farmers, as a profession, tend to stick together as a community (F-B, pos.172), this effect did not seem to have a considerable impact on linkages between farmers. It is possible that, in some cases, farmers only interact with farmers located on the same patch of leased land, considering others as direct competitors, which was not the case in the studied regions. In most instances, the connection between farmers is excellent, and a common identity can be underlined, bolstering trust and the possibility to minimise risk through sharing. The growers associations extensively support this already valuable relationship (V-A, pos.48), leading to a strongly connected and uniform cultivation side of the value chain.

Centralisation and Governance

In the literature, agri-food systems are described as being highly decentralised (see section 4.2.4). That may be true for the system perspective, including farmers, associations and knowledge; however, no chain can be entirely centralised or decentralised; some nuances are present. If we initially look at the situation between headquarters, hereby the lead firm, and their factories in the sugar industry, these nuances become apparent. The lead firm for Case A seems to provide guidelines regarding new technology but leaves the processing to the factory. A factory cannot decide on new technology, e.g. a new machine for extraction, without having it run by the headquarters. The argument here is that the shared, combined knowledge and experience of the whole group on a particular processing step always outweighs the idea of a single entity (H-A, pos.24). The sugar factory supports this claim and furthers that they are pretty free regarding individual projects and new installations once the headquarters approves these since they financially support the proposals. Since the factory runs the campaign and coordinates the processes around it, it does not have the feeling of being in a captive relationship (S-A, pos. 44). In Case B, a more open, independent coordination seems to be in place, with only a few supporting lines. The factory is regarded as a stand-alone unit, and while it reports to the headquarters, it is solely responsible for the operation in the case region. The factory does, same as in Region A, benefit from the possibilities of a R&D network and technology developments undertaken by the headquarters and is supported when necessary (H-B, pos.12). Apart from that, they act independently when cooperating with authorities or local policy (S-B, pos.18), while the hierarchy is described as being carried out on a more horizontal level (H-B, pos.12). Case C then presents a dilemma: while the headquarters envisages a central organisation with local freedom, stemming from the idea of subsidiarity (H-C, pos.9), the point of view from the sugar factory sounds a lot less free, as they can decide relatively little freely. Sales planning is done centrally, and there are only small degrees of freedom for the factory regarding strategic planning:

> *"[If] we look at our strategic planning in the factory, we also have small degrees of freedom there, I'll say so, it's already controlled a lot by the head office, and if not, then it is at least monitored."* (S-C, pos.18)

To summarise, the lead firms in Cases A and C play an essential role in the governance of the factories, while Case B sees much more individual freedom. In all three case regions, some form of reporting is in place, while Cases A and C need approval before committing to projects. All cases benefit from the network of knowledge of the headquarters' R&D. The impression of an elevated position of the lead firm, with a more (C, A) or less (B) powerful position manifests. Farmers and growers associations are not in a captive role in this value chain, nor are they influenced directly by the lead firm. Instead, they are free to choose which crops to grow, and while specific incentives are frequently communicated to them by the factories and the industry in general or by growers associations, they do not necessarily have to cultivate sugar beet. Therefore, they contain power in the sense that factories cannot exploit or take advantage of them without risking their resource supply. In regions where multiple factories are vying for farmers' favour, this power grows with their freedom of choice and another layer is added. The growers associations are in a unique position since they have to fulfil the needs of farmers while also successfully negotiating to reach an agreement with the sugar factories. Farmers have high levels of trust towards them while being dependent on them simultaneously. This gives them a unique role due to their power on the one hand (combining the interests of all farmers, negotiating with the sugar industry) and sense of responsibility (caring for farmers as much as possible) on the other. Their balancing and bridging characteristics are a key part of the functioning relationship. Since they represent the farmers directly while trying to find the most optimal middle way for all involved during price negotiations, the processing side (headquarters and factories) has to respect their power in this regard. Therefore, a mutual interest and understanding system remains between the cultivation side and processing, while the situation is much more hierarchically ordered in parts between headquarters and factories. Therefore, it is not an easy task to decide on whether this particular case of a low-tech value chain or even a value web is centralised or decentralised and which configuration mode concretely applies. For a decentralised version speaks the farmers' flexible and powerful role, while arguments for a centralised system can be found in the relationship between headquarters and factories. Interestingly, the growers associations' power and governance over the farmers get never regarded negatively during the interviews, quite the opposite, while it certainly is a centralised system, since they bundle interests centrally and communicate in their place. The possible explanation is undoubtedly the high levels of trust and the generally good relationship between them. Additionally, members of the growers associations are often, by profession, farmers, thus having high levels of understanding and relatability. Following the (global) value chain configuration ideas of Gereffi et al. (2005), an approach to this particular, somewhat local, sugary configuration would be Fig. 4.5.1:

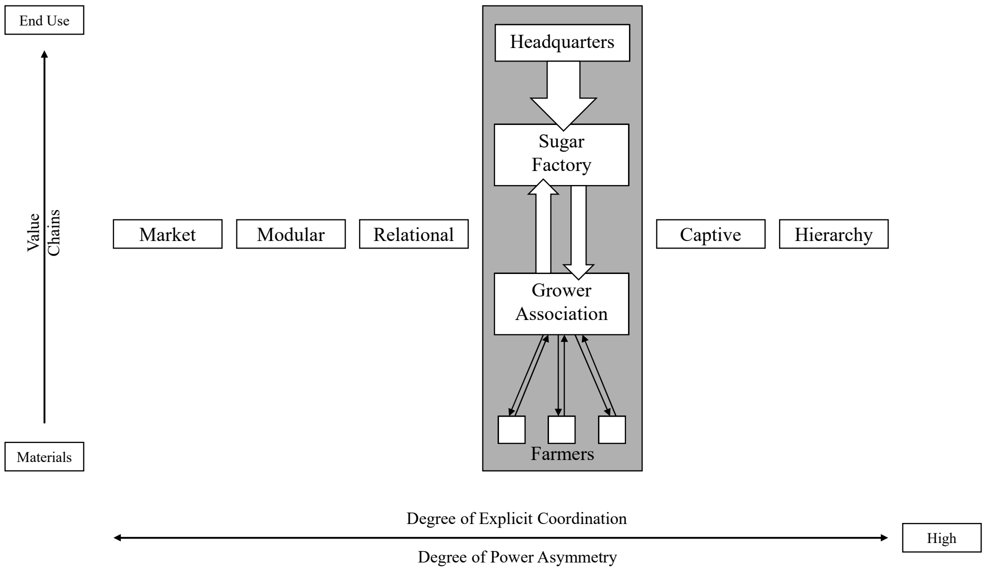


Figure 4.5.1: Sugar value chain configuration (own graphic based on Gereffi et al. (2005))

The special relationship between farmers and the growers association is depicted by two, instead of only one arrow as suppliers. While the growers association does not deliver the material to the factory, it is the decisive instance for price negotiations. Although between factories and farmers agreements regarding delivered quantities and price are in place, these are primarily negotiated by the growers association, hence their relational connection to the sugar factory. The position of sugar factories, as discussed in the forthcoming chapter on knowledge and innovation, can be seen as precarious. Despite their freedoms, from a value chain configuration point of view, they are in a hierarchically subordinate position to the headquarters and lack, in many cases, freedom of choice. While they have a certain power in their processing capabilities, most critical decisions (technology, R&D projects, varieties, machinery) are decided only in agreement with the lead firm or by it completely. Therefore, in comparison to the other configuration models, sugar can be categorised between relational, due to its cultivation part, and captive, because of its organisational and management side. While many of these arguments can also be made for the discussion on whether the chain is centralised or decentralised, like the flexibility of farmers as an indicator of low levels of centralisation, the rather central positions and connections of and between growers associations, sugar factories and headquarters tend to favour a centralised view. In the end, a combination of a more decentralised lower and a more centralised upper half seems to be the best fit.

Circular Sugar Factories

Across all factories, white sugar is regarded as the main product at the end of production. White sugar can be sold in different particle sizes, from powdered sugar, over icings to chunks and other dried products, and in the form of liquids, like syrups. While the marketed end products and some minor steps to prepare the sugar at the end of the chain differ, the steps beforehand are the same. In all interviews, customers of these end products were never concretely named but only hinted at. Soft drinks seem to be the largest buyer, with chocolate, bakery, confectionery and dairy following (H-B, pos.36). During the analysis of the interviews, it quickly became apparent that sugar production and beet processing work nearly the same in all factories (see section 4.3), with the only meaningful differences occurring in if and how by-products are utilised and valorised. The main reasons for this lack of differentiation are seen in the ease of the process itself and its long history of continuous improvements, but also a relatively small count of suppliers for machinery and downsizing of capacity, the latter due to the quota regime (H-A, pos.16). What transforms this typical agri-food value chain into a more bioeconomic value web is the use of by-products, the recirculation of residues, thereby following a cascading approach and thus allowing for circularly using sidestreams. While white sugar was always the main output, using various sidestreams became both possibility and reality over the years. Reasons for that lie in a combination of external drivers affecting headquarters or sugar factories in a way that leads ultimately to the adoption of Sustainable Supply Chain Management (SSCM). Sidestreams are, in all cases, valorised to (1) *maximise profits*, (2) *increase stakeholders' social well-being* while also (3) *limiting negative environmental consequences*. Aspect (3) is closely related to (1), since in the current policy regime, limiting negative environmental consequences almost always means to maximise profits, either directly due to regulations or indirect due to customer demands. When asked about the reasons for increasing use of sidestreams, the responses directly fall into those lines. Most commonly referred to was an increase in the energy efficiency of the production process and thereby saving energy (e.g. S-C, pos.152), followed by a better valorisation of residues for financial reasons (S-A, pos.296), general financial incentives triggered by subsidisation policies (H-B, pos.150) and also particular demands from customers and thus the market (H-C, pos.25). These factors can be observed in all case regions and led to a situation where nearly 100% of the raw material is utilised in some form. Fig. 4.5.2 provides an updated overview based on Fig. 4.3.1 of the possible sidestreams, underlining their cascading and circularity efforts.

Following the cultivation and processing steps, nearly all residues are utilised. Beet leaves are ploughed back into the soil as fertiliser due to their high nitrogen content, stones left after cleaning are sold to construction and roadwork, and the soil is sometimes returned

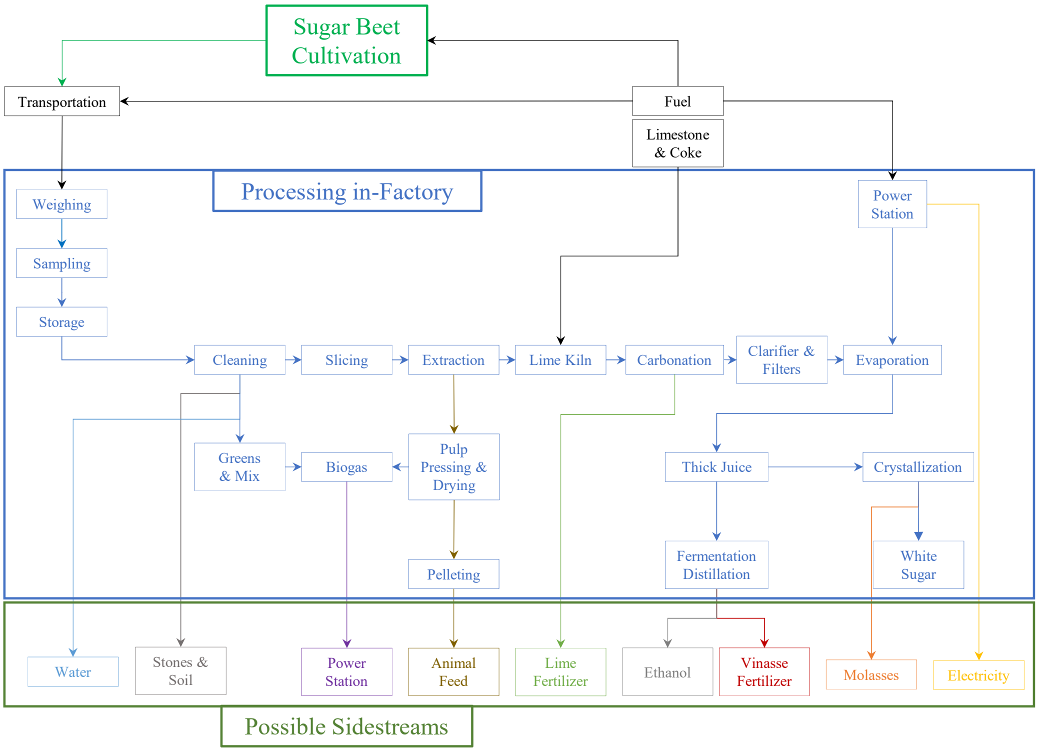


Figure 4.5.2: Sidestreams of sugar beet processing (own graphic)

to the farmer for use on-field, while wastewater is purified and then used in the extraction process. While the pulp is pressed and dried to be used as pellets for animal feed, it can also be fed with residues from the cleaning step (greens and a mixture of roots) into a biogas plant, often on-site, providing energy either for the factory or to be fed into the gas grid. The excess lime from the carbonation is being sold as fertiliser, and residual steam from the evaporation step can also be used to dry beet pulp, making it more efficient energy-wise. Excess molasses can also be used for animal feed, while excessive thick juice can be further processed into bioethanol by fermentation. All by-product processes were encountered in the regions except for steam drying, biogas, and bioethanol production. For these, policy and subsidisation play a significant role.

External Drivers influencing the Value Chain

The most significant external driver is policy. The EU agricultural policy, as agreed upon at the Stresa conference in July 1958, established a common pricing system (Common Agricultural Policy – CAP) to protect farmers (Haque et al., 2009), and is an especially complicated matter to tackle (Cadillo-Benalcazar et al., 2021) and, combined with national agricultural regulations on top, would in many ways go beyond the scope of this study. However, what can be said in shortness is that reforms in the CAP in the early 2000s led to a new Common Market Organisation for sugar (which did not change significantly since its inception in 1968, as discussed in section 4.3), which drastically restructured the market by progressively reducing the price of sugar and sugar beets, leading to a decisive decrease in production, and by that, 79 factory closings and consolidation efforts (Haque et al., 2009). However, following the outline of the 2003 Biofuel Directive – a frontrunner for the 2007 Renewable Energy Road Map – non-food sugar was excluded from the production quotas (Swinbank, 2009). This led to a situation where factories could follow the incentives provided by both the new CMO and Biofuel Directive and tap into the production of Bioethanol. This would not have been feasible, thus possible, if it was not for the policy change (H-B, pos.150). Not all producers followed suit; some were concerned about the volatility of Bioethanol:

> *"The price of the bioethanol have since the plant was built been very volatile and more or less only decided by the political winds, and we have had [...] bloody red years sometimes where if you would have been the [...] ethanol company and not a sugar company [...] you would have closed. [...] And so I think now maybe the wind is like that [...], but [...] when the next plan will come then you will reduce even more [...] of your first generation fuel you can put to the gasoline, [...] because first-generation fuel is on the way out."* (H-A, pos.265-269)

Others did not want to be overdependent:

> *"At that time, we were working [under the sugar quota], and we didn't want to start a product where we were again very dependent on political decisions"* (H-C, pos.133)

In any way, reactions to this first significant change in EU sugar policy in 2006 led to a more consolidated but still policy-distorted market, which was in desperate need of fundamental reform – liberalisation – happening in 2018. What it did achieve, however, was boosting the possibility to valorise sidestreams and providing a financial incentive to do so. In regards to principles of bioeconomy, against all odds, this can be seen as a good thing. However, when it comes to biogas, subsidisation policies can, in extreme cases, also counter a primary principle of bioeconomy – circularity:

> *"It would be even more feasible because we now process the biogas in the sugar factory to natural gas quality, which means a lot of effort. The raw gas could also be burnt directly in the sugar factory, at least during the campaign. That would be much more effective. [...] But there are political reasons against it. There is so much more money for the purified and processed gas, and afterwards, it can be bought back cheaper. That is the perversion of our economy at the moment. [...] So the pipelines are there; they have been laid. One could switch over immediately. [...] But that is subsidy policy, which leads to stupid excesses. That's simply the way it is."* (V*-B, pos.180-192)

In general, there has not been an independent EU policy regarding biogas. The Waste Directive and the EU Bioeconomy Strategy only briefly discuss biogas solutions, and the Renewable Energy Directive and the Landfill Directive only impact it indirectly (Gustafsson & Anderberg, 2022). While no discernible progress toward a common biogas policy was made during the last 20 years, this began to change recently: Biogas solutions are essential to three new strategies established under the European Green Deal in 2020. Before, biogas was mostly driven by national and regional efforts and laws, resulting in various settings (Gustafsson & Anderberg, 2022) and strange configurations, like the example given above. Nevertheless, national and international regulations and policies substantially influenced the sugar value chain across all regions over the last 20 years, leading to more circular and cascading examples. Especially valorising biogas and bioethanol, as sidestreams and their – as will be touched upon in the subsequent section (4.5.2) on knowledge and innovation – early hints at transforming sugar factories to biorefineries were substantially boosted by policies and regulations. They would not have been feasible without them and ultimately helped design the value chain more towards a bioeconomic value web.

Subsidisation, regulations, and policies are by no means the only external factors influencing the value web of sugar. The recent end of the quota system had an unprecedented incision. As the quota put a cap on production, the cultivated area was also far smaller across Europe, mainly due to the restructuring in 2006. With the liberalisation of the market, every sugar producer expanded their cultivated areas to utilise their factories to the full extent, and the first harvest under that new regime in 2017 was an especially good one. Therefore, the price for sugar on the world market tanked, leading to European sugar producers marketing the quantities supposed to go to the world market in Europe instead, thereby crashing the price of the European market even more. On top of that, a sizeable French sugar company, heavily reliant on cash flow, had to sell sugar with losses to stay afloat, which further dropped the price. For the sugar industry, the quota meant a drastic cut. Due to a drought in 2018 and smaller cultivated areas due to the crashed prices, the quantities were declining significantly after the first year, leading to some recovery in price, and with the recent temporal lag, it is believed to continue doing so. With the market liberalisation, European sugar now has to compete for the first time against producers from third countries, which is regarded as a challenge by sugar producers due to heavy governmental support in these countries. They see themselves on a twofold, non-level playing field, competing with subsidised industries on the one hand and dealing with increasingly high environmental standards in Europe on the other, leading to a challenging situation (H-B, pos.84). Another example elaborated on during the interviews was the recent ban of a specific group of pesticides, Neonicotinoids, in the EU, due to rising safety and toxicology concerns for ecology and humans (Blacquière et al., 2012; Thompson et al., 2020; Wood & Goulson, 2017). In agriculture, this is not unheard of; however, some European countries received special permits for using Neonicotinoids despite the ban, while others did not, which – for obvious reasons – was not received positively by the actors. Being pre-approved with special approvals and individual authorisations led to a gross distortion of competition and thereby frustration among farmers and associations. Coupled with direct payments – country-specific special regulations – offered another challenge for the market, which should not be possible in a common European agricultural policy (V*-C, pos.63). These market distortions due to pesticide use and different prices due to direct payments are frequently brought up, as well as the problematic competition situation in the world market. Besides those, shifting customer demand and more customer attention are also regarded as a hurdle in the future (H-C, pos.25) but do not seem to be that influential compared to the other presented challenges:

> *"The changes in the value chain were always reactions to changes in the external framework conditions. Agricultural policy, the end of the sugar market regime, price cuts, the abolition of the quota system. Such things were actually the decisive factor."* (K-B, pos.28)

There are, however, more challenges for the sugar value chain in the case regions than those following policy and market distortions and societal ones. An often stated problem is the lack of truck drivers combined with the language barriers of seasonal workers (S-A, pos.152). During the campaign, the factory has to run 24 hours, seven days a week, so the logistical operation needs to run in a 24/7 manner, resulting in an immense workload. While the cooperation with logistical companies improved over the years, often due to the development of a shared, digital portal, which organises the transport (S-C, pos.104), the scarcity of skilled human capital is believed to get worse in the coming years (V*C, pos.73). The hauliers are also seen as multipliers since they provide advertisements on how a factory presents itself to the outside world by leaving the yards clean and communicating well with the farmer, which requires specific skills often not readily available (S-C, pos.104). Another often-repeated human capital problem is that it is not as attractive to new generations as other sectors, emphasising the problem of finding new talent in the coming years, especially in cultivation (V*-C, pos.73). Being a farmer is also very different in modern times; the work settings shifted rapidly with the digitalisation in the last 30 years, requiring a comprehensive mix of abilities and experience. Especially with precision farming, it has become much more complicated and requires more time investment (F-B, pos.8). Then, shifts in other agricultural markets can have an influence as well. Due to changing customer behaviour towards consuming more sustainable and less animal-produced products, by-products used as animal feed, such as dried pellets, suddenly have fewer regional buyers (S-C, pos.138), with a downward tendency. Not remaining in regional cycles – as it would be favoured from a mere bioeconomic point of view – but having to be transported over long distances in order to be used as feed is yet another communicated problem. Often, this is not economically feasible, leading to investigating different alternative paths for this by-product. A viable solution that does not involve having the material used as fuel, thereby disregarding ideas of cascading altogether, does not seem to have been found yet

(V*-C, pos.107).

As we can see, with its unique value chain configuration, the sector is indeed in an intriguing moment. While the general situation is not regarded as dramatic by farmers, sugar companies find more harsh words toward the immediate consequences of the market liberalisation:

> *"I'm sure next will happen that since there is not any more profit in the business that companies who cannot pay the farmers because maybe they do not have money to pay for the beets, they will go bankrupt. Or I mean that would be a transition period, of course but if you don't earn any money, then, in the end, is a question of how big your bank account is and you can loan then or - I mean that's the next two years. [...] I think the politicians were just not aware of those things happening. It happened with the milk also. It's totally the same. So, I think they should not be surprised."* (H-A, pos.40)

> *"So, post-quota, it has been a hassle, it has been a real challenge to operate, [...] and also in the long-run global sugar prices cannot persist on this levels. Because it is a nonprofit level [...]. So, the outlook is better, but it depends a little bit on how long the winter will last. But at the moment, excuse me, it's like deep, deep, deep winter."* (H-B, pos.20)

While this time and discussed value chain configuration is a pretty challenging one for sugar producers, it can also be seen as favourable in the greater scheme of things, especially regarding innovation.

4.5.2 Knowledge and Innovation

Actors' Characteristics and Knowledge Flows

As already mentioned, the profession of being a farmer has changed tremendously over the past decades and now requires a broad set of skills; interestingly, a recurring skill or ability seems to be a certain open-mindedness towards the "new". In all interviews, farmers, when asked about their openness toward new methods of cultivation and subsequently their willingness to try them out, responded similarly, ranging between "happy to try something out" (F-C, pos.101) to "I think it's important we do R&D; I think, it's important with the research" (F-A, pos.287), while the knowledge providers did also confirm this openness (K-B, pos.108). This open-mindedness is an important factor in the ability to absorb and implement new knowledge and can function as a crucial factor for the future, as new cultivation methods and varieties ask for this kind of absorptive capacity from farmers. Furthermore, the profession seems to entail a dynamic of "birds of a feather flock together" since a lot of informal meetings take place, both on- and off-season (F-A, pos.175), the social circle of farmers is skewed toward other farmers (F-B, pos.172) and their general relationship is in all cases described as positive (F-C, pos.59). Possible reasons might include that the profession is not an aggressive competitive one but instead is embedded into a system based exclusively on natural circumstances, which helps build common ground and identity with few starkly opposing opinions. Combined with a significant randomisation element in weather and lousy climate, which helps intensify relationships and boost linkages between farmers or at least empathy for one another, their closeness can be observed. This, in turn, leads to a higher willingness to cooperate and interact with one another, which can also be noticed in the acquisition of new technology and general, more formal activities. It is one thing to talk informally to each other, but a decisive other to buy a five-figure combine harvester with your neighbour. Machines are exchanged, joint accounting is brought up, and general cooperation in all matters of farming is taking place (V-B, pos.52), leading to the buildup of valuable trust between farmers. Most of the time, these relationships are informal, and the shared knowledge is mostly know-how. The know-what then comes from close contact with primarily the growers association but also with a knowledge provider, for example in the form of a research organisation, or the sugar factory in the form of advisors. Hierarchies are often very shallow between these actorial groups (K-B, pos.50), allowing for a more effortless flow of implicit and explicit knowledge. The growers association fulfils an essential role in knowledge diffusion since it has the farmers' trust regarding the contracting with the sugar factory, and therefore knowledge communicated between them is seldomly lost or unwelcomed out of mutuality. The growers association also takes responsibility when it comes to bundling external sources of knowledge and transporting them to farmers and thereby filling in a knowledge-brokering position, often also bridging information from European-level knowledge providers, like the CIBE, to farmers. There are also working groups for farmers, organised by growers associations, where the possibility to discuss recent trends is given, and by that knowledge can also be shared (V*-C, pos.37). The growers associations and the knowledge providers also give out a steady supply of informational materials over different mediums, magazines, and the possibility to partake in various meetings. Since tacit knowledge is hard to transport by publications, knowledge providers were found to organise field days:

> *"If after a certain time it turns out that a new process or a new technology brings advantages, then, of course, we put that on the Beet Meeting, for example, or in publications, etc.; that is, not in any journals, because farmers don't read that kind of thing, but they do read the farmers' newspaper, [...] or the association news [...]. And we also have many field days, and these are also opportunities where we can, for example, show the practitioners the trials directly and present the results."* (K-B, pos.30)

The farmers themselves confirm the mentioned absent linkage to academic research and focus more on the opportunities associations and knowledge providers presented (F-C, pos.79). The field days, as a very primordial type of network, have been a recurring theme for knowledge diffusion and learning during the interviews. All interviewed farmers are very willing to participate in those, with reasons varying between free consulting and the possibility to share implicit knowledge with others and gain new insights. They are also seen as far more efficient in implementing knowledge than other forms, like magazines, and also reach typically uninvested farmers:

> *"So, just one of these cases in an area [...] [is] actually [...] a much more effective way than writing a report. [...] I think [...] it's much more time-effective, also for us because writing up a report around [...] is maybe a month of work, but here it takes one day of demonstration, and you really come instant by heart. That is really something to learn from, I think."*(K-A, pos.88)

Implemented changes in one farmer's fields are furthermore also quickly noticed by neighbouring farms and, due to their general positive relationship, often get adopted by them as well (K-A, pos.88) – provided an appropriate attitude, of course. This rather effortless knowledge transfer can be seen as an advantage for agricultural innovation systems. The proposition of the more hands-on, direct approach of field trials as a medium of knowledge diffusion was observed across all cases. Another aspect is that through the high levels of interaction and cooperation driven by the farmers, the association and the knowledge providers, certain actors taking positions as "knowledge archivists" – actors with profound experiences in their field and greatly influencing connected actors – are more accessible included in the network of farmers and easier access to them is provided.

While knowledge flow is an imperative between farmers, the association and the regional knowledge provider, the contact knowledge- and learning-wise to the sugar factories are in no way assessed as bad; merely, due to the contractual situation, a slight barrier is communicated (S-B, pos.104). While the factories are oriented more towards growers associations and, to a lesser degree knowledge providers, advisors for cultivation purposes are there to support the farmers to ensure an optimal yield and consistent quality across supplying farmers. However, this contact is regarded rather as a formality amongst farmers and not as a prime way to achieve new knowledge or cultivation practices since they prefer more independent consultation (F-B, pos.156), resulting in being, compared to other possibilities, regarded as less advantageous (F-B, pos.152). In the end, farmers have a broad range of possibilities to gather information and many ways year-round to learn (F-A, pos.159), but the information load was never described as too much. It therefore seems that at least the interviewed farmers do have a high absorptive capacity based on their flexibility, open-mindedness, identity and self-perception that favours hands-on approaches. Strong, trusting bonds help mitigate and share risks, while new information spreads among them quickly.

Innovation Types and Modes

Where this openness and "always wanting to improve"-state of mind primarily can be seen is in the so-called "on-farm research":

> *"That means that innovative farmers always have ideas about what they want to try out and then let others participate. That means that people meet and talk about it, but they don't deal with large-scale statistical evaluations; instead, these are all ultimately experiments that are carried out on a farm and bring about an increase in knowledge. And if one person has tried something and we have discussed it, and the next person says: 'I'll try that next year too', then that is also a certain research activity."* (V*-C, pos.79)

Provided an innovative farmer, on-farm research is a prime example of learning-by-doing, and by that also DUI. The example of a "revolving cycle of trial and error" is given, since every field and area is different. Therefore, fields must be linked with practice and tried out (K-B, pos.31). In general, an overarching innovation mode of DUI can be underlined for the cultivation side. Farmers mostly have high absorptive capacity regarding new knowledge and excel in relational capability. Reasons can be found, as said, in a common ideology, a common goal, low hierarchies, high levels of trust and open-mindedness towards new knowledge and learning in general. The connection to growers associations as a knowledge broker, connector, and empathetic partner that bundles and bridges interests can be highlighted, with knowledge providers fulfilling their role of being a gateway, or interface, to academia. Recent findings are monitored, filtered, and evaluated and are then provided to farmers and growers associations. This "interface"-role is crucial because new technologies, varieties, and methods stemming from the rather STI-dominated mode of academia are pushed into the innovation system. Combining these settings, hints toward open innovation can be seen. Inbound knowledge is technology driven – by academia – and often with a clear focus on efficiency, and find its way into the cultivation side mainly by knowledge providers. Once there, sharing due to mutual trust, a supportive culture, (absorptive) capacity and also high relational capability of actors does happen, not least due to the relatively simple resource of the sugar beet. While there is not a particular leadership in this system, farmers themselves gave the impression of being driven and open-minded (van Lancker et al., 2016).

Regarding the production half of the value web, processing sugar did not undergo a significant or radical technological change for 150 years, only scaling to larger quantities (H-A, pos.56), hinting at a rather locked-in state of its production. This does not necessarily mean a bad thing, though, since this lack of (perceived) need for radical innovation has led to increased focus over the years on efficiency and optimisation of the process, as is the case for many mature industries. As the processing of sugar is energetically intensive, a lot of research effort went into raising the processing amounts (S-A, pos.268), accelerating the process, lowering the energy use (H-A, pos.125-152) and for the last few years, adopting a circular mindset by reusing by-products, mainly for harnessing an independent energy production (H-B, pos.76). However, progress in optimising the process is still regarded as the main driver (S-C, pos.166). Therefore, an incremental approach toward innovation can be underlined. This is even more apparent when looking at the responses to which innovation or change has been the most significant one in the cultivation and processing of sugar beet in the last 20 years.

While technology-wise, the example of integrating a steam-dryer into the evaporation station of the factory to improve the efficiency (H-A, pos.125) was given, replies almost solely focused on the same two changes, both happening *outside* the factories. First, the progress in seed development and breeding of new varieties lead to sugar beets that are much more resistant to insects, foliar diseases and weather conditions while growing faster and having much higher sugar content. Breeding is believed to have contributed to roughly half the yield increase over the years while also pushing seeding times earlier into the year, contributing to higher yields (K-A, pos.84). Being more resistant to diseases and pests, like Rizomania or Nematodes, leads to helping whole regions to survive (S-C, pos.190), and breeding varieties that distribute the sugar content more over the whole beet instead of only certain parts (F-B, pos.272) enormously boosted the yield development. Since weight and size, thus transportability, constitute a significant concern and price factor, developments there had to be made without substantially increasing the size of the beets, which could be achieved by continuous research (K-C, pos.19). As a second meaningful change occurring over the years, progress and technology improvements in machinery and harvesting are stated to had a considerable impact:

> *"Breeding progress is a big part of this, as are technical innovations in agricultural technology. But [...] also in the field of soil management [...], harvesting technology, [...] cleaning technology. [...] [Therefore], yield-stabilising cultivation and soil cultivation, and then yield-securing and loss-minimising harvesting. And then the logistics chain, the beet loading system, was a decisive innovation that enabled us to build the modern logistics flows that exist today."* (H-C, pos.47)

Both technical progress, as well as progress in breeding and varieties, are based on insights in an STI setting and pushed by knowledge providers. However, they often are influenced by needs formulated by farmers or growers associations, which adopt an innovation mode more along the lines of DUI. In that specific system, both modes find an application and are strongly intertwined due to the unique relational configuration of its actors. Farmers generate new knowledge with on-farm research (DUI), which spreads due to good interlinkages quickly, thus allowing for problems to reach knowledge providers in a timely manner, allowing them to find solutions. In addition to this bottom-up approach, a technology-push, top-down (STI) initiated by knowledge providers is in place. Influenced by the needs of the general sugar industry and its market, but also by the scientific sphere, research is conducted without a preceding connection to the farmers. A certain intricate duality in the innovation system can thus be seen, which clearly benefits from the solid relationship and trust between the actors of the cultivation side. New findings often need to be tested during field trials or in test areas, for which farmers' communicated openness, flexibility, and absorptive capacity are especially beneficial. Once in place, new knowledge flows fast due to the unique value chain configuration, and the flexibility of the system as a whole can be regarded as a significant advantage in future innovation processes, either incremental or radical. Especially against the backdrop of the needed changes communicated by bioeconomy, this is a precious setting.

Innovations in cultivation resulted in a significant push factor for the factories since they now had to process much larger volumes per campaign and needed improved logistics per day, leading to more optimisation and efficiency developments and efforts in turn, since not handling or using everything is seen as a missed opportunity and financial loss (S-A, pos.196). This mindset of "need to use all" and improved efficiency across the whole processing can be observed in all sugar companies. Since the development and implementation of new technological applications in the factories need permission from the headquarters, they play an essential role in the innovation capacity of the factories, and the tendency to focus on incremental innovation in the last few years can be observed in them:

> *"[...] We also are quite exquisitely focusing ok, process engineering, process optimisation, that's something where we also distinguish ourselves [...], we are focusing on things which are important for us in our factories we have. Not necessary that we develop new types of processes, which are really unique to our own, which we haven't tried out now, it's really focusing on what we have at the moment and what we think is necessary for the future."* (H-B, pos.56)

A positive trait of the described, hierarchical governance situation between headquarters and factories is the ease of developing technologies holistically by the lead firm and then pushing to some, if not all, factories (H-B, pos.60). While this form of knowledge and technology spread is done directed and on purpose, it still leads to a faster diffusion of new technology across the sector, which can positively influence the development of newer technologies. While the overarching lead firms have their research and development departments and are also working on funded projects with academics, universities and research organisations (H-C, pos.39), it is not entirely clear if STI or DUI is the primary innovation mode adopted on their level. Going from the evident activities and the fact that R&D departments also focus on automation, industry 4.0 and new valorisation options instead of only focusing on optimisation (H-A, pos.60), STI seems the most likely; however, since mainly incremental innovation was adopted during the last few decades, it cannot be concluded that these came solely out of the STI dynamics. Most likely, a mixture of prior experience in using and progress of the R&D departments is behind the most developments, while the activity in joint projects seems to have gained its momentum only during the last 10 – 15 years. All sugar companies had much active participation in different research projects, which seem to not focus on process optimisation but rather on new products and possibilities and follow distinct notions of sustainability and circularity, like components from beet tops or fibre from beet pulp (H-A, pos.60). While companies participate in joint research, thereby bolstering the spread of knowledge and opening up towards science, connections to competitors are, if any, mainly to be found during these, but seldom out of them. The importance of networks, however, is directly acknowledged, even if the process could take some time:

> *"[...] Everyone is part of a network, and especially nowadays it can be more and more important [...], and the only way you can do and to achieve that, is being very open-minded towards the development outside. So, thinking more by networks instead of just ok, we have one singled-out research facility, where we cooperate with one singular party'. I think [...] we are very slowly developing more network-based thinking, but that goes very slowly, as you can imagine."* (H-B, pos.64)

Regarding an open innovation approach, some chances, but also challenges are presented. While factories need to have a certain absorptive capacity for the adoption of new technology, which can often be attributed to comparatively simple processing that is indeed scalable and innovations being incremental, a lack of trust between factories and headquarters remains to be assumed due to the hierarchical governance situation communicated in some cases and is a significant hurdle. However, a chance for open innovation can be seen in the high similarity of the sector; thus, despite hierarchies, a fast diffusion rate of new technology and knowledge can be assumed, and due to a high absorptive capacity and pressure from the lead firm in the factories, also their implementation. The technology supplier situation discussed earlier – relatively small count of suppliers for machinery and downsizing of capacity – plays into that as well. If included in the innovation process, for example during joint projects, they could fulfil a multiplicative function, and the fact that they are only a few can even be seen as an advantage in that case since they could – given they have the needed capacities – provide new, improved machinery for many actors at the same time.

Nonetheless, non-incremental innovations in the factories – e.g. steam-drying, bioethanol, biogas – as well as research projects were all following notions of eco-innovations. Undoubtedly always with efficiency or optimisation reason behind, but they still led to a significant improvement in reusing and valorising sidestreams, leading to less waste and less energy-intensive processing overall. It could be argued that these kinds of innovation were, on a very high level, driven by progress toward a more sustainable bioeconomy.

External Factors Influencing the Innovation System

The external factors that influence the sugar industry's innovation system are primarily in line with those previously pointed out as influencing the value chain. The market applies pressure to the innovation system because the price directly depends on the process quality and, therefore, the amount and quality of the raw material. Not only did that drive the development of more potent sugar beet varieties, but, consequently, that also means that the longer the campaign runs, the more product can be produced, resulting in various efforts targeting more functional storage solutions to prolong the campaign and shield sugar beets against outside influences. While natural factors, like temperature, precipitation and sunlight, can sadly not yet be influenced, other things can be, and thus a ventilation and heating solution was designed (K-A, pos.76). This can work as a fine example of bottom-up, DUI-induced innovation since the need was communicated by farmers and transported to knowledge providers, which came up with a solution that is now being tested and trialled. More anthropogenic external factors, like market liberalisation, exposed far more significant challenges. With the end of the quota system and the entailing drop in prices, fewer beets were cultivated in the years after the liberalisation. Now, beets need to be cultivated for field trials and on-farm research to flourish, which was a problem after the price drop. Since prices are recovering, beet cultivation seems to regenerate, but this hint at a potential problem still needs to be kept in mind. The cultivation part of the value chain, while being quite resilient against outside factors, does still react quite fast, which does not have exclusively positive effects. Societal factors, most prominently a shift in consumer perspectives towards sustainability, required industrial customers to adapt. This goes hand in hand with the political framework, which acts as a driving factor in that development since its aim towards a more sustainable economy and society acts as a meta-level transition with profound effects across all actors. For the innovation system of the sugar industry, it can be seen as the primary driver behind many changes in the last twenty years. Big industrial customers are increasingly aware of CSR and are focused on CO_2- and water footprints (H-A, pos.52), which led to a drastic shift in corporate strategies to take up aspects of sustainability, also leading to taking advantage of the opportunity sugar beet offered with bioenergy (S-B, pos.232) in times of the first restructuring:

> *"[...] it was simply our blocked path of conventional development, which naturally led us to look at new markets and new developments. [...] And normally, one or two factories are closed and the beet is then processed in a third factory. That is the way to react to the market pressure and the pressure for efficiency. And [...] we didn't necessarily want [...] to be closed, so this location had to find something else, open up to new development perspectives."*(S-B, pos.232)

Since sugar processing is highly energy-intensive, raising sustainability awareness would induce problems on the regulation side, thereby influencing this shift in corporate strategy in lead firms even more. While the sugar industry is already geared to high efficiency and uses nearly a hundred per cent of the beet (H-C, pos.25), this push marks the beginning of a broader transition from "how can we valorise what is already there and make our processes more efficient" to "what else can we produce" (H-A, pos.60). With the end of the quota system, this development was further accelerated. The protected market had a blocking position for the transition towards new bio-based products since, under the quota regime, there was no need for the companies to innovate on that level due to the lack of such an intense pushing, external, and financial incentive:

> *"For one thing, at the time of the sugar market regulation, the pressure was not so great to sell the by-products at a profit, but they were simply there, and you just had to get rid of them, whether you made a profit or not [...]. The money was made with sugar. Now that the economic situation is getting more difficult, you have to see that as a source of income and also try to generate profit contributions. So I would say that it was really the sugar market regulation that blocked [this development] [...]"* (S-C, pos.140)

After the shift in EU policy and customers as well as consumers also hopping on that train, the end of the quota system led to a veritable run towards finding a future for the sector. It can be seen as a rather radical incision and fueled the search for new products, and since a policy regime favouring sustainable solutions was in place, the focus was explicitly put on the sidestreams and possible cascades. Discussions regarding going beyond mere energy recovery toward material recovery processes – lactic acid, pectin – were started (S-B, pos.180), and a transition to a bio-based economy that uses sugar as the basis for new bio-based ingredients became a realistic possibility (H-B, pos.28). These bio-based ingredients were mentioned many times, hinting at the role of sugar factories as biorefineries and using sugar as a platform chemical to produce bioplastics and other composite chemicals, thereby improving the value (Cárdenas-Fernández et al., 2017). Using sugar factories as biorefineries producing bio-based materials from sugar (H-A, pos.409) can also combat the lingering tendency of a decreasing sugar consumption by providing an alternative product (H-B, pos.28). This transformation would allow the factories to run much longer while processing higher volumes and solve the problem of more land-locked factories, especially in eastern Europe, to reach global markets and also help regions in which cultivation faces issues with the soil and other poor natural conditions by lowering the needed quality of cultivated sugar beets.

> *"And [if] you [can] make some all year production, then it's better than having four months of sugar beets. So, can you make some products the whole year, and can they be based on beet pulp or sugar or molasses or thick juice. Of course, the bigger the profit of the site, the better is the likelihood also that you can pay the price for the sugar beets, which is high enough that people would*

> *grow them and not grow something else. And that is a whole time to balance that. We are competing against all other crops."* (H-A, pos.60)

Besides the described competition against other crops, other challenges can be seen for that future implementation. First, progress in cultivation needs to consider the nature of the soil, the nutrient cycle and its biological limits. Until now, developments and research towards extracting proteins out of sugar beet leaves mainly failed since ploughing them down into the soil after harvesting provided nitrogen as a fertiliser for the following crop (K-C, pos.47) and the fact that they lack transportability due to a high water content of $> 85\%$ (H-C, pos.111). Utilising the beet leaves would also mean to, in an optimal scenario, collect them during harvest. Modern machinery does not support that (yet), and can further not weigh more than the amount the soil can tolerate before it compresses too much. Harvesting twice is therefore also not regarded as a viable option financially and from soil-protection perspective. Of course, an increase in cultivated area also means more transport, which, in turn, funnels into more carbon-dioxide emissions. That problem may be solved soon with logistics based on electrical motors, but it is still a huge challenge today. Some European countries use biogas produced from their factory wastes to fuel their logistics; however, a recent study (Mottschall et al., 2020) came to a relatively modest conclusion in that regard. While ultimately possible if a high enough valorisation is given for the effort, the example of beet leaves underlines some of the underlying minute challenges on the cultivation side. Not touched-upon, but definitely something to think about is the increasing use of herbicides and pesticides in conventional agriculture, which manoeuvred the cultivation side into a dependent state and somewhat a lock-in. An example of its negative impact can be seen in the ban of Neonicotinoids, which led to a massive outcry amongst the community. Cultivation without them is, in some cases, also not feasible, amplifying this argument. While the gain is obviously huge, the pain stemming from new regulations or bans must also be kept in mind. The biggest challenge, however, is seen in a lack of supportive policies and the resulting high financial obstacle for consumers and companies alike:

> *"At the moment, I think all this is failing because of financial hurdles, i.e. it is simply too expensive. As long as oil is as cheap as it is at the moment, research activities in these areas have an incredibly hard time. The sugar beet is a brilliant fruit [...] and now we have to think about what else we can make out of it because the consumption of sugar alone in the form of food is reaching its limits. [...] I think the consumer is very open-minded, but no consumer will buy a drinking straw made from renewable raw materials that is three times more expensive, if the drinking straw is made from petroleum or ultimately from chemically produced raw materials, the chemically produced drinking straw, costs a fraction of the price."* (V*-C, pos.111)

A strong lobby of the oil industry is seen as an influencing factor for that, while the political side is called upon to present incentives for change (V*-C, pos.113). Indeed, interviewees saw the challenges not in the innovativeness nor the innovations but in the framework conditions, how they developed, and fear even more significant challenges ahead (H-C, pos.49). One recurring fear lies in policies or regulations influencing breeding solutions, herbicides/pesticides, biotechnology (especially gene-modified crops) or CRISPR/Cas9. These can significantly impact cultivation practices and yield, but they are highly discussed topics in politics and society. Nearly every actor underlined progress in breeding technology as the lead innovation for the sugar beet industry in the past but now see themselves confronted with their somewhat dependent relationship with them. Support is demanded from policymakers, also in light of the sustainability shift in consumer demands. Sugar producers lastly communicate fear of being successors of oil companies regarding their positioning and reputation they have in society, although being operational excellent (H-B, pos.190). This pressure from the customer side, combined with the recent market deregulation and a policy regime more focused on sustainability and circularity, substantially shocked the sugar industry into a state of rethinking – which can be regarded as an opportunity for the bioeconomy and innovation indeed.

4.5.3 Application of Bioeconomy

> *"Bioeconomy, yes, yes, that is [...] also becoming a bit of a lifestyle [...]"*
> (V-C. pos.103)

One of the most interesting things to observe during the interviews was the answers to the question, *"Have you ever heard of bioeconomy? If so, what's your opinion of it?"*. While, without exception, all actors had a very sustainable and forward-thinking approach to their activity in the value web, only headquarters – probably due to the CEFS introducing the term – were well aware of the term itself. Five out of the other 14 could at least make some sense of it, and the rest had never heard of it. To some degree, that is not surprising, as it underlines the redundancy of the concept, and when looking at the answers given, its non-significance is clearly communicated since *"everyone has his own perception and idea what it is, [...] [which] is creating [...] quite some fuzz"* (H-B, pos.194). Interviewees' responses furthermore ranged from bioeconomy being a *"buzz-word for looking at valorisation of a raw material"* (H-A, pos.365), a *"modern world word"* (V-A, pos.220-224) to a *"hollow term [that] everyone also abuses"* (H-B, pos.206) – *"just as sustainability, it's a bit of a whore"* (V*-B, pos.204). And although this comparison lacks empathy, there is some truth to it. Like sustainability, bioeconomy lacks a common understanding – and that is not an inherently bad thing since the broader and vaguer the concept is, the more can be interpreted into it on the policy level, the more projects can be funded under its wings, and the more money can be handed out with markings of its purpose. However, this point of view is not perceived positively, and a wish for *"clear commitments what we are going to do, how we are going to do it and which road [to follow]"* (H-B, pos.206) is communicated.

Both headquarters and sugar factories perceive themselves as sustainable (S-B, pos.232), and for farmers and growers associations, sustainability is even seen as their foundation (V*-C, pos.93), *"[...] what farmers are born with"* (H-C, pos.139). Even if not directly labelled as "bioeconomy" by the different actors, the influential role of the underlying principles across different actorial layers of a broader sustainability transition becomes apparent. Especially when looking at the primary developments happening in the innovation system since the early 2000s, a focus on bioeconomic principles – use of sidestreams along the three R's, thereby adopting a circular mindset and implementing cascading during processing – can be observed and was already touched upon in section 4.5.2. Even before the term got introduced and the focus started to shift, the sector pursued the valorisation of as much raw material as possible, and with the advent of political incentives for the use of biogas and bioethanol, it saw the opportunity and proved to be flexible in this regard. Of course, the main driver was and is financial, but there is also an excellent foundation of a biomass-based value chain that is hugely efficiency-driven and soaks up new cost-saving opportunities like a sponge with an easy enough processing stage to be able to adapt rather quickly. Then the market liberalisation happened, and of course, it initially led to fear, uncertainty and despair, but it also opened up new pathways previously blocked by a substantial lack of incentive and need because of a protected quota regime. Now, the hit the sugar industry took was undoubtedly more challenging than anticipated due to recent societal shifts towards sustainability influencing the market and the reaction of third countries, but the opportunities presented are not to be dismissed. While during the quota, research and development aiming at new products or alternative by-products were not seen as needed, and profit from existing ones was welcome but in no way a driving factor, this changed when the price of sugar tanked. Undoubtedly, the driver behind searching for alternatives was not bioeconomy but trying to survive, but the liberalisation influenced the already based on bioeconomic principles sector to adopt their underlying bioeconomic potentials. From an innovation system perspective, this external shock did what it was initially supposed to do. Bio-based products and alternative valorisation options during processes are getting discussed (H-A, pos.60), and research initiatives toward sugar biorefineries are gaining momentum (Alexandri et al., 2019; Ubando et al., 2020), ultimately, hopefully, achieving not incremental innovation but disruptive instead. In light of Geels (2010) multi-level (sustainability) transition – and thereby in a neo-classical way – this all makes perfect sense. Stimulating transitions in sustainable directions needs conditions under which markets operate to significantly change, for example, by policy instruments (Geels, 2010). The sugar industry requires change and more radical innovation regarding future external factors. According to Geels (2002) technology transition, radical innovations occur when processes on the regime and landscape level open windows of opportunity; in the case of sugar, the recent market liberalisation might be the direct reason, but indeed not the only process; societal demand for more sustainable, nature-preserving products, following a history of constant change towards a greener pan-European policy regime is a major factor as well. This ongoing trend is observed and recognised by the interviewees as well:

> *"And currently, of course, the sustainable supply is more relevant from our customer's point of view, [...] also in the context of the climate debate, that I produce a sustainable product. Customers do not want to be associated with the burning rainforests in Brazil [...]. And, of course, it has a completely new relevance for us today, because it is also becoming more and more of a topic on the customer side or on the side of society as a whole. [...] In the past, customers were not so interested in it. It [...] has been changing for several years, and is [....] just picking up speed [...]." (H-C, pos.25) "[and] as a company, in order to keep our place in society in the long term, we have to face these developments, and since we know very well that we can only get there step by step, we would rather start early."* (S-B, pos.192)

For the cultivation side, the effects of the market liberalisation are not as threatening as for processing, and farmers were also able to balance it out due to their flexibility, but the system change toward sustainability laid bare challenges of a different nature. While sustainable practices are seen as pivotal since soil health is a significant factor in future-proofing the livelihood of farmers and is therefore handled with special care (F-A, pos.235), a particular communication problem is described:

> *"[...] we farmers are the actors on the land, but far too little is actually done with the actors on the land, and far too much is said about it in politics. What I mean to say is that no farmer is opposed to doing something good for nature because he lives from it. And no farmer contaminates his soil if he has been living from it for generations. So that is sometimes the misconception that prevails. And we live sustainability, and I think we would live it even better if we supported the farmers there more."* (F-B, pos.228)

As pointed out, societal factors are also crucial for a successful transition, and naturally, social understanding and reputation play a major role since they directly influence the demand side. One communicated example of challenging communication was transport: Lorries transport sugar beet for up to 120 days to the regional sugar factory during a typical sugar beet campaign, which has significant CO_2 emissions. However, sugar beets also store CO_2 – a fact that is promoted only subordinated (S-C, pos.154), but would lead to more understanding, especially when the argument is furthered, and the significant energy needs a sugar factory has is set into a perspective of circularity and, hopefully soon, biorefinery that answers the plate vs tank debate with *"why not both?"*. While improving energy efficiency was a significant driver for incremental R&D progress in the sector in the past, a more recent goal is to find alternatives to fossil fuels (H-B, pos.80). When considering the sustainability-oriented landscape, this does not come surprisingly;

however, sugar producers' lack of trust in political decision-making leads to high levels of uncertainty and frustration (H-C, pos.45), and in some cases, frustration and exasperation:

> *"Politically, yes, well, many things are being decided very quickly at the moment […]. Every party wants to be greener than the original […]. It is undoubtedly important to be prudent from time to time, to base decisions on factual arguments and also to give enough time to perhaps wait for one or two investigations before making political statements that can then no longer be retracted, that is ultimately made without a factual basis […]."* (H-C, pos.55)

Condemning too quick and inconsiderate political decisions, the interviewee in this example refers to the ban on neonicotinoids. This kind of alienation between policymakers and the sugar value chain actors is frequently repeated and supports the claim of their relationship being a major challenge and hurdle for purposeful support and knowledge exchange.

Nevertheless, the recent incision can ultimately be regarded as beneficial. While the sector, due to being completely biomass-driven, always adopted sustainability principles, market liberalisation led to a window of opportunity for its bioeconomy foundation to play to its full potential. Research is conducted, and a shifting mindset can be observed, aiming not only toward using sidestreams and trying for circularity but also providing glimpses at a path towards an integrated sugar factory biorefinery concept that produces bio-based material. Due to the unique configuration of the value chain (see section 4.5.1), this incision, while obviously bundled with a certain frustration, is met with flexibility and adaptive capacity across all actors – now also being less risk averse – and thus making it an almost perfect breeding ground for the transition to a genuinely sustainable, while mature, low-tech industry. In all that, bioeconomy as a term did not matter. Aspects of it, certainly, ideas like circularity and cascading, definitely, but those can also be attributed to sustainability.

> *"And it's a very cool concept for the future but yeah, I think, especially on the EU regulative side, they are not doing the best to promote it. I mean they throw around the term whenever they can […]"* (H-B, pos.200)

And it does not need to be like this because, deep inside, the concept makes perfect sense: Making economy more bio – that is it. Bioeconomy, if done correctly, could be a lot more focused than sustainability, with clear goals and implications, and could significantly help low-tech industries that may already have a (wrongfully) bad reputation or struggle with the greater sustainability transition, making them more attractive to society, improving the human capital situation while positively influencing customer markets. That possibility, however, is not taken yet. Main issues of lacking vertical communication, fuzziness and a reputation of "yet another vague sustainability term" substantially hinder what a deliberate conceptual framing could achieve. The sector and its actors are acting towards bioeconomic principles, and their future visions – although needing a market liberalisation – go hand-in-hand with it. The bioeconomy could function as a key narrative element in boosting not only the sugar industry's sustainable development but also the development of other agri-food sectors, which is partly already well underway. Most agri-food mature industries rely on specific biomass as a resource; However, due to the lack of communication from the political side and resisting a more explicit definition, this is not yet the case. Framing sectors that use biomasses as a resource and apply cascading and circularity approaches during their processing steps while staying financially viable as bioeconomy would go a long way. Not only would it help transport the message more efficiently, but also with regards to innovative potential it would help strengthen the ongoing pathway, lead to a more apparent distinction between sustainability and bioeconomy, and ultimately de-fuzz the term by transforming it into a valuable tool to combat wicked problems ahead.

4.6 Conclusion

This study aimed to investigate which characteristics a low-tech, agri-food value chain and its actors present, how knowledge flows and innovations are achieved and ultimately to look into the applied characteristics of bioeconomy. After nearly 50 years of a quota regime being in place, the recent market liberalisation led the European sugar industry to face an unprecedented challenge. The empirical cases studied covered three distinct regional sugar value chains, with interviews also including headquarters and affiliated knowledge providers to not only shed light on the dynamics of the supply chain but also on the value web and the impacts external and internal factors have on both the value web configuration but also on knowledge and innovation dynamics.

After presenting recent theory on low-tech, agri-food innovation systems, modes and value chain configuration as well as dynamics, the leitmotifs were distilled into a comprehensive analytical framework that updated the main research questions of this work. Following a thorough deep-dive into the sugar industry, its actors, processes and drivers, the chosen qualitative research method and the selected cases were introduced before the results, structured by the updated research question, were exhaustively illustrated by closely intertwining them with statements of the interviewed actors. Thereby, a unique value chain configuration could be excavated, and its actor connections and relationships explored while emphasising sidestreams and cascading – bioeconomic principles – to follow the value web perspective. Once the conditions were set, an in-depth analysis of knowledge flows and innovation dynamics, revealing a segregated innovation system split into cultivation and processing, its modes and influential external drivers, was carried out. Finally, the influence of bioeconomy, as well as applied characteristics of the concept, were looked at before concluding this work.

In the process, the initial, main research questions – as repeated below – could be answered; the main results are summarised afterward.

1. Which specificities regarding governance, cooperation dynamics, and actorial relationships does a low-tech, agri-food value chain offer, and which differences occur?
2. How does knowledge flow, how are innovations achieved in a low-tech, agri-food value chain, and which factors have an influence?
3. Which characteristics of bioeconomy find application, and in what ways do they influence decision-making in the low-tech value chain of sugar?

Without question, the sugar industry value chain is a prime example of bioeconomy, implementing inherently bioeconomic concepts amd characteristics by adopting cascading in focusing on valorising and reusing the source material and sidestreams as efficiently as possible, arriving at a prime example of circularity. Its value chain configuration and governance uniquely combine a decentralised lower cultivation half with a more centralised, hierarchic, processing upper half, decisively influencing trust and thus knowledge flows between the actors. The growers associations take a central role in knowledge brokering, bridging positions, uniting interests and providing support. While the profession of farmers seems to bring a sustainable mindset with them, a confident, cooperative attitude, high flexibility and open-mindedness are also in place, positively affecting their absorptive capacity and relational capability. Although the hierarchic relationship between headquarters and factories differed between cases, its potential to provide access to a supportive network and thus information and challenges for innovation due to a lack of freedom could be seen across all regions. Due to the high relational capacity and, certainly better in the lower half, the absorptive capacity of actors, relatively swift reactions to external influences could be observed. While adopting innovation in both parts was almost exclusively incremental and following DUI, the more radical novelties, like ventilation of beet storages, reusing steam to dry pulp in the factory or using by-products in a biogas plant followed STI, were conducted either by knowledge providers or R&D units of the headquarters. While in the lower, cultivation half, a climate of open innovation could definitely be hinted at, the upper half lags behind in that regard a bit. Being protected during the quota system and adopting more innovation from DUI than STI, sugar companies now look towards new products and processes in their factories, hinting at open innovation activities and a transformation to biorefining. Thanks to the external push due to the market liberalisation, an opening-up towards new technologies can be observed, and the bioeconomy as a factor declared.

These findings contribute to the theory in various some ways. First, it strengthens the literature on agri-food value chains from an economic geography perspective, emphasising knowledge dynamics and innovation. It thereby follows von Tunzelmann & Acha's (2011) argument against true low-tech since high technologies permeate all sectors equally in a modern world. It also supports Geels (2002) multi-level transition approach by showcasing a beginning paradigm shift in a sector due to changing policy landscape and a deliberate external shock. The knowledge brokering role of growers associations and relatively high absorptive capacity of farmers provide another perspective on regional innovation systems that were believed to significantly lack this capacity (Isaksen et al., 2018) and could potentially hint at a possible future pathway by purposefully deploying actors onto brokering positions. It also contributes to the literature on the bioeconomy by showing yet another example in which the terminology did not matter, but its principles. Actors practice bioeconomy daily, follow the concept, which is at the core of their profession, and yet have never heard of the term before and disregard it. This communication issue is frequently stated and is a massive blockage for it from reaching its true potential. The market liberalisation shocked the sector, but it also laid bare its potential by shifting the focus towards a radical, bioeconomic innovation in transforming the factories into integrated biorefineries. With improved terminology, a straightforward definition and framework, as well as direct, vertical communication across all layers, would undoubtedly be a substantial improvement for the sugar industry and possibly for other mature agri-food industries. The term can function as an excellent transport medium for low-tech, agri-food sectors revolving around biomass, having frequently flat hierarchies, simple processing and cooperative actors and thus can work as other textbook examples, promoting the concept in a more nuanced way. However, for that to work, bioeconomy needs to distinguish itself significantly from sustainability to give actors a common theme in order to follow the steps towards a bioeconomic future, just like the sugar industry demonstrated just recently: in February 2022, a €3 million subsidy was given to the Cosun Beet Company for constructing a sustainable biorefinery, converting sugar beet pulp into plant-based products (Cosun Beet Company, 2022).

Finally, this study invites other researchers to further the results by looking into different agri-food or general low-tech examples, thereby underlining the need for a concise bioeconomy framework; it helped underline its potential relevance for the ongoing sustainability transition, and more research on the matter could help promote that. Also, when considering the fact that a large part of the interviews was conducted shortly after the end of the quota in 2018, an update to look into recent developments, innovations and how far the implementation of biorefineries is may well also contain valuable insights. Another exciting thread of thought that could be taken up would be to focus more on the regional comparison aspect and thus possible regional development avenues a shift of low-tech industries, like agri-food, toward a concrete bioeconomy framework can provide for lagging regions, possibly also enhancing their attractiveness.

> *"If we look at the global development, we are anything but sustainable. We are on an absolutely ruinous path altogether. [...] We all do it together. Always according to the slogan: you do it better first, we are just trying to put the cloak of sustainability over it."* (V*B, pos. 132)

Appendix

4.A Interview Guidelines

Farmer

I **Introduction**

(a) How long have you worked as a farmer?
(b) How has your job changed over the years?
(c) How large is your area under cultivation?
(d) For how long have you been growing sugar beet? What was the reason for you to do so?
(e) What other crops do you grow?
(f) How has growing sugar beet changed over the years for you? What changes did you recognise?
(g) Are their changes regarding the way you grow sugar beets planned?
(h) In comparison to other crops, is growing sugar beet the most profitable option?

II **Work with the Sugar Factory**

(a) What does the arrangement with the sugar factory look like? (Contract Farming?)
(b) If CF: How satisfied are you with the model? Is it fair from your point of view? In which areas are there clear guidelines, in which areas do you have freedom? Can these guidelines be met?
(c) If not: From where do you get your seeds?
(d) By whom and how are the beets transported? Do you see any problem in the form of transportation?
(e) Are there better ways of harvesting/transporting sugar beet in your opinion? If so, why aren't they applied?
(f) Where do you get your knowledge about innovations, new farming methods etc. from?
(g) If there would be an innovative and profitable way of growing sugar beet, would you adapt it?

III **Contact and Cooperation**

(a) Do you have contact with others farmers? If so, to what extent?
(b) Are you a member of a farmer's association or union? If so, how would you rate its work?
(c) Do you feel well represented by the Farmers' Union?

(d) Are there specific support programmes/policies for sugar beet farmers in Sweden?

IV **Utilisation of By-Products**

(a) How important is sustainability to you?

(b) What kind of by-products (residues, wastes, leftovers on the field) do you encounter?

(c) How do you use these? Are they economically important for you?

(d) Can you imagine an even more efficient usage? What potential do you see in using them?

(e) In your opinion: What has been the single most important innovation in the cultivation of sugar beets over the last 20 years?

(f) How open to new procedures would you rate yourself?

V **Have you ever heard of bioeconomy? If so, what's your opinion of it?**

Grower association

I **Introduction**

(a) How is the association organised?

(b) When was the association founded?

(c) How many members (sugar beet farmers) do you have?

(d) What percentage of all sugar beet farmers joins the LRF/Betodlarna?

(e) Is it mandatory for a farmer to join the LRF/Betodlarna?

(f) What differences are there between LRF and Betodlarna? Can a farmer join both of them?

II **Organisation and Membership**

(a) In what form can farmers participate and come up with ideas of their own?

(b) Which linkings and connections are there between the farmers?

(c) What partners does your organisation you have? Why are you engaged with them?

(d) Are there specific support programmes for the farmers?

III **Cooperation and Contact with the Sugar Factory**

(a) What does your contact to Nordic Sugar and the Örtofta sugar factory look like?

(b) What arrangement/contract for sugar beet farmers is there at the moment? How would you rate it? Is it fair for the sugar beet farmers?

(c) What improvements do you wish for?

(d) What is your general opinion on the work of Nordic Sugar and the Örtofta Sugar Factory?

(e) What has changed for sugar beet farmers over the years?

IV **Knowledge and Innovation**

(a) What kind of research and innovation activities are there in your association?

(b) Are you in contact with universities, research facilities, technological suppliers?

(c) Have you been involved in research projects about sugar beets in the past?

(d) Are you currently involved in any sugar beet research projects?

(e) How open do you think sugar beet farmers are to new methods?

V **Utilisation of By-Products**

(a) What role does sustainability play for you? Why?

(b) What by-products (residues, wastes, leftovers on the field) do farmers encounter while growing sugar beet?

(c) In what way are they used? Are they economically important for the farmers?

(d) How would you rate the current usage of by-products?

(e) Is there an even more efficient use from your point of view?

(f) What general potential do you see in using by-products of sugar beet cultivation?

(g) Are there or were there projects in the past focussing on the by-product utilisation of sugar beet cultivation?

VI **Have you ever heard of bioeconomy? If so, what's your opinion of it?**

Knowledge provider/technological supplier

I **Introduction**

(a) How is the NBR organised? What are your working fields? (Do you focus only on cultivation or also on processing?)

(b) What customers do you have? How does your facility work typically?

II **Knowledge and Innovation**

(a)

(b) Which universities and other research institutions are you in contact with?

(c) What projects do you work on at the moment? Are projects currently planned for the future? With whom?

(d) In your opinion: What has been the single most important innovation in the cultivation of sugar beets over the last 20 years?

(e) How are innovations developed by you implemented by farmers or other companies?

III **Contact and Cooperation**

(a) In what form is contact and cooperation with farmers and the farmers' association organised? How is contact and coordination organised with the sugar factory?

(b) How has this contact and cooperation changed over the years?

(c) What is your general opinion on the work of Nordic Sugar and the Örtofta Sugar Factory?

(d) What has changed for sugar beet farmers over the years?

(e) With which other companies are there cooperations?

IV **Usage of By-Products**

(a) What role does sustainability play for you? Why?

(b) What by-products (residues, wastes, leftovers on the field) are produced during sugar beet cultivation?

(c) In what way are they used?

(d) How would you rate the current usage of by-products?
(e) How would you rate the economic and sustainable potential?
(f) What other ways of using these by-products are there?
(g) Why aren't they used yet?
(h) How would the most effective and efficient way look like, in your opinion? How to apply it?
(i) Are there or were there projects in the past focussing on the by-product utilisation of sugar beet cultivation?

V **Have you ever heard of bioeconomy? If so, what's your opinion of it?**

Sugar factory

I **Introduction**

(a) What distinguishes the Örtofta Sugar Factory from other sugar factories in Sweden? What is special about your factory?
(b) What specific function does your company have in comparison to other Nordic Sugar factories? How did it happen, and why?
(c) What freedoms does your company possess regarding the fact that ist a Nordic Sugar factory? What can you decide freely, what are you ordered to do?
(d) How many employees do you have per campaign?

II **Way of the sugar beet**

(a) How many raw material suppliers (= sugar beet farmers) do you have, and how are they distributed geographically? In what way did the geographical distribution change in the last years?
(b) How has the market for your products developed in recent years? Please describe the geographic development of your sales markets.
(c) What does the arrangement with the farmers look like? (Contract Farming?) What is your opinion about it?
(d) How is contract farming implemented?
(e) What is the contact to the LRF/Betodlarna like? Do you see any improvements?
(f) By whom and how are the beets transported? Do you see any problem in the form of transportation?
(g) Are there better ways of harvesting/transporting sugar beet? If so, why aren't they applied?
(h) How many sugar beets do you process per campaign? In what way did that number change over the last 10 years, and why?
(i) What by-products (residues, wastes, sidestreams) are there in your production process?
(j) How do you use these by-products?
(k) If you sell/forward them: to whom?
(l) How has the use of by-products developed in your company? What boosted/blocked the development?
(m) What (economic) significance do these by-products have in your company today?

(n) Can you imagine an even more efficient use of the subsidiary flows in your company? Would you also be willing to convert your production processes?

(o) How would an even more efficient use of the by-products affect your supplier and customer relationships?

(p) What potential and challenges could result from an even more efficient use for your added value?

III **Knowledge and Innovation**

(a) What role does sustainability play for your company? Why?

(b) What measures have you taken to make your company more sustainable?

(c) How important are innovations in terms of sustainability?

(d) Please describe the research and innovation activities in your company!

(e) Which goals do you pursue with innovation projects?

(f) Which universities and other research institutions are you in contact with?

(g) What projects do you work on at the moment? Are projects currently planned for the future? With whom?

(h) What is your motivation behind these?

(i) In your opinion: What has been the single most important innovation in the cultivation and processing of sugar beets over the last 20 years?

IV **Have you ever heard of bioeconomy? If so, what's your opinion of it?**

Headquarters

I **Introduction**

(a) How would you compare Nordzucker to other northern-European sugar producers? What is special about you?

(b) What differences are there between the sugar factories? What distinguishes, for example, the Swedish Sugar Factory from other ones?

(c) In which areas can your sugar factories operate freely and make decisions on their own? In which areas do you set guidelines?

(d) How has the market for your products developed in recent years? Please describe the geographic development of your sales markets.

(e) Who are your biggest customers?

II **Knowledge and Innovation**

(a) What role does sustainability play for your company? Why?

(b) What measures have you taken to make your company more sustainable?

(c) Please describe the research and innovation activities in your company!

(d) Which goals do you pursue with innovation projects?

(e) Are innovations applied in all sugar factories or only in certain ones?

(f) Which universities and research institutions are you in contact with?

(g) What projects do you work on at the moment?

(h) What projects are planned for the future? What is your motivation behind these?

(i) In which areas are investments made (primarily)?

(j) In your opinion: What has been the single most important innovation in the cultivation and processing of sugar beets over the last 20 years?

(k) Where do you see the sugar industry in the next 20 years?

(l) Which possibilities and problems lie ahead, in your opinion?

III **Sugar Beet Value Chain**

(a) What sorts of sugar are being produced in your factories? (Only white sugar?)

(b) How are the sugar beet farmers distributed geographically around your factories? In what way did the geographical distribution change in the last years?

(c) Is Contract Farming applied in all of your factories?

(d) Is contact with sugar beet farmers at every location organised through a farmer's association? Do you see any improvements in the way you cooperate with farmers or the farmer's association?

(e) Are there differences in sugar beet transportation between the companies? Do you see any problem in the form of transportation?

(f) Are there better ways of harvesting/transporting sugar beet? If so, why aren't they applied yet?

(g) In what way did the number of processed sugar beets change over the last 10 years? Why?

(h) What are the differences in the value chain between the different countries?

(i) What by-products (residues, wastes, sidestreams) are there in the sugar production process?

(j) How do you use these by-products?

(k) If you sell/forward them: to whom?

(l) How has the use of by-products developed? What boosted/blocked the development?

(m) What (economic) significance do these by-products have today?

(n) Can you imagine an even more efficient use of the subsidiary flows? Would you also be willing to make changes to your factories to do so?

(o) Are there plans for the future usage of by-products?

(p) How would an even more efficient use of the by-products affect your supplier and customer relationships?

(q) What possibilities and challenges could result from an even more efficient use for your added value?

IV **Have you ever heard of bioeconomy? If so, what's your opinion of it?**

V **What is, from your personal point of view, the most optimal way of going forward in the next few years after the market deregulation?**

4.B Criteria Catalogue

I	Innovation and knowledge	
1a	Factors influencing knowledge generation	positive negative
1b	Influential aspects of knowledge spread between actors	positive negative
1c	Challenges for the implementation of innovative approaches	
1d	Identified needs for change or innovation	ecological social economic
1e	Possible future knowledge or innovation implementations	
1f	Influential changes or implementations of innovation in the past	
1g	Type of innovation	technical non-technical sustainable
1h	Degree of innovation	incremental systemic/radical
1i	Regional embeddedness of the generation of knowledge and innovation	
1j	Inter-regional knowledge or innovation transfer	
1k	Regional differences in knowledge and innovation activities	
II	**Bioeconomy characteristics**	
2a	Applications of bioeconomy characteristics	
2b	Concrete influences of the concept on decision-making	
2c	Understandings of bioeconomy	
2d	External factors applying pressure	call for change from society economic pressure influential policies or governmental actions
2e	Regional differences in application and understanding of bioeconomy	
III	**Value chain**	
3a	Value chain designs or configurations	Advantageous or beneficial challenging or hindering
3b	Sugar industry or low-tech industry specific settings	
3c	Cooperation dynamics, governance and power structures (applications?) of the value chain	
3d	External factors influencing the value chain and its actors	
3e	Regional embeddedness of the value chain	
3f	Regional differences in value chain configuration	

Chapter 5

Conclusion

"And it is not our part here to take thought only for a season,
or for a few lives of Men,
or for a passing age of the world.
We should seek a final end of this menace, even if we do not hope
to make one." (Tolkien, 1954, p.266)

5.1 Summary of Results

By performing three studies on embedded bioeconomy structures from the meta to the micro aggregation level of economic geography, this dissertation made a significant effort to investigate innovation and knowledge dynamics as its central drivers not only within the limits of the respective layers but also encompassing the concept holistically as well. Moreover, it broadened the perspective on the research field and its intricacies and achieved a much clearer understanding that can help reveal the underlying potential of the bioeconomy.

Chapter 2 gave an initial introduction and overview of the main themes of this thesis and elaborates on their intersection by conducting a literature review focusing on the emergence of their combination and its interactions. The initial lookup underlined a vast increase in interest in this combination in the last ten years and mirrored the momentum the bioeconomic concept gained on the policy level in Europe since 2008, before the Paris Agreement and the global focus shift towards sustainability initiated a drastic surge. Reviewing the collected literature, an emphasis on the process of innovation amplified by interdisciplinarity and adaptive policymaking in the bioeconomy is presented, as well as knowledge as the most critical resource declared and learning as an interactive process between actors as a driver for its creation and diffusion communicated. Along those lines, contributions also discussed consumer behaviour and acceptance as vital elements while pointing out the benefits of looking at innovation in the bioeconomy from a multi-dimensional, collaboration-focused innovation systems perspective. Based on the literature review, the study then developed a set of seven criteria and attributed keywords, which are assumed to influence innovation occurrence in the bioeconomy positively. Due to being a meta-level, policy-oriented concept, results show that drivers from the innovation systems perspective neatly apply to the bioeconomy and that a combination of STI and DUI innovation modes is the most beneficial. The not yet fully utilised potential in adopting circularity and cascading as principle innovation drivers in bioeconomic settings is highlighted as well, and an absolute lack of case-oriented research on bioeconomic innovation systems concluded.

The second study then distanced from the meta-discourse in a two-step fashion. By extracting and evaluating information on the meaning of bioeconomy from three distinct macro-level spheres – policy and funding, science and research, social and societal – a comprehensive set of keywords was created with the help of a data-driven approach utilising modern data science methodology centred around text mining. This novel conceptualisation effort leverages the bioeconomy's lack of demarcation and builds a strong and objective foundation for the subsequent step that delves deeper into the meso-scale of a network based on the European funding program Horizon 2020. Being Europe's fundamental research and development instrument to create and diffuse knowledge across borders and bolster the European research landscape, it provided an excellent environment to examine the distribution of the bioeconomic concept. For the bioeconomy itself, investigating network structures and key actors, as well as their spatial distribution both in the abstract network and on the accurate geographical scale, revealed crucial results. Since innovation is a key driver for the bioeconomy, answering questions regarding who is central in working on the concept and developing it further, how the network is structured regarding knowledge flows and which implications can be derived is vital for understanding the concept and unfolding its shortcomings. Based on evaluating descriptive, structural and centralistic parameters, with the relevant theory being presented beforehand and merged into an analytical framework, the analysis showed an underrepresentation of eastern-European countries in leading positions and an overrepresentation of academia in project participation. The initial descriptive analysis also illustrated a broad diffusion of the concept across all projects funded in H2020, yet again underlining its holistic scale. A leading group of actors inside the network, mainly consisting of large research organisations like Fraunhofer, CNR or CSIC, occupies dominant and bridging positions along multiple centralistic dimensions, thereby substantially influencing knowledge generation and diffusion inside the network therefore also impacting the connotation of the term itself. These actors also play a crucial role in the network's structural integrity and power distribution, so new actors and new knowledge have a more challenging time entering. By that, the Matthew-effect and homophilic tendencies of actors in the leading group are underlined. Besides the skewed west-east distribution, the analysis also revealed an underrepresentation of companies, especially SMEs and low-tech, in central and connecting positions. While appearing in a good spot numbers-wise, they do not matter in the knowledge dynamics of the network. This leads to limited novelty entering the network and due to the dominant position of the central actors favouring intra-industry linkages, a lack of diversity and interdisciplinarity negatively narrows the bioeconomy's direction. Chapter 3, therefore, not only illustrates the European bioeconomy network and its implications regarding actor relationships and knowledge dynamics but also quantitatively operationalises the bioeconomy and presents a new perspective.

The final study (Chapter 4) continued downwards to the micro-level of firms and value chains. It builds conceptually on the results of Chapter 3 by aiming to unfold innovation and knowledge mechanics and machinations in a previously in research underrepresented low-tech, agri-food setting while also relating to theoretical impressions on innovation in the bioeconomy gained in Chapter 2. It seeks to considerably expand the perspective of how innovation is achieved in the bioeconomy by presenting an in-depth look into the actorial relationships and configurations of three low-tech, agri-food value chain cases. The work harnessed the simplicity of the sugar value chain as a case and interviewed the same actor groups in three regional case studies, which ensured comparability and a robust research framework. Structurally, the study compiled an analytical framework comprised of an outer innovation system shell with its drivers and externalities influencing an inner value chain setting centred around sugar beet as biomass and being looked at from a value web perspective due to bioeconomic principles like circularity and cascading impacting its configuration. The qualitative content analysis then fine-sliced the interview findings, highlighted the specificities of an agri-food sector, and answered the formulated research questions regarding its value chain configuration, knowledge and innovation mechanisms and the influence of the bioeconomy. One of the key findings is related to the relationships and cooperation between the actors and comprises a unique value chain setting. While the cultivation side, encompassing farmers, growers associations and partially knowledge providers, is well-connected and actors display high absorptive capacity and relational capability as well as trust, the relationship between the individual headquarters and sugar factories is described as a lot more hierarchically governed and less flexible, leading to the suspicion of a novel value chain setting with a hierarchic upper and a relational-flexible lower half. This unique setting greatly influenced the knowledge dynamics. Growers associations hold an emphasised role and function as knowledge brokers, often translating information from the knowledge providers and transporting it via various channels to the farmers, who in turn showed high flexibility and openness towards these new methods, and put much trust into the associations. Learning occurred both intentionally, due to field days, and unintentionally during on-farm research and via interpersonal relationships between the farmers, positively influencing their absorptive capacity regarding new knowledge. The study also revealed a precarious situation innovation-wise for sugar factories due to them being governed by the respective lead firm and having few freedoms. While having access to the R&D network the lead firm provides, ideas and projects of the factories have to be approved first. Innovation is described as being almost exclusively incremental and efficiency-focused in both halves of the value chain and following a DUI pattern. A further exciting outcome is that more radical innovations are directly influenced by focusing on the valorisation or utilisation of sidestreams and by-products – both bioeconomic principles. Regarding the bioeconomy, the interviews showed that although actors live by the concept, most of them never came into contact with the term. The significance of this communication problem is amplified when regarding the fact that implemented radical innovations are centred around the bioeconomy concept, and thus much potential is lost in translation. The recent market liberalisation of the sugar industry triggered a frantic search for alternative products based on sugar beet and pointed towards bio-based material and bioraffination, both core ideas of the bioeconomy. The study, therefore, concludes with a definitive potential bioeconomic pathway for low-tech industries revolving around biomass, with sugar being a prime example of a transformation toward a sustainable bioeconomy. External drivers like a shifting customer demand towards sustainability and, thus, a new market environment, as well as research and technology being able to deliver needed knowledge on top of the menacing societal challenge of climate change work as influencing factors in the innovation system. The results also showed that the value chain configuration of the sugar industry is well-suited to adopt this transformation due to lead firms in a pushed situation due to recent market developments and a cultivation side having high flexibility and capacity on top of an open innovation spirit. However, a significant challenge is presented in communication and the need for policies reaching the micro-level and providing concrete incentives for firms to follow the path the sugar industry just recently took to transform into a bioeconomy sustainably.

5.2 Limitations

While all analyses and data collection activities presented in this dissertation were carried out to the best of the authors' knowledge and ability, certain important limitations must be discussed in the following.

Most noticeably, data for the literature review collected in Chapter 2 and some of the interviews conducted for Chapter 4 are roughly four years old at the time of writing, which may be seen as a shortfall due to their lack of actuality. In a research field like the bioeconomy that ultimately aims to combat climate change's effects, time is an essential resource, and, therefore, the topicality of research results is vital. Initially, in Chapter 2, the advanced search for literature on bioeconomy innovation in the Web of Science Core Collection resulted in a total of 292 publications found; when repeating this search in 2022, nearly double that count of publications are found for the last three years alone, hinting at an even more considerable increase than noticed in 2018. However, it must also be noted that in the initial reviewing process, a substantial amount of publications did not present any relevant novelties regarding innovation in the bioeconomy; thus, an assumption can be made that the research field did not change dramatically over the last three years and that the results are still valid. This argument can be further supported when considering that the most influential works on the topic, according to their citations total and per year, did also not change. Nevertheless, the lack of recency is still a weakness in the significance of Chapter 2 and must be regarded as such; an updated study with a similar data science foundation as the operationalisation conducted in Chapter 3 could therefore be an exciting avenue for future work on the topic. In comparison, the problem of recency is a lot less dramatic in Chapter 4; due to the ongoing pandemic, it would also be detrimental and add a substantial skewness to the results if the interviews were exclusively conducted after the outbreak in 2020. By performing almost all of the 17 interviews pre-pandemic and closely after the market liberalisation, an untainted opinion on the challenge of climate change could be investigated. For Chapter 4, difficulties in acquiring interview partners posed a further challenge that influenced the total number of interviews conducted and led to only three regional value chains being compared. This work's results must be considered with this limitation in mind. For further comparative analysis, more case regions would, of course, pose a valuable extension. Another direct limitation is that some interviewees required non-disclosure agreements, which led to the complete anonymisation of the study and the elimination of the possibility of making regional comparisons. These could have provided yet another perspective, shedding light on regional innovation systems, their influence on the embedded value chains and possibly including regional parameters into the analysis. The study resulted in the bioeconomy being a potent driver for low-tech, agri-food chains, and thus potentially supporting disadvantageous, rural regions – comparing their settings with one another could yield exciting results. Of course, general limitations regarding the analysis of interviews apply as well but were avoided as much as possible by using a straightforward methodology based on Qualitative Content Analysis and coding undertaken in MaxQDA. Still, as is the case for all qualitative methods, subjectivity and bias can not be ruled out entirely, and the results should be regarded with that limitation.

For the second study, a different set of limitations presented itself. The most crucial restriction for Chapter 3 lies in the assumed knowledge transfer between organisations participating in a joint project, upon which the entire network analysis is built. While transferring knowledge and inducing learning is one of the key pillars of European funding policy and other authors working on networks based on affiliation data regard projects also as "[...] intended to stimulate collective learning and knowledge diffusion" (Bednarz & Broekel, 2019, p.1465), the assumption of knowledge transferring between actors is an important one to highlight. Another limitation of Chapter 3 is that although the emphasis was put on avoiding judgemental decisions influencing the data when carrying out the three mining efforts, the inspection of the sub-programmes still followed a case-by-case decision process done by hand. Although this step was done inversed, meaning that all programmes were excluded where bioeconomy was not assumed, it still involved subjective decision-making and thus needs to be mentioned. Another limiting factor can be seen in the constructed keyword list and its precision in identifying projects involving bioeconomic principles. While with the split into two sets of words and word groups and by checking the accuracy afterwards on the distinctly bioeconomic sub-programme, a lot of effort was made to increase precision as much as possible – which of course, does not imply completeness of the project dataset and therefore the network as well. However, what is not reflected in the study but into which a lot of time went is searching for a potentially more accurate and precise option to filter the project database. Sadly, both strictly more fancy options of machine learning based on different training datasets and deep learning performed with a multi-layer neural network ultimately did not perform better than regex-filtering with the two sets of keywords, which provided by far the best results[1].

Moreover, the perspective taken in Chapter 3 was to consider the bioeconomy conceptually but could not engage with the individual projects in more detail. Questions may be asked about what is unique about them, what contents are described by their description and how they compare to the rest of Horizon 2020, thus examining what makes bioeconomy projects bioeconomic – this path was sadly not taken. This provides yet another excellent opportunity for another dive into the European funding world, maybe also into Horizon 2020's successor, Horizon Europe. What could also sadly not be solved in this study but what could improve its results substantially is that individual research institutes of larger national research institutions – like Fraunhofer – are recorded under the name of the central organisation. By that, a not solved skewness lies in the data that must be critically regarded. Breaking down this summarisation and shedding light on the internal networks of these organisations, let alone comparing them structurally, would definitely be an exciting adventure.

5.3 Contributions to Literature

Despite these limitations, the studies conducted in this thesis contributed to the literature in various ways. As a guiding principle, the dissertation aimed at unravelling innovation in different bioeconomic settings to make the concept more concrete and tangible to not only add to the ongoing discussion on innovation in the bioeconomy but also to support future policy applications. Methodologically, it combined the new with the old and followed an impetus that sees the "study of geography [...] as a more pragmatic, open and approachable discipline that is more interested in the art of the possible rather than the traditionally more aloof and classical approach of the economists" (Howells & Bessant, 2012, p.930) to do the bioeconomy justice. On a holistic scale, it built its motivation of unravelling on authors like Bauer (2018, p.96), who regard "[...] perspectives on innovation for the bioeconomy [as] a complex fabric, woven of conflicts [...]" and Sanz-Hernández et al. (2019, p.115), who conclude that "that the field of bioeconomy lacks mixed methodological

[1] evaluated by calculating Cohen's Kappa (Landis & Koch, 1977) across all approaches

designs and needs multidisciplinary research [...] [and] a holistic and multidisciplinary vision that can account for such a multi-dimensional and complex reality", thereby being in line with Golembiewski et al. (2015, p.315), who argue that "[...] a comprehensive and common definition to monitor and institutionalise the bioeconomy still needs to be developed within scientific as well as societal debates". Therefore, a multi-level, mixed methods view on innovation in the bioeconomy was undertaken over the course of this work, progressively zooming in deeper. While the individual chapters are self-contained, they are nevertheless interconnected in losely building up on each other.

Initially, in its quest to provide an overview of the research field and deduce a set of criteria for bioeconomic innovation, Chapter 2 combines the central literature on the topic and distils it into a concise set of criteria that can function as a baseline for further research that tackles innovation in the bioeconomy. It thereby expands on e.g. Purkus et al. (2018) or Kardung et al. (2021), whose works also tried to answer the question of which conditions favour the emergence of innovations in the bioeconomy. While not directly referenced, the gathered information and the set of criteria from Chapter 2 were supportively used at the start of Chapter 3 to exclude non-bioeconomic programmes from the dataset.

Further, chapter 3 significantly adds to the research body on the conceptualisation of the bioeconomy by presenting a novel approach based on data science and text-mining. By spatialising this data afterwards and doing a comprehensive network analysis, it also contributes to economic geography. While the spatiality of knowledge networks has been in focus for around 15 years in economic geography (Broekel & Mueller, 2018), social network analysis on a larger scale and based on funding data is – unfortunately, and unjustifiably – still in its infancy (Fritsch & Kauffeld-Monz, 2010). Research involving network analysis on Horizon 2020 data is extremely scarce (Enger, 2018; Wanzenböck, Lata, et al., 2020) and in some cases, lacks comprehensiveness (Bralic Antonia & Vjeran Strahonja, 2017; Ferrer-Serrano et al., 2021). Therefore, conducting an in-depth social network analysis on Horizon 2020 data is a significant contribution. Chapter 3 does also mount on the recommendations of Golembiewski et al. (2015) by contributing not only to the tangibility of bioeconomy but also by revealing collaboration dynamics and tracking implementation, while also answering to Purkus et al. (2018) by focusing on the contributions of networks to the concept and revealing its leading driving organisations. By examining structures, dynamics and said central actors of the network and locating them, the study provides a detailed insight into the knowledge dynamics of a European funding network and its shortfalls – thereby presenting an exciting avenue for further research on similar concepts or international R&D networks. While network analysis revolving around the bioeconomy did take place in the past (Giurca, 2020; Korhonen et al., 2018), their scope remained on the sectorial scale, resulting in Lovrić et al. (2020, pp.10-11) stating that "the greatest potential scientific contribution of the study is in its potential to be replicated in the overall bioeconomy field, where longitudinal analysis of all its segments could provide a new perspective on which factors foster and impede the development of research and innovation [...]", to which Chapter 3 provided a comprehensive answer and invites future researchers to build on this foundation.

Finally, Chapter 4 zoomed in on the actor and firm-level, filling an important gap for bioeconomy, in which the focus historically is more on high-tech and low-tech seems underrepresented (Esposito et al., 2020; Mehmood et al., 2021), despite authors stating low-tech as a potential driver for the bioeconomy (Cuerva et al., 2014; Wydra, 2019). It thereby also connects to Chapter 3, which concluded a definite need for research on low-tech and firm-level perspectives. With a focus on innovation settings and knowledge flows, Chapter 4 contributes to the literature body of economic geography, in which discussions on knowledge dynamics are a welcoming addition (Asheim, 2007), especially if they are based on value chains (Boschma, 2022). By examining three regional value chain cases, a concrete example of carried-out bioeconomy was achieved, significantly adding to its clarification. The potentially influential role of farmers due to their high absorptive capacity and openness to change was a result of Wensing et al. (2019) as well, which could be highlighted and built upon by this study by shedding light on their relationships with other actors along the chain. The work also added to the literature on value chains by presenting a novel configuration based on the sugar industry that could be in place in other agri-food settings. By investigating collaboration and open innovation, Chapter 4 also touches upon Golembiewski et al. (2015), who see both concepts being applied across value chains as critical requirements for knowledge and technology creation – which could be confirmed here. Due to the chapter adopting an analytical framework based on an innovation system shell and a value chain (-web) core and extensively examining both, it runs in parallel to Bauer (2018), who sees requirements for a greater transition toward the bioeconomy in consumers, institutions regarding policies and regulations, as well as innovation throughout value chains. By shedding light on these parameters, the work also delivers some of the key ingredients a governance framework for the bioeconomy needs, as is requested by Dietz et al. (2018). The case of the sugar industry, a sector that recently underwent a major incision in form of a market liberalisation, which, in the light of the transition literature (Geels, 2002; Köhler et al., 2019; Loorbach et al., 2017), can be seen as a needed external shock to begin the transformation process from an incremental to a radical regime; the sugar case here functions as a snapshot of a sector at the start of this transition and thereby adds an exciting and original example to the literature. The chapter thereby also revealed the significant potential a low-tech, agri-food sector has in light of a transformation towards bioeconomy with biorefineries as potential avenues, supporting studies conducted on this pathway (e.g. Bauer, 2018; de Oliveira et al., 2020; Hernández-Pérez et al., 2020). Finally, the revealed challenges for this transformation to happen are also in line with other authors: Purkus et al. (2018, p.3968) conclude that "[...] policies have an important role to play in supporting functioning bioeconomy innovation systems [...]", while Staffas et al. (2013, p.2766) already stated "[...] a need for considerable support in the forms of policies and/or financial instruments introduced for making the required investments economically feasible and manageable by industrial stakeholders" as a major challenge. Nevertheless, Chapter 4 underlines the bioeconomy as a potential avenue for the low-tech, agri-food sector towards sustainability transitions and supports this claim with an in-depth look into a compelling case. It supports the bioeconomy literature by providing an alternative perspective toward a more biomass-centred approach that must be communicated across all levels and requires special political attention and care, opening the door for subsequent research considerably.

5.4 Policy Recommendations

In this dissertation, various policy recommendations were discussed that are now, to conclude and end, going to be summarised and extended.

First, while regarded as problematic, the fuzzy nature of the term bioeconomy and its inherent demarcation problem is not all bad: the broader a term is, the easier it is to promote and fund because it can imply and mean many things. However, the lack of a unified understanding in politics, business, and civil society must be seen as a clear challenge. A first possible goal is, therefore, to make the concept of the bioeconomy more tangible. In the course of this thesis, the views on the bioeconomy from a wide variety of authors, organisations and stakeholders were considered, and the results were surprising, if not worrying. While the concept was mostly well-known at the higher levels and organisations belonging to the agricultural sector had at least "heard of it before", the situation of the companies and small-scale actors was worse: if they had already stumbled across the term, then, for the most part, a twisted perception of what it means, let alone implies, could be observed – despite them clearly being involved in bioeconomy . Therefore, communicating the concept across relevant sectors should be prioritised. Farmers, whose livelihood is based on bioeconomic principles and who are generally believed to support the transformation towards a bioeconomy strongly, are insufficiently included in policy approaches. The bioeconomy should therefore continue to be conducted as a political meta-discourse but policy also needs to actively involve and communicate more clearly with the implementing actors. A more concrete understanding and communication – as Chapter 4 concluded – may lead to a situation in which actors are able to use the bioeconomy concept as a connective, bolstering element.

In order to overcome the current lock-in of a fossil-based production mode, it is therefore imperative to also diffuse the concept in a comprehensible way – including especially its circularity aspect – in political,economic and societal spheres. Knowledge and innovation are the most significant influencing factors for a transformation process toward the bioeconomy. Innovation in the context of the bioeconomy should therefore be thought of as broadly as possible and involve as many (diverse) actors as possible in the process to raise awareness of the concept and thus create widespread acceptance. To address the underrepresentation of companies and the central role of a few research organisations shown in Chapter 3, a stronger emphasis on applied research projects on the bioeconomy is necessary. At the same time, these applied research projects may require additional checks ensuring their sustainability focus, especially with the resource of land in mind. In summary, a multi-dimensional understanding along all actor levels with a focus that is not exclusively knowledge-based but also market-oriented and entrepreneurial can make a definite contribution to the success of the bioeconomy concept. To achieve this, funding in the context of the bioeconomy should be based on the fundamental principles of socio-technical transformations (Coenen et al., 2012). This means that interdisciplinary and transdisciplinary approaches should be prioritised by policies and that the natural and social sciences must be concretely included in the research. A focus on generally practice-oriented research that involves not only the high-tech but also the low-tech sector and thus clearly addresses organisations and companies, e.g. in the area of agri-food, is another possibility. This sector, in particular, has much untapped potential that can be used bioeconomically. This practical orientation is also intended to focus clearly on companies. More concretely, funding policy targeting the bioeconomy should shift even more towards including companies or practitioners, in order to diffuse the concept in their networks as well and to ensure feasibility. This may require reforming application procedures in order to incentivise or prioritise projects involving underrepresented or isolated actors (e.g. SMEs, practitioners). In that way, network structures, especially in the European funding landscape, could be optimised substantially while also providing access to funding for more actors.

As the example of the sugar industry revealed, external drivers play a significant role for innovation in the bioeconomy. Political incentives, like supporting bioethanol or biogas, initiated a substantial shift in the processing of some cases and led to the adoption of clearly bioeconomic pathways and more circular solutions. Furthermore, the sugar industry also showed a possible but far-reaching idea to overcome innovation barriers and locked-in states: open competition – here induced by market liberalisation – triggering competitive pressures and leading to rapid rethinking and adjustment of routines. Of course, external shocks like these may not be desired or possible in many cases, but the example still showed what political intervention can achieve and in which ways it can steer and control into a wanted direction. These processes rely on financial implications for the companies, ranging from small nudges to extreme market intervention. Policies should therefore create more concrete financial incentives with the overarching goal to initiate bioeconomic concepts, like zero waste, circularity or cascading. As Chapter 4 concluded, firms often hold more innovation potential than anticipated and it may be enough to give a monetary push for it to emerge. That seems especially true for mature, low-tech industries with established production processes – like the sugar industry – which were surprisingly flexible, given the right reason.

Another externality that should not be neglected is society. A socio-technical transformation can only succeed if the social side is also reached by it. One hurdle for the bioeconomy at present is the attempt at social change, which happens apart from society because comprehensive involvement of society has been lacking up to now. Acceptance not only plays a central role among consumers but also significantly impacts the implementation of new knowledge and should therefore be given primary consideration. Project calls should, therefore, not only encourage involvement of small companies as described above but could also themselves address socially relevant issues and involve societal actors more generally. In addition, it is a good idea to provide further support for the application and implementation of results achieved through early communication with potential users.

Last but not least, it must always be kept in mind that measures that work in one place cannot necessarily be considered a universal solution. In geography, space matters. It is not an empty construct but always has a complex structure of local actors, knowledge and particularities that must not be disregarded (Barca et al., 2012). For the bioeconomy, the focus should be placed on structurally weak regions, for example by promoting regional alliances or providing incentives for agricultural actors. It is precisely these regions that may hold opportunities for the bioeconomy in the future, with low-tech industries as potential drivers. Therefore, research and policies in the field of the bioeconomy should be transdisciplinary, company- and society-oriented, innovation-led, and spatially differentiated. The bioeconomy holds potential and opportunities to be uncovered; it just needs to be communicated more meaningfully.

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Eigenständigkeitserklärung

Hiermit erkläre ich, dass diese Arbeit bisher von mir weder an der Mathematisch-Naturwissenschaftlichen Fakultät der Universität Greifswald noch einer anderen wissenschaftlichen Einrichtung zum Zwecke der Promotion eingereicht wurde. Ferner erkläre ich, dass ich diese Arbeit selbstständig verfasst und keine anderen als die darin angegebenen Hilfsmittel und Hilfen benutzt und keine Textabschnitte eines Dritten ohne Kennzeichnung übernommen habe.