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A concise study using disciplinary, stakeholder and technology perspectives

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Abstract

Technology transfer from academia to industry in emerging knowledge areas such as the bioeconomy is considered a major challenge. In this regard, there have been an increasing number of policy and funding initiatives (e.g. Bioeconomy Science Center, Horizon 2020) aiming at enhancing industrial implementation and commercialisation of research generated in academia. These initiatives also foster interdisciplinary research, as it provides enormous potential for innovation, and it is essential to effectively solve the global challenges of the twenty-first century. This thesis focuses on the specific case of the knowledge-based bioeconomy (KBBE) as an example of such a highly interdisciplinary and emerging knowledge area with a potential to solve the global challenges of the twenty-first century. However, technology transfer entails new challenges in a context of collaborative research due to the cognitive distance between different and unrelated disciplines. Hence, the aim of this thesis is to analyse mechanisms for a successful technology transfer in emerging knowledge areas such as the bioeconomy by emphasising the particularities of interdisciplinary research settings using three perspectives: disciplines, stakeholders and technologies. As such, this thesis consists of a state-of-the-art and theoretical framework review. This is followed by an exploratory multiple case study approach to understand particularities of technology transfer in interdisciplinary research settings from a disciplinary perspective. In addition, a participatory and bottom-up study with key technology transfer stakeholder groups (i.e. academic scientists, technology transfer facilitators, firms/entrepreneurs) from Germany was conducted to provide the first overview of factors affecting technology transfer in the bioeconomy. Finally, from the third perspective, this thesis empirically demonstrates how interdisciplinary research can be depicted and assessed at the level of technologies by taking bioplastics as an example of a highly interdisiciplinary and emerging technology within the bioeconomy.

The main finding of this thesis is that integrating knowledge across different disciplines as well as between the key technology transfer stakeholder groups is pivotal for successful technology transfer in emerging knowledge areas such as the KBBE. In particular, from the disciplinary perspective, results of eight comprehensive case studies (four interdisciplinary academic research groups and four interdisciplinary spin-offs operating in the bioeconomy) illustrate through content analysis the high relevance and attention that interdisciplinary collaborations acquire in the research setting of the bioeconomy. This analysis also emphasises the need to study technology transfer from the overall spectrum of technology transfer stakeholders who jointly shape the technology transfer process (academic scientists, technology transfer facilitators, firms/entrepreneurs). From the stakeholder perspective, the participatory and bottom-up study with 90 stakeholders by means of multidimensional scaling and hierarchical cluster analyses indicate that factors related to interdisciplinary collaborations and collaborations between academic scientists and firms as well as those tied to financial issues or consumer acceptance are assigned the highest level of importance. However, these factors are also characterised by the lowest level of coherence across key stakeholders. In light of the increasing importance of interdisciplinary collaborations, evaluating interdisciplinary research is indispensable for funding agencies and policy-makers. Consequently, a novel approach by drawing upon a sample of 890 patents and 8979 patent citations is constructed to analyse technology transfer from a technology perspective. Thus, this novel typology can help firms, funding agencies and policy-makers to improve their technological capabilities by facilitating knowledge sharing and transfer across technological areas, and to support the design and development of science and innovation policies that foster interdisciplinary research. Hence, this thesis aims at advancing the state-of-the-art with regard to the use of interdisciplinary indicators by constructing novel patent indicators that can be used to assess the degree of interdisciplinarity in emerging knowledge areas. To sum up, the outcomes of this thesis seek to contribute to the analysis of successful technology transfer in emerging knowledge areas such as the bioeconomy by understanding the particularities of interdisciplinary research settings.

Zusammenfassung

Der Technologietransfer von der Wissenschaft in die Industrie gilt vor allem in neu entstehenden Wissensgebieten als große Herausforderung. Um speziell diesen Herausforderungen zu begegnen, werden eine zunehmende Anzahl an politischen Initiativen angestoßen, wie beispielsweise das EU-weite Forschungsprogramm „Horizon 2020“ oder das „Bioeconomy Science Center“ in Nordrhein-Westfalen. Diese Initiativen verfolgen das Ziel, universitäre Forschung in industrielle Anwendungen zu überführen, wobei vor allem interdisziplinäre Forschungsansätze gefördert werden, welche hohes Innovationspotenzial versprechen, um den globalen Herausforderungen des 21. Jahrhunderts zu begegnen. Als Beispiel für ein derart hochgradig interdisziplinäres, neu entstehendes Wissensgebiet betrachtet diese Arbeit die Bioökonomie, mit dem Ziel, Mechanismen für einen erfolgreichen Technologietransfer zu identifizieren. Aufgrund der kognitiven Distanz zwischen unterschiedlichen Disziplinen und Akteuren innerhalb der Bioökonomie stellt der Technologietransfer jedoch neue Herausforderungen dar. Daher wird in dieser Arbeit der Technologietransfer innerhalb der Bioökonomie aus drei unterschiedlichen Perspektiven, nämlich aus Sicht unterschiedlicher Disziplinen, Stakeholder-Gruppen und Technologien, analysiert.

Zur Betrachtung der ersten Perspektive erfolgt ein explorativer, multipler Fallstudienansatz, um die Besonderheiten des Technologietransfers in interdisziplinären Forschungsbereichen aus jeweiliger, disziplinärer Sicht zu verstehen. Zur Analyse der zweiten Perspektive wird eine partizipative, Bottom-up-Studie mit wichtigen Stakeholder-Gruppen des Technologietransfers (Wissenschaftler, Technologietransfer-Vermittler, Unternehmen/Unternehmer) durchgeführt, um einen Überblick über diejenigen Faktoren zu geben, die den Technologietransfer in der Bioökonomie maßgeblich beeinflussen. Aus der dritten Perspektive zeigt diese Arbeit schließlich empirisch, wie interdisziplinäre Forschung auf Technologieebene dargestellt und evaluiert werden kann. Hierzu wird am Fallbeispiel Biokunststoff ein stark interdisziplinäres und aufstrebendes Technologiegebiet innerhalb der Bioökonomie untersucht.

Die Haupterkenntnis dieser Arbeit ist, dass die Integration und der Austausch von Wissen über verschiedene Disziplinen und Technologiebereiche sowie zwischen den wichtigsten Stakeholdergruppen des Technologietransfers der Schlüssel für einen erfolgreichen Technologietransfer in neu entstehenden Wissensgebieten wie der Bioökonomie ist. Insbesondere aus disziplinärer Perspektive verdeutlichen die Ergebnisse von acht Fallstudien

(vier interdisziplinäre, akademische Arbeitsgruppen und vier interdisziplinäre Spin-offs in der Bioökonomie) eine hohe Relevanz einer interdisziplinären Kooperationen im Forschungsumfeld. Des Weiteren unterstreicht diese Analyse die Notwendigkeit, den Technologietransfer aus dem gesamten Spektrum der unterschiedlichen Stakeholder zu betrachten, da diese den Technologietransferprozess gemeinsam gestalten.

Aus Perspektive der Stakeholder-Gruppen zeigt die partizipative, Bottom-up-Studie mit insgesamt 90 Stakeholdern, dass die Faktoren Interdisziplinarität, Kooperationen zwischen Wissenschaftlern und Unternehmen sowie Verbraucherakzeptanz eine hohe Bedeutung beigemessen werden. Diese Faktoren zeichnen sich jedoch auch dadurch aus, dass sie im Vergleich zwischen den Stakeholder-Gruppen insgesamt ein niedriges Maß an Kohärenz aufweisen. Daraus ergibt sich, dass angesichts der zunehmenden Bedeutung interdisziplinärer Kooperationen, die Bewertung des Ausmaßes interdisziplinärer Forschung für Förderorganisationen und politische Entscheidungsträger unerlässlich ist, dazu jedoch die unterschiedliche Betrachtung und Bewertung des Technologietransfers durch die Stakeholder-Gruppen berücksichtigt werden muss.

Für die Betrachtung aus technologischer Perspektive wird ein neuartiger, auf Patentdaten basierender Ansatz entwickelt, um Interdisziplinarität innerhalb eines Technologiegebietes zu analysieren und erstmalig quantitativ zu erfassen. Basierend auf einer Stichprobe von 890 Patenten und 8.979 Patentzitaten im Technologiefeld Biokunststoff wird dargestellt, wie interdisziplinär das Technologiegebiet ist und welche Technologiefelder innerhalb des Technologiegebietes von besonderer Bedeutung sind. Unternehmen, Fördereinrichtungen und politischen Entscheidungsträgern wird dadurch ermöglicht, den Wissensaustausch und -transfer über Technologiebereiche hinweg effizienter zu gestalten und entsprechende Entwicklungspfade für Förderprogramme aufgezeigt. Zusammenfassend zielen die Ergebnisse dieser Arbeit darauf ab, durch ein besseres Verständnis über die Besonderheiten interdisziplinärer Forschungsumgebungen, zu einem erfolgreichen Technologietransfer in der Bioökonomie beizutragen.

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List of abbreviations

AUTM	Association of University Technology Managers
BECY	Strategic Network Bio-based Economy
BioSC	Bioeconomy Science Center
BMBF	German Federal Ministry of Education and Research
CEA	Controlled Environmental Agriculture
CEO	Chief Executive Officer
CTB	Title/Abstract/Claims
DeCi	Digital Science Center
ELLS	Euroleague for Life Sciences
EPO	European Patent Office
EU	European Union
GEWISOLA	German Association of Agricultural Economists
GMO	Genetically modified organism
KBBE	Knowledge-based bioeconomy
KETs	Key Enabling Technologies
ICA	Interfaculty Committee Agraria
ICT	Information and Communication Technology
IP	Intellectual Property
IPC	International Patent Classification
IPR	Intellectual Property Rights
IObio	Industrial Organization in the Bioeconomy
IT	Information Technology
OECD	Organisation for Economic Co-operation and Development
PBAT	Polybutylene adipate-co-terephthalate
PBS	Polybutylene succinate
PCL	Polycaprolacton
PHAs	Polyhydroxyalkanoates
PLA	Polylactic acid
RBV	Resource-based view
R&D	Research and Development
R&D&I	Research & Development & Innovation
R&I	Research and Innovation
SMEs	Small and Medium-sized enterprises
US	United States
WIPO	World Intellectual Property Organization

Chapter 1

1 Introduction

1 Introduction

1.1 Research problem

Technology transfer, described as the process of transferring scientific knowledge and technologies from academia to business[1], has established itself as an indispensable part of research and innovation (R&I) at European level. The numerous initiatives that the European Commission has launched to enhance technology transfer present visible evidence for this.[2] As a result, the utilisation of research results is currently taking an important relevance in the work of academic institutions.[3]

Interdisciplinary research collaborations, on the other hand, are essential to effectively solve the global challenges of the twenty-first century.[4] Interdisciplinary research is also considered the major source and the basic instrument for innovation.[5] Broadly, interdisciplinary research refers to a mode of research that combines different disciplines, areas of research practice, or technologies to work together on a specific problem.[6] The growing relevance of interdisciplinary research has also been reflected by an increasing foundation of academic organisations targeting interdisciplinary collaborations.[7] Governmental funding initiatives fostering interdisciplinary research collaborations equally show these desires.[8] Globally, the enhancement of interdisciplinary research has become an important goal for policy-makers, academic scientists, academic institutions[9] and firms.

An example where both of these phenomena are crucial is the knowledge-based bioeconomy (KBBE). Therefore, this thesis focuses on the specific case of the KBBE as an example of a

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[1] Association of University Technology Managers AUTM [www.autm.net].

[2] European Commission (2007); European Commission (2008a); European Commission (2008b); European Commission (2012a).

[3] Etzkowitz et al. (2000); Larsen (2011); Pyka et al. (2016); Shane (2004); van der Steen and Enders (2008).

[4] Biancani et al. (2018); Klein (2008); Repko and Szostak (2016).

[5] Bruns (2013); Dingler and Enkel (2016); Klein (2008); Whalen (2018).

[6] Repko and Szostak (2016).

[7] MacLeod (2016).

[8] Mugabushaka et al. (2016); Rafols et al. (2010).

[9] This thesis uses the term "academic institution", defined as an educational institution dedicated to teaching and/or research. Thus, this term covers universities and research institutes.

highly interdisciplinary and emerging knowledge area.[10] The KBBE relies on knowledge, Research & Development & Innovation (R&D&I) in order to produce products and technologies based on biological and renewable resources.[11] The bioeconomy is a suitable case for interdisciplinarity and technology transfer as it builds upon the combination of a wide spectrum of scientific disciplines and technologies[12] developed in academic institutions.[13]

In practice, the growing importance of technology transfer and interdisciplinary research entails a new learning experience for a wide range of stakeholders: academic scientists, academic institutions, technology transfer offices, firms, funding agencies and policy-makers. Firstly, academic scientists may adapt their research practice by forming interdisciplinary consortiums, or even changing their research agenda and topics to investigate. Secondly, academic institutions may change their organisational structures and research programs to meet interdisciplinary demands. In a similar vein, firms may learn by adopting more interdisciplinary teams or departments. Finally, evaluations of science will have to take into account the contribution of interdisciplinary research to Research and Development (R&D). Thus, funding agencies, networks, technology transfer offices and policy-makers may adapt their funding programs to foster interdisciplinary collaborations as well as the impact of research on society.

These changes in the way research is being organised, managed, funded and evaluated raise several questions with respect to technology transfer and interdisciplinary research. Firstly, extant research has focused on general aspects of technology transfer.[14] However, little is known about the particularities of technology transfer in a context of collaborative innovation across different disciplines. Secondly, stakeholders (e.g. academic scientists, university administrators and firms stemming from different disciplines and industries) have different perceptions about technology transfer.[15] This challenges the process of technology transfer and thus, it necessitates a study that examines how different stakeholders perceive factors affecting technology transfer. Furthermore, the evaluation of interdisciplinary research becomes essential

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[10] Boehlje and Bröring (2011); Golembiewski et al. (2015).

[11] European Commission (2012b).

[12] European Commission (2012b); OECD (2009).

[13] McMillan et al. (2000).

[14] Perkmann et al. (2013); Phan and Siegel (2006); Rothaermel et al. (2007).

[15] Rogers (2003).

for funding agencies, technology transfer offices and policy-makers. Previous studies focused on assessing the extent to which publications build upon knowledge from different disciplines.[16] However, little is known about the topic of evaluating interdisciplinary research taking technological areas as unit of analysis.

This background motivates the investigation of technology transfer in interdisciplinary research settings, taking the KBBE as an example of a highly interdisciplinary and emerging knowledge area. This study also aims at contributing to existing research by incorporating different perspectives explained above: disciplines, stakeholders and technologies.

1.1.1 Technology transfer

Broadly, the concepts of technology transfer and knowledge transfer have often been used interchangeably in literature. Bozeman (2000) argues that technology and knowledge are inseparable simply because when a technological product is transferred or diffused, the knowledge associated to its use and application is also diffused. However, some authors clearly differentiate between these two terms.[17] For a matter of simplification, the term technology transfer, including technological knowledge and technologies will be used along this thesis.

When approaching the matter of technology transfer, one will inevitably be confronted with the different types of technology transfer that exist. As such, various definitions and concepts for technology transfer have been discussed in the literature based on the disciplines and purposes of the research.[18] For instance, technology transfer encompasses technology transfer between companies, technology transfer between countries, or technology transfer from academia to industry.

To ensure a consistent use of the terms, Mansfield (1983) makes a useful distinction between different technology transfer types*: "Vertical technology transfer occurs when information is transmitted from basic research to applied research, from applied research to development, and from development to production. Such transfers occur in both directions and the form of the information changes as it moves along this dimension. Horizontal transfer of technology*

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[16] Cassi et al. (2017); Leydesdorff et al. (2018); Leydesdorff and Rafols (2011); Mugabushaka et al. (2016); Porter et al. (2007); Porter and Rafols (2009); Rafols et al. (2010); Rafols and Meyer (2007); Rafols and Meyer (2009).

[17] See e.g. Gilbert and Cordey-Hayes (1996); Gopalakrishnan and Santoro (2004).

[18] Bozeman (2000); Zhao and Reisman (1992).

occurs when technology used in one place, organisation, or context is transferred and used in another place, organisation, or context".[19]

This study focuses solely on what Mansfield (1983) refers to as vertical technology transfer, so technology transfer from academia to business. Thus, the present thesis refers to technology transfer from academia to business, but for a matter of simplification, the term technology transfer will be used along this thesis This type of technology transfer can be defined as: *"the process of transferring scientific findings from one organisation [academia] to another [industry] for the purpose of further development and commercialisation."*[20] Hence, other ways of transfer (e.g. between countries) are not within the scope of the present thesis.

Technology transfer mutually depends on three groups of stakeholders[21]: (1) academic scientists, who discover new technologies; (2) technology transfer facilitators, who act as intermediaries between academic scientists and industry, and manage intellectual property rights (IPR); and (3) firms/entrepreneurs, who adopt and commercialise technologies developed by academic scientists.

However, these three groups of stakeholders generally may have different perceptions about both the understanding and the objectives of the technology transfer process.[22] This is because the stakeholder groups all have different organisational cultures, motives, missions, practices[23], as well as ways of communicating.[24] These differences create challenges within the technology transfer process.

Table 1-1 summarises the key stakeholders involved in technology transfer and their primary motives with respect to technology transfer. Academic scientists, who represent the providers of technology, view technology transfer as a means for serving the community through the increased production and sharing of knowledge. [25] Their main objective is to be attaining recognition within the scientific community through publications in top journals, presentations

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[19] Mansfield (1983, p. 28).

[20] Association of University Technology Managers AUTM [www.autm.net].

[21] Siegel et al. (2004).

[22] Rogers (2003).

[23] Santoro and Chakrabarti (2002); Siegel et al. (2004).

[24] Langford et al. (2006).

[25] Siegel et al. (2004).

at conferences, and research grants.[26] Conversely, firms and entrepreneurs, as the recipients of technology, tend to emphasise profit maximisation and the economic benefits of technologies developed in academic institutions.[27] Meanwhile, the general mission of technology transfer facilitators is to enable or assist in the process of transfer by acting as intermediaries between academic scientists and industrial firms or entrepreneurs. Their objective is to protect and manage the IPR of the inventions generated by academic scientists and to market the intellectual property (IP) to firms.

Table 1-1: Key stakeholders involved in technology transfer and their primary objectives[28]

Stakeholder	Actions	Primary motive(s)	Secondary motive(s)	Organisational culture
Academic scientists	Discovery and production of new knowledge and technologies	Recognition within the scientific community through publications and grants	Financial gain and a desire to secure additional research funding (mainly for graduate students and lab equipment)	Scientific
Technology transfer facilitators	Collaborations with faculty members and firms/entrepreneurs to commercialise knowledge and technologies	Protect inventions, market technologies	Facilitate technological diffusion and secure additional research funding	Bureaucratic
Firms/ entrepreneurs	Commercialisation of knowledge and technologies	Economic benefits	Maintain control of proprietary technologies	Organic/ entrepreneurial

Technology transfer occurs both formally and informally.[29] Formal means involve or result in a legal instrumentality, such as patents, licenses or the foundation of university spin-offs.[30] Conversely, informal channels facilitate the flow of technological knowledge through informal communication processes.[31] Informal instruments include publications, collaborations (e.g. consulting and joint research), contract research, conferences, academia and industry interactions, industry-sponsored workshops, meetings and fairs, research mobility, personnel

[26] Siegel et al. (2004).

[27] Siegel et al. (2004).

[28] Source: Own table based on Siegel et al. (2004a, p. 120).

[29] Bradley et al. (2013).

[30] Bradley et al. (2013).

[31] Link et al. (2007).

exchange, or hiring students and sponsored research.[32] The present research alludes to technology transfer including both formal and informal mechanisms.

1.1.2 Interdisciplinary research: The case of the bioeconomy

The literature has not agreed on common terms to describe interdisciplinary research and several closely connected concepts are still discussed. The most widely recognised distinction is between 'multidisciplinary', 'interdisciplinary' and 'transdisciplinary' approaches.[33] Multidisciplinary is often recognised as a first step. Here, knowledge from two or more disciplines is integrated to solve a single problem, but research stays within disciplinary boundaries (each discipline uses its own rules, methods, approaches).[34] Interdisciplinary research is identified as a second stage. In this case, there is a much further degree of knowledge integration from different disciplines and research shares rules, methods and approaches.[35] Transdisciplinary goes beyond multidisciplinary and interdisciplinary research. It aims at integrating not only knowledge from two or more disciplines but also knowledge from stakeholders beyond academic disciplines, for example, farmers or consumers organisations.[36] **Table 1-2** summarises the main objectives and the stakeholders involved for each variety.

Table 1-2: Definition of key terms related to interdisciplinary research[37]

Concept	Objective	Stakeholders involved
Multidisciplinary	Aims at integrating knowledge from different disciplines where each discipline follows its own sets of rules and methods (each discipline stays within their boundaries)	Scientists
Interdisciplinary	Aims at integrating knowledge from different disciplines more closely together	Scientists
Transdisciplinary	It goes one step further than interdisciplinary research. It aims at integrating different disciplines more closely together by also integrating inputs and ideas from relevant non-scientific stakeholders into the research agenda.	Scientists and non-scientists

[32] Bradley et al. (2013); Link et al. (2007).

[33] Wagner et al. (2011).

[34] Klein (2008).

[35] Klein (2008).

[36] Klein (2008).

[37] Source: Own table based on Klein (2008); Porter et al. (2006).

In this thesis, the term interdisciplinary research is used as it is often used as a generic concept comprising all the above explained terms. Following this, interdisciplinary research can be defined as *“a mode of research by teams or individuals that integrates information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines or bodies of specialised knowledge or area of research practice”*.[38]

Interdisciplinary research is proposed as the only plausible approach to solve the complex and wicked problems of the twenty-first century, e.g. climate change, scarcity of fossil resources, or water scarcity.[39] In this context, emerging knowledge areas and technologies such as KBBE, bioinformatics, information and communication technologies (ICT), nanotechnology, or neurosciences are often mentioned as examples where interdisciplinary research becomes pivotal.[40] These emerging knowledge areas are regarded as emerging between two or more disciplines and are characterised by having a strong innovation potential.[41]

In this thesis, the KBBE as a suitable case of an emerging knowledge area founded on different disciplines is selected.[42] Definitions of the term bioeconomy are plentiful and a common definition is still missing in the literature.[43] This research considers the initial definition of this term given by the European Commission. Following this, the bioeconomy is defined as *“the production of renewable biological resources and the conversion of these resources and waste streams into value added products, such as food, feed, bio-based products and bioenergy”*.[44]

The KBBE builds upon a wide variety of different and diverse scientific disciplines and technologies such as life sciences, agronomy, chemistry, ecology, food science, material sciences, social sciences, biotechnology, nanotechnology, ICT and engineering.[45] Specific examples of applications or technologies within the bioeconomy include bioplastics, biopharmaceuticals, biofuels, biogas, or biorefineries. These applications can be found in a wide range of different industries and sectors of the entire economy such as agriculture, forestry,

[38] Porter et al. (2006, p. 189).

[39] Biancani et al. (2018); Klein (2008); Repko and Szostak (2016).

[40] Mugabushaka et al. (2016); Rafols and Meyer (2009).

[41] Bröring (2005); Bröring (2010); Garcia and Calantone (2002); Rotolo et al. (2015).

[42] European Commission (2012b); OECD (2009).

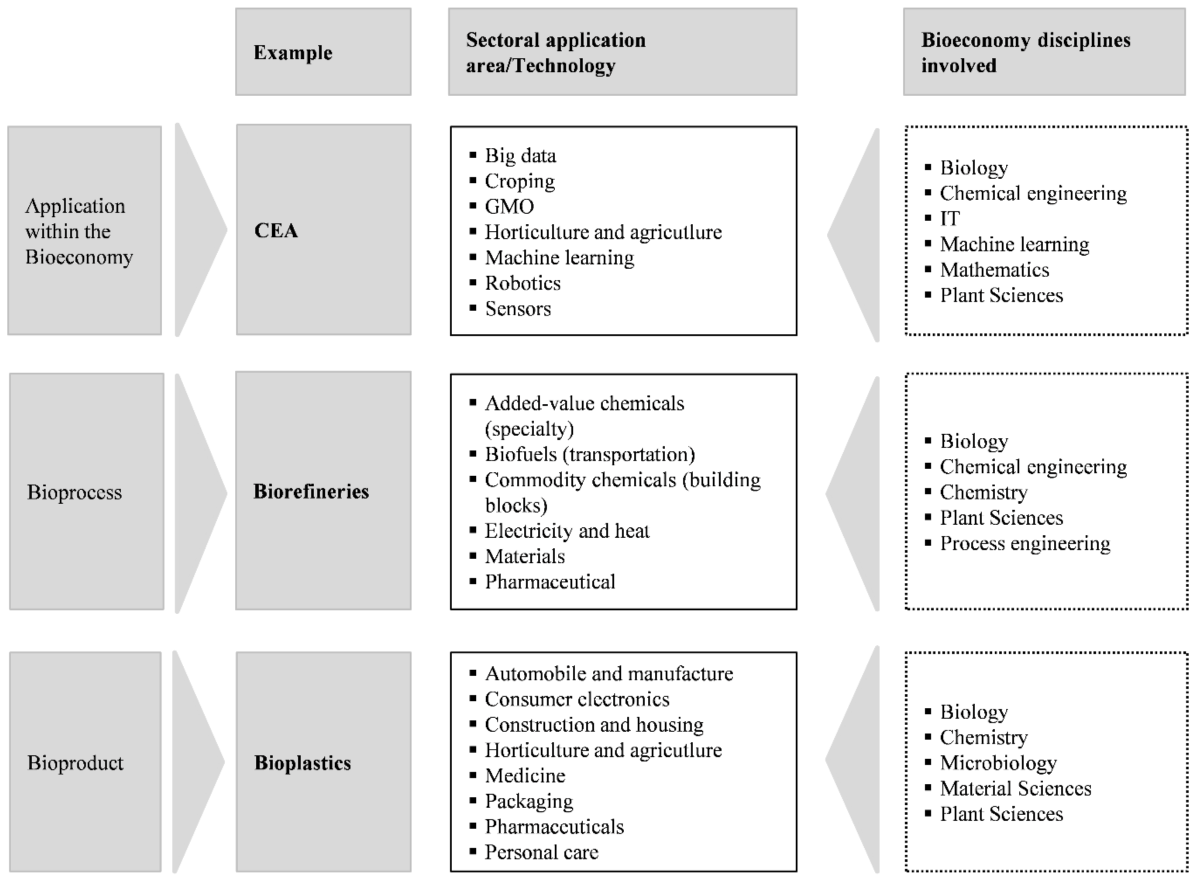
[43] Golembiewski et al. (2015); Staffas et al. (2013).

[44] European Commission (2012b, p. 3).

[45] European Commission (2012b).

fisheries, food, pulp and paper production as well as parts of chemical, pharmaceutical, biotechnological and energy industries .[46] Sectors in the bioeconomy are noted to have the potential to generate € 2 trillion in annual turnover and more than 22 million jobs in Europe.[47]

Figure 1-1 provides an example of interdisciplinarity in the bioeconomy by taking the cases of Controlled Environmental Technology (CEA), biorefineries and bioplastics. Each of these is selected to illustrate the sectoral application areas as well as the bioeconoy-related disciplines that are needed for their R&D and production. For example, the case of bioplastics as an example of a bioproduct in the bioeconomy needs the integration of disciplines such as biology, chemistry, microbiology, material sciences, or plant sciences. Bioplastics, in turn, can be commercialised in areas like automobile and manufacture, consumer electronics, construction and housing, horticulture and agriculture, medicine, packaging, pharmaceuticals or personal care.



[46] European Commission (2012b).

[47] European Commission (2012b).

Figure 1-1: Illustration of interdisciplinarity in the bioeconomy taking three examples within the bioeconomy: CEA, biorefineries, bioplastics.[48]

In light of the growing recognition of the importance of interdisciplinary research, funding agencies and networks operating in the bioeconomy have started to put a strong emphasis on fostering collaborations across bioeconomy-related disciplines. A central motive in most of the objectives of these networks is that scientific, societal and technological problems have become so complex that more and more often the involvement of a diversity of disciplines is needed. There is no bioeconomy-related network that does not mention the necessity of enhancing interdisciplinary research to achieve its goals. For instance, in Germany the BioEconomy Cluster, the Bioeconomy Science Center (BioSC), and the Strategic Network Bio-based Economy (BECY) are examples of networks that place interdisciplinary research as an important element of their strategies. Similar networks can be found in many other countries. **Table 1-3** provides an overview of networks and funding agencies that are supporting interdisciplinary research in the bioeconomy around the world. This overview was compiled by conducting a desk review of networks or funding agencies operating in the bioeconomy.[49]

Table 1-3: List of strategies aiming at enhancing interdisciplinary research across the world[50]

Organisation name	Country	Starting year	Objectives
Bioeconomy Campus	Taarvala, Finland	2014	▪ to illustrate the structures and functions of a future bioeconomy society and to offer the opportunity to test new solutions ▪ to develop new products and services based on biomasses ▪ to aim towards ecologically sustainable and wise use of resources
BioEconomy Cluster GISBERT: Bioeconomy Accelerator (project within the BioEconomy Cluster)	Leipzig, Germany	BioEconomy Cluster: 2012/13 GISBERT: 2016	BioEconomy Cluster: ▪ to promote the material and energetic use of biomass in the form of innovative processes used in the production of materials, platform chemicals, products and energy carriers on the basis of renewable non-food resources ▪ to create a bioeconomy model region for Germany and Europe

[48] Source: Own table based on Elvers et al. (2016); Pilla (2011); European Bioplastics [www.european-bioplastics.org]; Sánden and Pettersson (2014).

[49] The desk review included the term bioeconomy along with the terms organisation, network, agency, programme, or association. The search was carried from May to June 2018, thus it includes only those networks that were founded and provided online information until June 2018.

[50] Source: Own table.

			▪ to speed up innovation through the integrated, temporally and spatially coordinated up-scaling of processes and plants from laboratory to development demonstration scale GISBERT: ▪ to connect the research competencies of the BioEconomy Cluster with regional start-up support provided in Central Germany ▪ to accelerate business start-ups and spin-offs in bioeconomic fields of innovation
Biobased Delta	North Brabant, Netherlands	2012/13	▪ focuses on green chemistry in order to facilitate the transition to the biobased economy ▪ important themes are the valorisation of sugar, large-scale biorefinery and bio-aromatics ▪ more than 150 businesses are involved in the partnership (these range from Small and Medium-sized enterprises (SMEs) to multinationals in the agricultural, horticultural and chemical sectors)
Bioeconomy research community Oulu (BRC-OULU)	Oulu, Finland	2010	▪ researcher-driven network of active research groups within the domain of biomass conversion and valorisation ▪ to activate the local and national bioeconomies through R&I, taking into account the Nordic natural environment and its challenging preconditions regarding bio-based industries ▪ to train a new generation of young, cross-disciplinary doctors with knowledge of both engineering and the natural sciences to work on the utilisation of renewable raw materials
Bioeconomy Science Center (BioSC)	Aachen / Bonn / Düsseldorf / Jülich, Germany	2010	▪ to integrate highly diverse research disciplines and to bundle high-level scientific expertise into a single integrative approach ▪ to provide biomass and bio-based products and processes ▪ to increase the sustainable plant production at the same time as the natural resources for the sustainable plant production are conserved ▪ to incorporate research, teaching and training, to bundle competence, resources and innovative infrastructures, an integrative structure, and to contribute to the high-tech strategy
Euroleague for Life Sciences (ELLS)	Various	2001	▪ to offer students additional values by expanding existing activities and by developing new joint programmes in the field of Life Sciences ▪ to support the high quality of education by the sharing of expertise and facilities ▪ to provide transparent and easily accessible information about joint ELLS study programmes ▪ to increase student mobility by simplifying the process of student exchange
Interfaculty Committee Agraria (ICA) Bioeconomy Committee	ICA: Prague, Czech	ICA: 1988 Bioeconomy Committee: 2017	▪ to define ICA as representing the European Life Science Universities in the development of the Bioeconomy at the European level ▪ to contribute to the implementation of the European Union (EU) action plan for bioeconomy in education, research and innovation by seeking synergies among ICA members and other EU and international institutions, industries, and networks

Industrial Organization in the Bioeconomy (IObio)	Ås, Norway	2015	▪ to contribute to food security, sustainable resource management, innovation and value creation through research and knowledge production within food, forestry and other biobased industries
Iowa State University - Bioeconomy Institute (BEI)	Ames, United States (US)	2002	▪ to promote, develop, and demonstrate thermochemical technologies (using heat, pressure, and catalysts) for the production of fuels, chemicals, and power from biomass and fossil fuels
Strategic Network Bio-based Economy (BECY)	Hohenheim, Germany	n/a	▪ to build a network of researchers from the areas of agricultural, natural, business, economic, and social sciences and to support them in joint projects ▪ to include the university in important national and international committees and initiatives and network with central stakeholders ▪ to procure and carry out large national and international cooperation projects
Wageningen University & Research - Biobased Economy	Wageningen, Netherlands	n/a	▪ the synthesis between the circular economy, a more climate-neutral society and the Biobased Economy ▪ Wageningen University & Research is actively closing the loop by working on all the chains of the biobased Economy, through fundamental research, applied research and education

Despite the increasing importance of interdisciplinary research, this possesses specific challenges.[51] These challenges are met at several levels: knowledge challenges, cultural challenges and structural challenges.[52] Knowledge challenges are due to the cognitive distance among disciplines and concern the lack of familiarity that academic scientists have with other disciplines. Cultural challenges are due to the differences in the languages and ways of communicating that different disciplines use. Structural challenges refer to the organisational structure of science, including incentive instruments within organisations. For instance, journals are sceptical of publishing interdisciplinary research, and there are few journals that publish interdisciplinary research exclusively.[53] In addition, journals also find it difficult to find reviewers who can evaluate interdisciplinary research. Hurdles related to recognition also exist, such that academic promotional systems detract value published in interdisciplinary journals. Moreover, there are limited incentives for academic scientists to engage in interdisciplinary research.

[51] Bassett-Jones (2005); Dingler and Enkel (2016); MacLeod (2016).

[52] Huutoniemi et al. (2010).

[53] Huutoniemi et al. (2010).

1.2 Research questions and objectives

Based on the literature background from section 1.1, this thesis assesses aspects related to technology transfer and interdisciplinary settings in the particular case of the bioeconomy (by using disciplines, stakeholders and technologies as units of analyses). This objective is achieved by exploring the following main research question of the study:

M.R.Q: How can technology transfer in interdisciplinary settings such as the bioeconomy be assessed from disciplinary, stakeholder and technology perspectives?

To answer the main research question of the thesis, four sub-research questions are explored in the thesis. These sub-questions are described in the following section.

1.2.1 Evaluation of technology transfer from a disciplinary perspective

Technology transfer becomes pivotal to exploit the vast innovation potential of emerging knowledge areas that build upon the combination of diverse disciplines.[54] Thus, this thesis evaluates technology transfer from a disciplinary perspective by considering experts from different disciplines working together. However, technology transfer in interdisciplinary settings entails multiple challenges due to the different backgrounds, characteristics, interests and goals of the multiple disciplines involved.[55] Consequently, knowledge and technologies derived from collaborations across different disciplines are more difficult to transfer.[56] In this context, yet little is known about technology transfer in interdisciplinary settings like the bioeconomy. To this end, this study (Chapter 2) explores the following research question:

R.Q.1: How can the effectiveness of technology transfer in the interdisciplinary setting of the bioeconomy be assessed?

An exploratory case study research approach[57] and grounded theory[58] are used to explore this research question. A total of eight case studies: four academic research groups and four spin-

[54] Bozeman et al. (2014); Maine et al. (2014); Shane (2004).

[55] Bassett-Jones (2005); MacLeod (2016).

[56] Dingler and Enkel (2016).

[57] Yin (2015).

[58] Glasser and Strauss (1967).

offs[59] having collaborative projects involving diverse disciplines within the bioeconomy are identified. The "Contingent Effectiveness Model of Technology Transfer" proposed by Bozeman (2000) is applied to these case studies. This model explains how technologies are transferred and how the effectiveness of the transfer can be assessed by drawing upon different criteria. The model appears to be suitable for the particular research setting of the bioeconomy. Especially, interdisciplinary collaborations acquire high relevance in the setting under investigation. This thesis seeks to contribute to the existing body of literature on technology transfer given the particularities of interdisciplinary settings.

1.2.2 Evaluation of technology transfer from a stakeholder perspective

Technology transfer in interdisciplinary research settings require not only cooperation among experts from different disciplines, but also cooperation among the overall spectrum of stakeholder groups that shape the technology transfer process.[60] These are academic scientists, technology transfer facilitators and firms/entrepreneurs.[61] However, each stakeholder group has its own specific objectives, skills and knowledge that are appropriate and pertinent to their role.[62] Hence, missing coherence among stakeholders make the technology transfer process more difficult.[63] So far, no study has focused on examining technology transfer by taking into account the mental models of the different stakeholder groups. Moreover, there seems to be a need for an empirical study that evaluate technology transfer by comparing the mental models of the stakeholder groups involved in technology transfer. Therefore, this work (Chapter 3) seeks to fill this research gap by exploring the following research questions:

R.Q.2: What are perceptions of factors that influence technology transfer in the bioeconomy from the point of view of the key stakeholder groups involved in the technology transfer process (i.e. academic scientists, technology transfer facilitators and firms/entrepreneurs)?

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[59] This thesis considers the term spin-offs. Following Clarysse and Moray (2005), a spin-off is defined as a company created by an academic institution, with technologies owned and financed by the academic institution. Contrary, a start-up is a company created outside the academic institution, with technologies licenced to the start-up by the academic institution and financed by outside funders.

[60] Maine et al. (2014).

[61] Siegel et al. (2004).

[62] Rogers (2003).

[63] Rogers (2003).

R.Q.3: What is the perceived relative importance and coherence of these factors as identified by the different stakeholder groups?

The mixed-method approach of group concept mapping, introduced by Kane and Trochim (2007), is used to answer these research questions. This method integrates and represents perceptions into a unified mental model derived by the key stakeholder groups involved in technology transfer.

1.2.3 Evaluation of technology transfer from a technology perspective

Despite the increasing attention of interdisciplinary research from scholars and policy-makers, there is little systematic evidence on how to operationalise and assess interdisciplinary research. Prior studies have focused on assessing interdisciplinarity of a research field or a discipline using publications as unit of analysis. However, there has been limited attention so far on how to operationalise interdisciplinary research and tentatively measure the degree of interdisciplinarity taking technological areas as unit of analysis. As such, the main research question analysed through this study (see Chapter 4) is as follows:

R.Q.4: How can the degree of interdisciplinary research be operationalised by drawing upon patent data?

To this end, the emerging domain of bioplastics was selected as an example of a highly interdisciplinary application area within the bioeconomy for the empirical operationalisation of the degree of interdisciplinary research. Patents, patent citations and the underlying technology classification of patents are used to answer this research question. In particular, this thesis develops three novel patent indicators and a typology that can be used by policy-makers, academic scientists, academic institutions, and firms to depict and assess interdisciplinary research. This study seeks to contribute to advance the state-of-the-art with regard to the use of interdisciplinary indicators for academic, industry and policy purposes.

1.3 Theoretical backgrounds, research approaches and methods

This thesis uses a broad spectrum of theoretical backgrounds to study technology transfer in the interdisciplinary setting of the bioeconomy based on the perspectives under analysis: disciplines, stakeholders, and technologies. As such, the theoretical backgrounds employed for each specific perspective that are analysed in this thesis are explained in the following paragraphs.

A) Technology transfer from a disciplinary perspective

There is enormous potential for innovation from research across different disciplines.[64] However, disciplines are rooted in different cognitive backgrounds, implying that collaborations across different disciplines entail cognitive distance. For the purpose of this thesis, cognitive distance refers to the extent to which bioeconomy-related disciplines differ in their background, perspectives, or concepts.[65] In addition, technologies and inventions developed at the confluence of different academic disciplines need to find ways to be commercially exploited. This is enabled by the technology transfer process, which is pivotal for enhancing innovation.[66] This process is successful only when these technologies and inventions have reached the market.

The resource-based view (RBV) emphasises the resources of a firm as a differentiator of competitive advantage.[67] For the purpose of this thesis, these resource typologies are developed in the specific context of academic research groups embedded in universities and spin-offs as these are the unit of analysis.[68] The RBV considers innovations as new combinations of existing and/or new resources and competencies.[69] Barney (1991) classifies resources into physical resources, human resources and organisational resources. Physical resources include the physical technology used in a firm, a firm's plant and equipment, its geographical location, and its access to raw materials.[70] Human resources include the training, experience, judgment, intelligence, relationships, and insights of individual managers and workers in the firm.[71] Finally, organisational resources include a firm’s formal reporting structure, its formal and informal planning, controlling and coordinating systems, as well as informal relationships among groups within a firm and between a firm and those in its environment.[72]

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[64] Bruns (2013); Dingler and Enkel (2016); Heinze et al. (2009).

[65] See definition of interdisciplinary research in Porter, Roessner, Cohen, and Perreault (2006, p. 189).

[66] Bozeman (2000); Tatikonda and Stock (2003).

[67] Barney (1991); Barney et al. (2001); Mustar et al. (2006).

[68] This is in line with other studies, see e.g. Mustar er.al (2006), Powers and McDougall (2005) that have considered spin-offs as the unit of analysis.

[69] Penrose (1995).

[70] Barney (1991).

[71] Barney (1991).

[72] Barney (1991).

In the context of the RBV, the cognitive distance across disciplines leads experts to join collaborations with other experts from different disciplines to gain competitive advantage. Moreover, the RBV stresses the ability to acquire the resources needed to commercially exploit the opportunity of the new knowledge or technology. Thus, the RBV provides a valuable theoretical foundation to understand technology transfer in interdisciplinary settings. In this regard, an extensive body of research on technology transfer has focused on resources or competences needed for achieving effectiveness of the technology transfer process.[73] In this thesis, the “Contingent Effectiveness Model of Technology Transfer” developed by Bozeman (2000) is used as a conceptual framework since it allows evaluating the effectiveness of the technology transfer based on five dimensions and seven distinct criteria. Bozeman’s (2000) model has already been applied in various fields[74], however, it has never been applied in interdisciplinary settings. As a result, Chapter 2 of this thesis closes this gap by applying this model to the particularities of the interdisciplinary knowledge area of the bioeconomy.

B) Technology transfer from a stakeholder perspective

Technology transfer mutually depends on three groups of stakeholders: academic scientists, technology transfer facilitators and firms/entrepreneurs.[75] However, these stakeholder groups have different perceptions towards technology transfer depending on their objectives, interests and expectations.[76] This lack of coherence presumably hinders the process of technology transfer. Microfoundations[77] and stakeholder theory[78] have arisen in the domain of management, organisation theory, and strategy, as a new strand of research to understand the mental model of stakeholders.[79] These theories deal with the analysis of the individual behaviour and the way of thinking of stakeholders. In particular, research into microfoundations is concerned with examining the role of stakeholders, specifically their motivations, cognitive processes, and conceptual understandings of problems, in order to better represent the aggregate

[73] See reviews e.g. Bozeman (2000); Bozeman et al. (2014); Phan and Siegel (2006); Rogers et al. (2001); Tatikonda and Stock (2003); Vinig and Lips (2015).

[74] See e.g. Ramakrishnan (2004); Albors-Garrigos et al. (2009); Hendriks (2012); Mohammed et al. (2010); Kitagawa and Lightowler (2012); Smart and Benaroya (2016).

[75] Siegel et al. (2004).

[76] Rogers (2003); Siegel et al. (2004).

[77] Barney and Felin (2013); Cunningham et al. (2016); Foss and Lindenberg (2013).

[78] Freeman et al. (2010); Harrison and Wicks (2013).

[79] Barney and Felin (2013); Cunningham et al. (2016); Foss and Lindenberg (2013).

concepts or perceptions and/or relationships between these.[80] Likewise, stakeholder theory is an approach that identifies, and is informed by particular individuals or groups.[81] Thus, the theories of microfoundations and stakeholder theory provide the theoretical background for this thesis to investigate technology transfer from a stakeholder perspective.

By combining microfoundations and stakeholder theory, this thesis takes an alternative perspective in the area of technology transfer and factors affecting technology transfer: that of the individual level and its role in the process of technology transfer. In doing so, the stakeholders that are part of the technology transfer process are taken as unit of analysis and microfoundations are explored. This study echoes with an increasing number of research that argue that investigating the individual level is critical to understand the mechanisms behind technology transfer.[82] Furthermore, most studies have ignored implications of stakeholder differences in terms of the design, execution and consequences of technology transfer.[83]

Chapter 3 of this thesis addresses this gap by bringing together these stakeholder groups and representing their unified mental model. The perceptions expressed by academic scientists, technology transfer facilitators and firms/entrepreneurs are particularly important because of the mutual dependence of the three stakeholder groups in the technology transfer process. Microfoundations[84] and stakeholder theory[85] therefore seem to be useful approaches to examine the perceived factors affecting technology transfer, especially from the perspective of the key stakeholder groups.

C) Technology transfer from a technology perspective

This thesis uses patents as an example of a formal technology transfer instrument to assess the degree of interdisciplinarity in a technology network. Current studies have drawn upon publications to develop indicators to assess the degree of interdisciplinarity of a discipline or a research field.[86] However, the topic of evaluation of interdisciplinary research in a technology

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[80] Barney and Felin (2013); Cunningham et al. (2016); Foss and Lindenberg (2013).

[81] Freeman et al. (2010); Parmar et al. (2010).

[82] Ankrah et al. (2013); Bradley et al. (2013); Cunningham and O’Reilly (2018); Pinto (2017).

[83] Ankrah et al. (2013); Bradley et al. (2013); Pinto (2017).

[84] Barney and Felin (2013); Cunningham et al. (2016); Foss and Lindenberg (2013).

[85] Freeman et al. (2010); Harrison and Wicks (2013).

[86] See e.g. Leydesdorff et al. (2018); Leydesdorff and Rafols (2011); Porter et al. (2007); Porter and Rafols (2009); Rafols et al. (2010); Rafols et al. (2012).

field is yet scarce in the existing literature. Furthermore, previous studies drawing upon patents[87] are limited to the visualisation of technological areas in form of network maps without the aim of assessing the degree of interdisciplinarity. Filling this research gap, Chapter 4 of this thesis builds upon existing approaches to study technology transfer from a technology perspective. Therefore, this thesis aims at developing a novel patent approach that allows to evaluate the degree of interdisciplinarity of a technology field. In doing so, three novel interdisciplinary indicators are developed by drawing upon patents, patent citations and their underlying technology classification. As such, Chapter 4 of this thesis does not build upon any particular economic theory or theoretical foundation, but rather draws upon existing indicators and approaches.

1.3.1 Research approaches and methods

Before explaining the research approaches and methods that are utilised in this thesis to study technology transfer in the interdisciplinary setting of the bioeconomy, **Table 1-4** gives an overview of the study design. It provides an insight into the perspectives analysed, the aim of the study, the data used, and the research approaches and methods that are employed in the thesis.

Table 1-4: Overview of study design[88]

Chapter	Unit of analysis	Focus	Data	Approach	Method
2	Disciplines	Developing a conceptual framework to evaluate effectiveness of technology transfer in interdisciplinary settings	Documentation, archival records and 8 semi-structured interviews	Qualitative Exploratory	Case study research[89] and Grounded theory[90]

[87] See e.g. Kay et al. (2014); Yan and Luo (2017).

[88] Source: Own table.

[89] Eisenhardt (1989); Yin (2015).

[90] Glasser and Strauss (1967).

3	Stakeholders	Evaluating stakeholder's perceptions to technology transfer in interdisciplinary settings	90 stakeholders (Germany)	Mixed method Exploratory	Group Concept Mapping[91]
4	Technological areas	Developing an assessment tool to evaluate the degree of interdisciplinary research	890 patents and 8979 patent citations	Quantitative	Network analysis[92]

On a general note, this thesis employs qualitative and quantitative research approaches to study technology transfer in interdisciplinary settings from three different units of analyses: disciplines, stakeholders and technological areas. Qualitative research methodology is usually inductive (bottom-up), descriptive, exploratory, and interpretative, while the quantitative approach is deductive (top-down), objective, and non-interpretive. The research approaches and methods employed for specific aspects of technology transfer and interdisciplinary research that are analysed in the thesis are explained in the following paragraphs.

A) Technology transfer from a disciplinary perspective

This study utilises an exploratory and descriptive approach along with the qualitative method of case study research[93] and grounded theory[94] to explore how technology transfer works in interdisciplinary settings. Case study research is an appropriate method when aiming at answering "how" and "why" questions[95] and when there is little empirical evidence on a research topic.[96] Generally, case studies do not examine the cause-effect relationships; instead, the emphasis is on exploring and describing a novel phenomenon.[97] Some limitations of case studies are related to generalisability and representativeness.[98] To support findings from the case study research, grounded theory is used to discover relationships from data that can be converted into hypotheses for future research and, therefore, build upon existing theory[99]. As a consequence, this thesis uses a theory building approach by drawing upon case studies and

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91 Kane and Trochim (2007).

92 Borgatti et al. (2009); Brandes et al. (2013); Butts (2009); Ehrlich and Carboni (2005).

93 Yin (2015).

94 Glasser and Strauss (1967).

95 Rowley (2002); Weerd-Nederhof (2001); Yin (2015).

96 Eisenhardt (1989).

97 Yin (2015).

98 Stake (2008).

99 Glasser and Strauss (1967).

grounded theory in order to assess effectiveness of technology transfer in interdisciplinary research settings like the bioeconomy.

B) Technology transfer from a stakeholder perspective

To analyse stakeholders' perceptions of factors affecting technology transfer, this thesis presents the exploratory and mixed method approach of group concept mapping.[100] This methodology deems to be especially appropriate when aiming at integrating input from a variety of multiple stakeholders with different visions and perceptions on a topic of interest.[101] This empirical study employs a focus group discussion to obtain a list of statements. As a second step, each participant sorts the developed statements into piles based on perceived similarity, and then rates each of the statements by the level of relative importance. Next, quantitative multivariate analyses are conducted that include multidimensional scaling and hierarchical cluster analyses. Multidimensional scaling is used to visualise and represent the level of similarity of statements in the form of visual maps.[102] Hierarchical cluster analysis seeks to group statements on the maps into clusters of statements that reflect similar concepts.[103] Consequently, this thesis produces visual maps that represent the unified mental model from the point of view of the key stakeholder groups involved in technology transfer.

C) Technology transfer from a technology perspective

The present thesis draws upon patents, patent citations and their underlying technology classification to construct a novel approach that can be used to assess interdisciplinary research at the level of technological areas. To operationalise this novel framework, the specific case of bioplastics is used as an example of an emerging technology within the bioeconomy. This novel approach builds upon the method of social network analysis. Social network theory aims at examining the structure of social relationships in a group to uncover the informal connections between people.[104] In more recent studies, social network analysis has been applied to other contexts and disciplines beyond a group of people.[105] As such, network analysis can be viewed

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[100] Kane and Trochim (2007).

[101] Kane and Trochim (2007); Rosas and Kane (2012).

[102] Kruskal and Wish (1978).

[103] Everitt (1980).

[104] Ehrlich and Carboni (2005).

[105] Borgatti et al. (2009).

as the *"study of the collection, management, analysis, interpretation, and presentation of relational data"*.[106] In particular, this novel approach is based on the analysis of networks applied to citations from patents in the field of bioplastics. Network analyses are composed of two basic elements: nodes and edges.[107] A node refers to any kind of actor within the network (i.e. technological areas derived from patents). Edges or lines indicate relationships between nodes (in this case between technological areas). As a result, this thesis produces a novel approach based on network analysis to assess interdisciplinarity at the level of technological areas.

1.4 Structure of the thesis

The subsequent chapters 2-5 present qualitative, mixed approaches, or quantitative empirical studies focusing on technology transfer in interdisciplinary settings using the bioeconomy as an example of a highly interdisciplinary and emerging knowledge area. The chapters utilise disciplinary, stakeholder, and technology perspectives with respect to technology transfer and interdisciplinary research. Firstly, this thesis develops a conceptual framework to assess technology transfer in interdisciplinary settings (disciplinary perspective). Secondly, the present study examines technology transfer from the point of view of the key stakeholder groups involved in technology transfer (stakeholder perspective). Based on these studies, the increasing importance of interdisciplinary collaborations became clear, thus, this thesis develops a novel approach to monitor the degree of interdisciplinarity at the level of technological areas (technology perspective). **Figure 1-2** provides an overview of the organisation of the thesis. It presents the chapters in the thesis and the aspects analysed in them.

[106] Brandes et al. (2013, p. 2).

[107] Butts (2009).

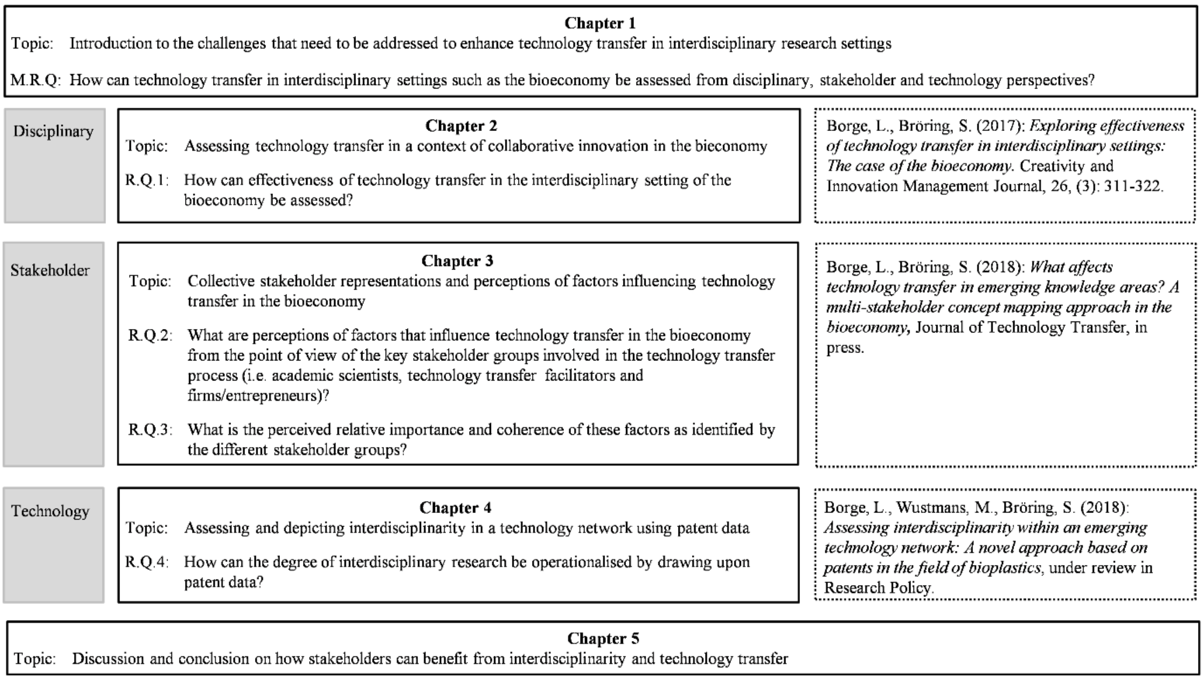

Figure 1-2: Organisation of the thesis[108]

Chapter 1 states the research problem and derives research questions and objectives of the thesis with regard to challenges of technology transfer and interdisciplinary research. It explains the theoretical background, research approaches and methods used to assess technology transfer in the interdisciplinary setting of the bioeconomy from disciplinary, stakeholder and technology perspectives.

Chapter 2 explores technology transfer in interdisciplinary settings such as the bioeconomy from a disciplinary perspective. It empirically investigates particularities of technology transfer in a context of collaborations among different disciplines, like the bioeconomy. Based on the results, a future research agenda on technology transfer from the perspective of the key stakeholder groups involved in technology transfer and from a technology perspective are proposed. The underlying study of this chapter has been published in the Creativity and Innovation Management Journal, and the paper was thereafter shortlisted for the best Creativity and Innovation Management Journal Paper Award 2017. A first idea of this paper was presented at the BECY Network meeting 2015 in Stuttgart, Germany and at the 2nd BioSC Forum 2015

[108] Source: Own Figure.

in Cologne, Germany. Furthermore, the paper was presented at the 2nd International BioSC Symposium 2017 in Cologne, Germany.

Next, Chapter 3 analyses and represents perceptions of factors that affect technology transfer in the bioeconomy from the point of view of the key stakeholder groups. This chapter also examines how the different stakeholder groups differ with regard to their perception of the relative importance and coherence of these factors. The underlying research of this chapter has been published in the Journal of Technology Transfer. A first version of this research was presented at the 20th Annual Interdisciplinary Conference on Entrepreneurship and Innovation 2016 in Leipzig, Germany and at the 56th Annual Conference of the German Association of Agricultural Economists (GEWISOLA) 2016 in Bonn, Germany.

Chapter 4 depicts interdisciplinary research in patent data for the specific case of bioplastics as an application area within the bioeconomy. In this regard, this chapter offers the first empirical operationalisation to assess interdisciplinary research at the level of technological areas. These novel interdisciplinary indicators enable policy-makers, academic scientists, academic institutions, and firms to assess the degree of interdisciplinarity. The underlying research study of this chapter is under review in Research Policy. Moreover, a first idea of the underlying study was presented at the 6th European Conference on Corporate R&D and Innovation 2017 in Seville, Spain.

Chapter 5 summarises findings of the previous chapters and highlights theoretical contributions of the thesis. It also presents implications of the study for policy-makers, funding agencies, academic scientists, academic institutions, technology transfer offices, and firms. The thesis is concluded with limitations and possible directions for future research in the domain of technology transfer and interdisciplinary research.

2 Evaluation of technology transfer from a disciplinary perspective

Chapter 2 answers Research Question 1:

R.Q.1: How can the effectiveness of technology transfer in the interdisciplinary setting of the bioeconomy be assessed?

This chapter is based on the following publication: Laura Borge, Stefanie Bröring (2017): *Exploring effectiveness of technology transfer in interdisciplinary settings: The case of the bioeconomy.* Creativity and Innovation Management Journal, 26, (3): 311-322.

2.1 Introduction

Interdisciplinary research holds great potential for creativity and innovation.[109] It is also praised for addressing global societal problems like climate change, or increasing global population.[110] Thus, the need for interdisciplinary research, a concept that refers to a mode of research that combines different disciplines or areas of research practice to work together on a specific problem[111], is being increasingly stressed.[112] The growing prominence of interdisciplinary research has also been reflected by an increasing foundation of academic organisations clearly targeting interdisciplinary research.[113]

On the other hand, the utilisation and transfer of research results is gaining increasing relevance in the work of universities and research institutes.[114] The numerous initiatives that the European Commission has launched to enhance technology transfer from academia to industry provide visible evidence for this.[115] In addition, the Horizon 2020 program[116] also puts a strong emphasis on fostering the dissemination and transfer of academic results to commercial application.[117]

Despite the vast opportunities that interdisciplinary research presents, it also raises new challenges. Such challenges are strongly connected to the diverse cognitive backgrounds, characteristics, interests and goals of the multiple different disciplines involved.[118] This implies that technologies and knowledge originated from collaboration across different disciplines are more difficult to transfer.[119] Consequently, there is room for considerable disagreement and

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[109] Bruns (2013); Dingler and Enkel (2016); Heinze et al. (2009).

[110] Klein (2008); Repko and Szostak (2016).

[111] Repko and Szostak (2016).

[112] Porter and Rafols (2009).

[113] MacLeod (2016).

[114] Etzkowitz et al. (2000); Larsen (2011); Pyka et al. (2016); Shane (2004); van der Steen and Enders (2008).

[115] See e.g. European Commission (2007); European Commission (2008a); European Commission (2008b); European Commission (2012a).

[116] The Horizon 2020 program is the EU Framework Programme for Research and Innovation running from 2014-2020.

[117] European Commission (2013).

[118] Bassett-Jones (2005); MacLeod (2016).

[119] Dingler and Enkel (2016).

misunderstanding about how technology transfer from academia to industry takes place in a setting involving multiple different disciplines.

As an example of such an interdisciplinary setting where innovation across disciplines is pivotal, the case of the bioeconomy is used. This emerging knowledge area serves as an ideal case for interdisciplinarity since it is not only based on a wide spectrum of academic disciplines and technologies, but it also builds upon many sectors and industries of the entire economy.[120] The bioeconomy is not only economically important; but it promises solutions to overcome current global challenges.[121] It strongly relies on knowledge, research and innovation to create products from renewable biological resources.[122] The KBBE is today's most discussed area of interdisciplinary research and development.[123] The bioeconomy sectors have the potential to generate € 2 trillion in annual turnover and more than 22 million jobs in Europe.[124] To this end, this chapter provides a comprehensive overview on effectiveness of technology transfer by exploring the following research question:

> **R.Q.1:** How can the effectiveness of technology transfer in the interdisciplinary setting of the bioeconomy be assessed?

Given the novelty of the research objective technology transfer in the interdisciplinary research setting of the bioeconomy, this chapter draws upon exploratory case study research[125] and grounded theory.[126] Based on empirical evidence gathered from eight comprehensive case studies, technology transfer in the interdisciplinary setting of the bioeconomy is investigated. Further, how the involved organisations manage effectiveness of technology transfer in a context of collaborative innovation is discussed. Whereas research on effectiveness of technology transfer has been conducted in the past[127], technology transfer in a highly interdisciplinary field, such as the bioeconomy, has not yet been analysed. Thus, this chapter seeks to contribute to close this gap in the existing literature and provide managerial

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[120] OECD (2009); European Commission (2012b).

[121] European Commission (2012b).

[122] European Commission (2012b).

[123] McCormick and Kautto (2013); Staffas et al. (2013); Vandermeulen et al. (2012).

[124] European Commission (2012b).

[125] Yin (2015).

[126] Glasser and Strauss (1967).

[127] See e.g. Bozeman (2000); Bozeman et al. (2014); Phan and Siegel (2006).

implications which can also be transferred to other cases of interdisciplinarity. Hence, the resulting insights from this study provide valuable input for both practitioners and academics in two ways. Firstly, they are expected to improve academic and managerial understanding of how technology transfer develops in specific interdisciplinary settings like the bioeconomy. The second contribution is the identification of factors that can lead to enhance the effectiveness of technology transfer processes in interdisciplinary settings.

The remainder of this chapter is structured as follows. Section 2.2 reviews extant studies on technology transfer effectiveness and discusses the challenges linked to interdisciplinary research and technology transfer in order to understand their implications for the particular research setting of the bioeconomy. Section 2.3 describes the chosen research strategy, i.e. exploratory case study research. Section 2.4 presents the main findings with respect to R.Q.1. Section 2.5 discusses the findings and concludes the study by highlighting academic and managerial implications as well as the limitations and suggestions for future research.

2.2 Theoretical background: Technology transfer in interdisciplinary research settings

2.2.1 Effectiveness of technology transfer

There exist different types of technology transfer (e.g. between companies, between countries, or from academia to industry). In this chapter, technology transfer from academia to industry is on the focus of the analysis. This type of technology transfer presents a particular context for innovation and interdisciplinary research. It can be defined as: *"the process of transferring scientific findings from one organisation [academia] to another [industry] for the purpose of further development and commercialisation."*[128] In this regard, academia is an important source of inventions that may result in new technologies of commercial significance.[129] However, inventions arising from academia require further and often substantial investments to ensure their marketability.[130] To turn inventions, which result from extensive research at academic institutions, into successful innovations and finally introduce them as products on the respective markets, they must be transferred to organisations with marketing and commercialisation

[128] Association of University Technology Managers AUTM [www.autm.net].

[129] Bozeman (2000); Chesbrough (2003); Löfsten and Lindelöf (2002); Ritter and Gemünden (2004); Shane (2002); Shane (2004).

[130] Chesbrough (2003).

experience.[131] This is enabled by the technology transfer process, which is crucial for enhancing innovation.[132]

Many models, methodologies and evaluation criteria have been proposed in the literature to assess technology transfer and to assess its effectiveness.[133] Bozeman (2000) proposes the "Contingent Effectiveness Model of Technology Transfer" that explains how technologies are transferred and how the effectiveness of the transfer can be assessed by drawing upon different criteria. The "Contingent Effectiveness Model of Technology Transfer" has been chosen as conceptual framework for the present study since it allows evaluating the effectiveness of the technology transfer based on five dimensions and seven distinct criteria.

This model (depicted in **Figure 2-1**) assesses the effectiveness of technology transfer along the following five dimensions: who is doing the transfer (transfer agent), how the transfer is done (transfer media), what is being transferred (transfer object), factors that influence the transfer (demand environment), and to whom the technology is transferred (transfer recipient). The interaction between these dimensions determines the effectiveness of the technology transfer process that can be observed by applying seven different criteria[134]: "Out-the-door" (refers solely to reception of a technology by the transfer recipient (e.g. firm)); Market impact and Economic development (assess the commercial impact of the technology transfer); Political reward (refers to the expectation of political benefits gained from participation in the technology transfer); Opportunity cost (considers possible other impacts resulting from technology transfer activities); Scientific and Technical Human Capital (evaluates the impact of technology transfer activities on capacity to perform research, social capital derived from interactions, and development of networks and infrastructure); Public value (assesses the effect of technology transfer on enhancing societally shared values).

[131] Shane (2004).

[132] Bozeman (2000); Tatikonda and Stock (2003).

[133] Bozeman (2000); Bozeman et al. (2014); Phan and Siegel (2006); Rogers et al. (2001); Tatikonda and Stock (2003); Vinig and Lips (2015).

[134] Bozeman (2000); Bozeman et al. (2014).

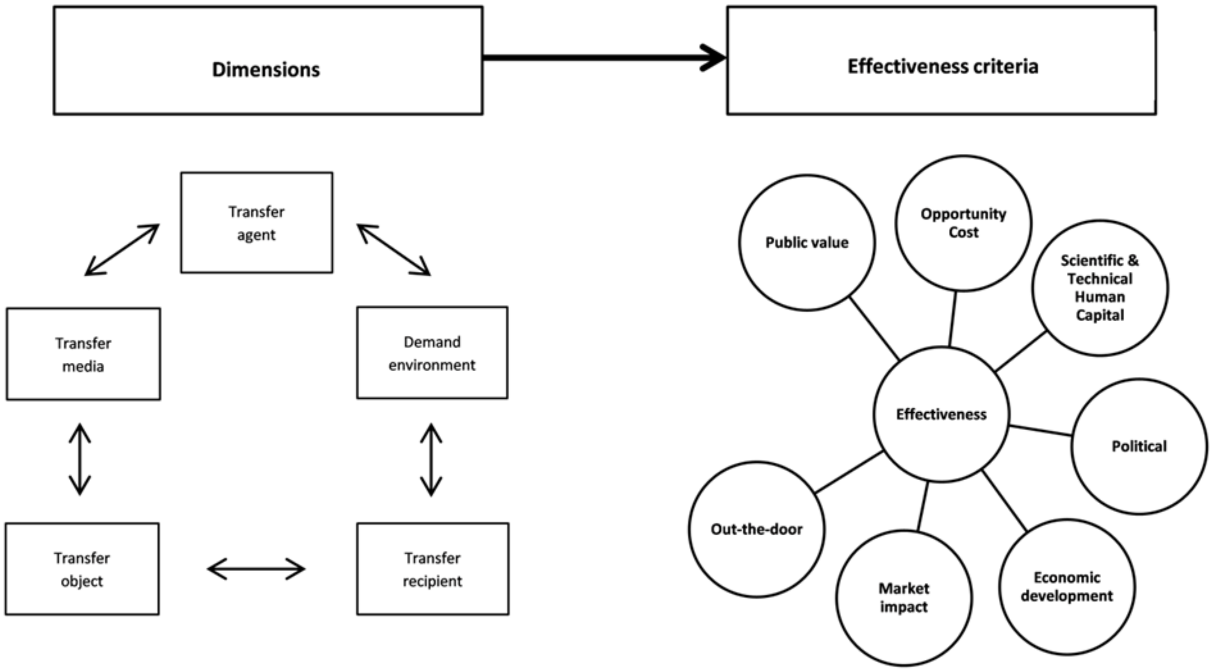

Figure 2-1: The Contingent Effectiveness Model of Technology Transfer[135]

Bozeman's (2000) model has already been used as conceptual framework or has been applied in various fields such as industrial ecology[136], high-tech sectors[137], medicine[138], education innovations[139], or aerospace engineering.[140] However, this model has neither yet been applied in a context of convergence of disciplines, nor specifically in the interdisciplinary knowledge area of the bioeconomy. As a consequence, this thesis extends the empirical relevance of this framework to technology transfer in a highly interdisciplinary field such as the bioeconomy.

2.2.2 Interdisciplinary research settings: The case of the Bioeconomy

In light of the growing body of literature on interdisciplinary research, several closely connected concepts (e.g. 'interdisciplinary', 'multidisciplinary', 'transdisciplinary', 'science convergence', or 'cross-disciplinary collaboration') illustrate the enormous innovation potential

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[135] Source: Own Figure based on Bozeman et al. (2014, p. 36).

[136] Ramakrishnan (2004).

[137] Albors-Garrigos et al. (2009).

[138] Hendriks (2012); Mohammed et al. (2010).

[139] Kitagawa and Lightowler (2012).

[140] Smart and Benaroya (2016).

at the intersection between disciplines.[141] In this way, interdisciplinarity is seen as a concept that brings together different disciplines or areas of research practice to work together on a specific problem.[142] It can be defined as *"a mode of research by teams or individuals that integrates information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines or bodies of specialised knowledge or area of research practice"*.[143] For the purpose of this study, this particular term is used rather than the keywords mentioned above since the bioeconomy brings partners from diverging disciplines together into teams to commonly work on a problem at the same time. As a result, this kind of work is not defined as 'multidisciplinary' since teams work together and not in a sequential way as would be expected in a multidisciplinary process. At the same time, the bioeconomy is not understood as 'transdisciplinary' since the focus of the study is not on the involvement of non-scientific stakeholders as it would be assumed in transdisciplinary research. On the other hand, 'science convergence' or 'cross-disciplinary collaboration' are seen as processes that occur as a result of collaborations between different disciplines.[144]

Despite the great innovation potential at the intersection of different disciplines, this also entails multiple challenges.[145] In this regard, interdisciplinary research can be explained by having the following characteristics.[146] Firstly, there are different knowledge backgrounds across disciplines. Secondly, language and ways of communication are deeply rooted in a specific discipline. Thirdly, there are different areas of interest, experiences and expectations across disciplines. Fourthly, there is different understanding of the tasks to be performed. Fifthly, there are different norms and standards. Sixthly, the current peer review system depreciates interdisciplinary contributions. Finally, academic promotional systems detract value published in interdisciplinary journals. Due to the above mentioned reasons, technologies and knowledge originated from collaboration across different disciplines are more difficult to transfer.[147]

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[141] Alves et al. (2007); Dingler and Enkel (2016).

[142] Repko and Szostak (2016).

[143] Porter et al. (2006, p. 189).

[144] Bröring (2005); Curran et al. (2010); Preschitschek et al. (2013).

[145] Bassett-Jones (2005); MacLeod (2016).

[146] Dingler and Enkel (2016); MacLeod (2016).

[147] Dingler and Enkel (2016); Golembiewski et al. (2015); Vom Stein et al. (2015).

As an example of a knowledge area in which interdisciplinary research and innovation become essential to achieve its goal of moving towards a sustainable future, the case of the bioeconomy is selected. In this research, the bioeconomy is defined as *"the production of renewable biological resources and the conversion of these resources and waste streams into value added products, such as food, feed, bio-based products and bioenergy"*.[148] Therefore, the bioeconomy draws upon a wide variety of different and diverse scientific disciplines and technologies such as life sciences, agronomy, ecology, food science, social sciences, biotechnology, nanotechnology, ICT and engineering.[149] Thus, the integration of elements across the disciplines within the bioeconomy becomes pivotal to address the challenges linked to the bioeconomy.

In this regard, many interdisciplinary research centres or initiatives are currently being launched aiming at foresting the development of the bioeconomy (e.g. the Biobased Delta in the Netherlands, the BECY in Germany, the Bioeconomy Campus in Finland, the BioSC in Germany, or the Industrial Organization in the Bioeconomy (IObio) in Norway). In order to synthesise a practical example of interdisciplinary research, the case of the BioSC was selected. At the BioSC, plant scientists produce plants for food, feed and biomass. Engineers and microbiologists develop new bio/chemocatalytical and biotechnological methods and processes for the conversion of renewable resources into useful substances, such as chemicals, proteins, enzymes, biopolymers or biofuels. Economists investigate the economic feasibility and social acceptance of the bioeconomy.

Following its interdisciplinary nature, bioeconomy applications can be found in a wide range of different industries and sectors of the entire economy like agriculture, forestry, fisheries, food, pulp and paper production as well as parts of chemical, pharmaceutical, biotechnological and energy industries.[150] In this regard, technology transfer across the broad coverage of disciplines and sectors within the bioeconomy is pivotal for its successful implementation.

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[148] European Commission (2012b, p. 3).

[149] European Commission (2012b).

[150] European Commission (2012b).

2.3 Materials and methods

Given the novelty and the exploratory nature of the research question, a multiple case study approach for the research design of this study is adopted.[151] Multiple case studies present a meaningful methodological approach when aiming at answering "how" or "why" questions [152] and in cases where there is little empirical evidence of the topic.[153] Case studies were supported by grounded theory.[154] Grounded theory is used to discover relationships from data that can be converted into hypotheses for future research and therefore, build upon existing theory.[155]

2.3.1 Selection of case studies

The case studies were selected through the BioSC. The BioSC was established in 2010 and it constitutes the first European competence network that brings together different research disciplines within the bioeconomy: (1) Sustainable plant bioproduction and resource stewardship, (2) Microbial and molecular transformation of resources into materials, (3) Process engineering technologies for renewable resources, (4) Economy and social implications. The objectives of the BioSC are twofold. The first goal is the integration of a wide range of research disciplines into a single integrative approach. For instance, at least two of the above mentioned research disciplines need to integrate in order to qualify for funding. The second objective is to foster cooperation between relevant actors in basic research, applied and industry-oriented research.

As such, four interdisciplinary academic research groups and four interdisciplinary academic spin-offs from different multidisciplinary universities or research institutes located in the German state of North Rhine-Westphalia were selected. According to the dimensions of Bozeman's (2000) model, the research groups would be transfer agents whereas transfer recipients would be represented by the spin-offs. The sampling criterion was based on the level of experience in developing technologies at the intersection of different disciplines within the bioeconomy and their involvement in technology transfer processes. The experts representing the academic research groups were professors working in a variety of disciplines related to the

[151] Eisenhardt (1989); Yin (2015).

[152] Weerd-Nederhof (2001); Yin (2015).

[153] Eisenhardt (1989).

[154] Glasser and Strauss (1967).

[155] Glasser and Strauss (1967).

bioeconomy and having collaborative projects with partners from other disciplines within the bioeconomy. The four academic spin-offs covered innovations or technologies at the interface of bioeconomy-related disciplines. **Table 2-1** provides the summary descriptions of the eight case studies, for which the code names Research group_A, Research group_B, Research group_C, Research group_D, Spin-off_A, Spin-off_B, Spin-off_C and Spin-off_D were established for confidentiality reasons.

Table 2-1: Overview of the case studies[156]

Dimension[157]	Transfer agent				Transfer recipient			
Case study	**Research group_A**	**Research group_B**	**Research group_C**	**Research group_D**	**Spin-off_A**	**Spin-off_B**	**Spin-off_C**	**Spin-off_D**
Background	▪Initiated in 2014. ▪Specialisation: Fluid engineering	▪Initiated in 2011. ▪Specialisation: Applied microbiology	▪Initiated in 2009. ▪Specialisation: Renewable energy plants	▪Initiated in 2001. ▪Specialisation: Sustainability of plant production	▪Founded in 2015. ▪Technology specialisation: microbial production strains for the production of amino acids and proteins.	▪Founded in 2011. ▪Technology specialisation: conversion of non-food fats and oils into high-quality road and jet fuels.	▪Founded in 2013. ▪Technology specialisation: fed-batch feeding of microorganisms in microliter scale.	▪Founded in 2008. ▪Technology specialisation: enzyme engineering
Bioeconomy disciplines involved	Chemical engineering	Biotechnology and Microbiology	Plant Sciences	Genetics and Plant Sciences	Biotechnology and Microbiology	Chemical engineering and Plant Sciences	Biotechnology and Microbiology	Biotechnology, Chemical engineering and Microbiology
Degree of maturity of the technology	Applied research				Early stage of commercialisation		Mature stage of commercialisation	
Initial founder	1 professor				2 academic scientists	4 academic scientists	5 academic scientists	1 academic scientist
Founder background	Chemical engineering	▪Chemical engineering; ▪Biology.	Biology	Biology	Biotechnology	▪3 engineers; ▪1 chemist.	▪1 biologist; ▪2 biomedical engineers; ▪1 robotics engineer; ▪1 marketing.	Microbiology
Number of employees (2016)	16	31	15	>40	8	1(+ external assistance)	6	5
Potential industrial sectors	Industrial biotechnology, chemical industry.	Industrial biotechnology	Renewable energy industry, biomass production.	Renewable energy industry, biomass production.	Industrial biotechnology	Aviation industry, chemical industry, oil industry.	Industrial biotechnology	Industrial biotechnology

[156] Source: Own Table.

[157] Dimensions are based on Bozeman (2000); Bozeman et al. (2014).

2.3.2 Data collection approach

The empirical research on the eight case studies was based on multiple sources of evidence[158]: documentation, archival records, and in depth semi-structured interviews. The collected data was triangulated by comparing data from different data sources to enhance internal validity.[159] The data collection process followed three main steps.

Firstly, the websites of the research groups and spin-offs were screened for getting a deep understanding of their background, their technology or specialisation, their evolution, their objectives, and the development of their future business strategies to commercialise the technology.

In the next step, information from available documents and archival records was extracted and analysed to supplement the information obtained from the websites. These documents and archival records consisted of progress reports, conference papers, business reports, articles in mass media, videos, or podcasts.

Finally, eight in-depth semi-structured face-to-face interviews were conducted with each scientist group leader and with the Chief Executive Officers (CEOs) of each spin-off. The interviews aimed at a detailed description of the organisation and the importance and usage of interdisciplinary research and collaborations in the creation of the technologies to be commercialised. Interviews lasted about 60 minutes, were digitally recorded and transcribed, and notes about the behavior of the interviewee were taken. Data collection took place from June 2015 to June 2016.

2.3.3 Data analysis

The procedure of data analysis was performed using content analysis[160]; also inspired by grounded theory.[161] The data analysis was conducted in two steps. Firstly, the qualitative set of data from different sources (transcribed interviews, archival records, field notes and other information on the cases) was analysed with the help of the software tool MAXQDA. This

158 Yin (2015).

159 Yin (2015).

160 Miles and Huberman (1984); Yin (2015).

161 Glasser and Strauss (1967).

allows for deductive (theory-derived) and inductive (emerging) codes.[162] Deductive codes were derived from the effectiveness criteria of Bozeman's (2000) model and focused on keywords describing each effectiveness criterion (e.g. technological benefit, profit, economic, funds, equipment, network, and sustainability). Emerging codes were developed from associations of the data to keywords related to interdisciplinarity (e.g. interaction, interdisciplinary, integration, cooperation across disciplines). Different categories describing the cases emerged from the content analysis. Subsequently, the coded data were tabulated based on word frequency to allow for identifying emerging relationships present in the data.[163] The analysis of the coded data facilitated a cross-case analysis to distinguish the similarities and differences among the case studies (see **Table 2-2**).[164]

2.4 Results

Based on the content analysis of the data, the findings acquired from the cross-case analysis are presented in detail for each effectiveness criterion used as deductive codes derived from the initial literature review.[165] These effectiveness criteria are the following: (A) "out-the-door", (B) market impact and economic development, (C) political reward, (D) scientific and technical human capital, (E) opportunity cost, and (F) public value. The cross-case comparison is then summed up in **Table 2-2**.

A) "Out-the-door"

The data of this study indicates that publications and patents are the most common instruments to transfer the developed technologies into prototype applications for the four academic scientists. The case studies related to spin-offs unfold that the technology developed by scientists was transferred from a research centre or university clearly addressing interdisciplinary research to a spin-off project. The idea of founding spin-offs rooted from a strong motivation of the founders to get the technology into application.

> "[…] it should be mandatory that professors really make commercialised views on [consider the potential for commercialisation of] the inventions and technologies they

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[162] Glasser and Strauss (1967).

[163] Yin (2015).

[164] Eisenhardt (1989); Yin (2015).

[165] Bozeman (2000); Bozeman et al. (2014).

have. This is also one of the ideas of the BioSC which has to generate some ideas, but which are really relevant for daily life and the planet." *(Quote 1, Spin-off_D, CEO)*

B) Market impact and economic development

Regarding the economic criterion of the technology transfer, a differentiation between academic scientists and spin-offs emerges from the data. On the one hand, all academic scientists identify competitiveness of the product and potential for commercial applications as relevant factors to take into account when developing bioeconomy technologies in academia.

> "There needs to be transfer but also needs competitiveness of the product." *(Quote 2, Research group_D, Professor)*

As for the spin-offs, they have achieved different levels of market impact and economic development so far. For instance, spin-off_A and spin-off_B are in the process of advancing the technology readiness level from lab to commercial scale in the following years. In contrast, spin-off_C and spin-off_D have already achieved some relevant revenues and economic growth.

> "One of the most important points is to have a clear picture where a technology really is and how far it is to be ready for market [launch]." *(Quote 3, Spin-off_B, CEO)*

> "The key is to find some new niches where it is worth to look into. This is something that we investigate all the time." *(Quote 4, Spin-off_D, CEO)*

C) Political reward

The data reveal evidence that the research groups receive a large number of funds devoted to interdisciplinary research projects within the bioeconomy. This indicates that policy-makers decided to implement funding opportunities and resources in the further development and commercialisation of bioeconomic research.

> "Since the BioSC is really willing to spend funds for project ideas not looking on research but also on an economic value, I think it really helps to bridge that gap not to end with a good patent but also to bring a product close to the market." *(Quote 5, Research group_A, Professor)*

Furthermore, the success of the spin-offs was also possible through the participation in numerous business plan contests as well as competition awards. Interviewees from the cases attribute this largely to the governmental support initiatives in the form of funding especially addressing the interdisciplinary field of bioeconomy. These initiatives aim at supporting and assisting founders of start-up companies in the particular field of the bioeconomy.

> "So we do industrial biotechnology and exactly in the year [2014] we got GoBio[166] they decided to switch the focus from this program from pharmaceutical applications to more industrial biotechnology. I think it was the year of the bioeconomy." *(Quote 6, Spin-off_A, CEO)*

D) Opportunity costs

The cases investigated in this study illustrate that the technology transfer had an impact on alternative use of resources by increasing research and transfer know-how in different bioeconomy disciplines. By working in close collaboration, the research groups and spin-offs are able to maintain and even increase research projects in their field of expertise.

E) Scientific and Technical Human Capital

Regarding the scientific and technical human capital, the empirical findings from the case studies reflect that existing networks, clusters or platforms especially addressing the bioeconomy were categorised as very important for the success of the research groups and the spin-offs. The participation in such networks and clusters results in collaborations among bioeconomy-related disciplines.

> "So they should organise the platforms or possibilities that the people from different disciplines might find to each other, to find a possible cooperation." *(Quote 7, Research group_A, Professor)*

> "There are platforms where people talk about technology development…there you have these exchange rounds or platforms where biologists or somebody from agriculture, they talk about "oh, I have a product at that plant" and I say: "OK I can help you how extract that". And therefore to have these platforms is my approach how to come to interesting questions." *(Quote 8, Research group_C, Professor)*

Furthermore, the participation in such networks and clusters leads to collaborations between academia and industry. For instance, by the collaboration with the university, spin-off_D was able to benefit from the lab and machine sharing and therefore to save a high amount of money.

[166] GoBio is governmental initiative created in 2005 by the German Federal Ministry of Education and Research (BMBF) to promote commercialisation of results in the field of life sciences.

F) Public value

Technologies, knowledge and innovations in the bioeconomy are driven by values related to the concept of sustainability. In this regard, the interviewees expressed their interest in developing sustainable products and technologies that contribute to overcome global major challenges. The governmental support towards the development of a sustainable bioeconomy was identified as a very relevant factor for the success of the business and the research groups.

> "[…] because the political framework is quite good for us. For example, BioSC is one example, that entire Germany, they really push and want to support the "green bioeconomy" that we get a more sustainable, protected environment. This is, of course, for us perfect because we can provide our part." *(Quote 9, Spin-off_D, CEO)*

The word frequency count analysis reveals that 'interaction', 'interdisciplinary', 'integration', 'cooperation across disciplines' are words that recur often. Thus, a new criterion to assess effectiveness of technology transfer based on inductive codes referring to interdisciplinary research and collaborations among different disciplines was added. This new criterion is named Resource complementarity and it comprises notions that are interlinked to the criteria of Opportunity cost and Scientific and Technical Human Capital.

G) Resource complementarity

All scientist group leaders work in interdisciplinary projects with scientists from different disciplines within the bioeconomy (e.g. biologists, chemists, economists, engineers). All spin-offs are composed of an interdisciplinary team involving different backgrounds ranging from natural sciences, or engineering to economics. In addition, the universities and research institutes where the professors work or where the spin-offs emerged from are gradually establishing new departments and research groups addressing interdisciplinary research. The goal of these institutions is to foster interdisciplinary collaboration between the natural and engineering sciences and the humanities and social sciences. Therefore, an increasing institutionalisation of interdisciplinary departments can be observed.

The case studies reveal that interdisciplinary research collaborations present an opportunity for technology transfer in the bioeconomy. Interviewees attribute this to the additional technological opportunities which are developed at the intersection of disciplines and that can be of interest to potential transfer partners in industry.

> "So I think one thing which definitely we should improve is a kind of to showcase that this […] trans-disciplinary approach is an opportunity for technology transfer." *(Quote 10, Research group_D, Professor)*

> "We have a cooperation contract with the university to work together in the fund projects to develop further…evaluate further [the technology]." *(Quote 11, Spin_off_C, CEO)*

The empirical data illustrate that the participation of academic and industry partners in the BioSC plays a crucial role in fostering interaction among the different disciplines involved in the bioeconomy. Interviewees from the cases associate this to the opportunities and the requirements this network offers. For instance, it offers an online platform that provides partners with the opportunity to share and discuss knowledge across different disciplines within the bioeconomy. Most importantly, as mentioned above (selection of case studies), the BioSC fosters interdisciplinary collaboration by making mandatory the collaboration between at least two different bioeconomy research disciplines in research proposals in order to be eligible for funding.

> "We were not be sitting here, if BioSc would not be existing. […] We also talk across disciplines. So this is hugely beneficial. This is great." *(Quote 12, Research group_B, Professor)*

> "And so the people can meet, they have an internet platform where every scientist can say what he can do and what he wants to do. Based on that initiative several people from the agricultural field as well as from the biology field approached me and therefore from my point of view the BioSC is doing a very good job in this regard." *(Quote 13, Research group_A, Professor)*

Table 2-2: Cross-case comparison regarding effectiveness criteria[167]

Effectiveness criteria[168]	Research group_A	Research group_B	Research group_C	Research group_D	Spin-off_A	Spin-off_B	Spin-off_C	Spin-off_D
"Out-the-door"	Transfer of knowledge and prototype applications of technologies by publications and patents.				Transfer of knowledge and technology from a research centre or university addressing interdisciplinary research to a spin-off project.			
Market impact and economic development	Recognition that competitiveness of products and technologies in the bioeconomy needs to be considered.				▪Market maturity and commercial impact is projected by end of 2017. ▪Several companies have declared interest to adopt the technology.	▪Market maturity and commercial impact is projected by 2018/2019. ▪Industrial partner to adopt the technology.	Market maturity and commercial impact have been achieved and are currently expanding their product portfolio.	
Political reward	Governmental funding support especially addressing the interdisciplinary field of the bioeconomy.				▪Initial funding support from a research centre. ▪Governmental funding support to business contests especially addressing the interdisciplinary field of the bioeconomy.		Governmental funding support to business contest especially addressing the interdisciplinary field of the bioeconomy.	
Opportunity cost	Expansion of the research team.				Expansion of the research team			
Scientific and technical human capital	▪Active member in several clusters, networks, platforms aimed at fostering interdisciplinary research in the bioeconomy. ▪Collaborations with industry partners.				▪Active member in a network aimed at fostering interdisciplinarity in the bioeconomy. ▪Collaborations with industry partners.	Collaborations with industry partners.	▪Active member in a network aimed at fostering interdisciplinarity in the bioeconomy. ▪Collaborations with industry partners.	
Public value	Conducting research aiming at developing knowledge and technologies addressing sustainability goals.				Produces a sustainable bio-based product by reducing dependency on fossil carbon sources.	▪Produces sustainable bioenergy. ▪Product does not compete with raw materials derived from food.	Produces a sustainable bio-product by reducing dependency on fossil carbon sources.	
Resource complementarity	▪Team composed of staff with different backgrounds. ▪Institutionalisation of interdisciplinary departments. ▪Expansion of research projects where integration across disciplines needs to be demonstrated.				▪Team composed of staff with different backgrounds. ▪Development of technologies where integration across disciplines is needed.			

[167] Source: Own table.

[168] Effectiveness criteria are based on Bozeman et al. (2014).

2.5 Discussion and conclusion

The empirical findings of this study illustrate that effectiveness of technology transfer in the interdisciplinary setting of the bioeconomy can be assessed by using the seven distinct criteria proposed by Bozeman (2000) and Bozeman, Rimes, & Youtie (2014). Therefore, the "Contingent Effectiveness Model of Technology Transfer" appears to be suitable for the particular research setting of the bioeconomy. In particular, the findings show that quotes related to interdisciplinarity recur often, which emphasises the high relevance and attention that interdisciplinary collaborations acquire in the research setting of the bioeconomy. This indicates that a successful integration of bioeconomy-related disciplines is key to achieve technology transfer. In this regard, the findings of this research point towards two main categories of factors enhancing interdisciplinary research and thus, effectiveness of technology transfer in the bioeconomy: individual characteristics and institutional settings. The first category refers to individual support to interdisciplinary research. The second and most important category relates to the creation of a framework aiming at fostering interdisciplinary research collaborations and technology transfer.

With regard to individual support to interdisciplinary research, the case study results indicate that the academic research groups and the spin-offs benefit from the creation of an interdisciplinary team. Consequently, the beneficial engagement across disciplines requires trust and effective communication among all the partners involved. However, this also presents barriers rooted in the different backgrounds, languages, ways of communication, interests and experiences that each discipline has.[169] In line with other authors[170], achieving successful interdisciplinary research will require the removal of barriers to the flow of information between the disciplines relevant to the bioeconomy.

Most importantly, the findings reveal three main enabling factors related to institutional settings. The first determining factor is the institutionalisation of interdisciplinary departments at university or public research level. The second crucial factor for fostering interaction among disciplines is the provision of a network or platform such as the BioSC. This network operates in three complementary directions that are key for achieving interdisciplinary collaborations and technology transfer. Firstly, it facilitates cooperation among different disciplines by

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[169] Dingler and Enkel (2016).

[170] See e.g. Bassett-Jones (2005); MacLeod (2016).

organising events, meetings, conferences, and the provision of an online platform. These activities allow scientists from different disciplines and backgrounds to discuss knowledge extensively. Secondly, it provides funding to research projects where integration across bioeconomy disciplines needs to the demonstrated (e.g. only if at least two disciplines within the bioeconomy are collaborating, the state-financed funding will be granted). Thirdly, the BioSC engages academic and industry partners to achieve technology transfer (e.g. collaborative projects with industry, conferences involving academia and industry). These findings also complement recent discussions that networks create a good framework for fostering creativity and innovations.[171] Another determining factor is the support of business plan contests that require cooperation across different bioeconomy-related disciplines.

Resulting from these findings, this study extends the empirical relevance of the “Contingent Effectiveness Model of Technology Transfer” developed by Bozeman (2000) to technology transfer in a highly interdisciplinary field such as the bioeconomy by adding a new criterion: Resource complementarity. This extension of the model is illustrated in **Figure 2-2**. The extended model recognises five dimensions: transfer agent, transfer media, transfer object, demand environment, and transfer recipient. Layers have been added to each dimension. The layers indicate the multiple dimensions that simultaneously can appear in the particular setting of interdisciplinarity. For instance, in a bioeconomy project, the transfer agents could be the faculty of biology and the faculty of chemical engineering working together developing a specific enzyme; or the transfer recipients could be industries belonging to different sectors like chemical or biotechnology.

The extension of the model considers eight distinct criteria to assess effectiveness of technology transfer: “Out-the-door”, market impact, economic development, political reward, opportunity cost, scientific and technical human capital, public value, and the new criterion*:* Resource complementarity. Resource complementarity refers to the capacity to create new knowledge and technologies based on the interaction of partners from different disciplines. This can be assessed in the following ways. Firstly, by an increasing number of teams composed of staff with different backgrounds. Secondly, by the institutionalisation of interdisciplinary departments. Finally, by setting mandatory requirements for funding that enforce interdisciplinary collaborations.

[171] Alves et al. (2007); Dingler and Enkel (2016).

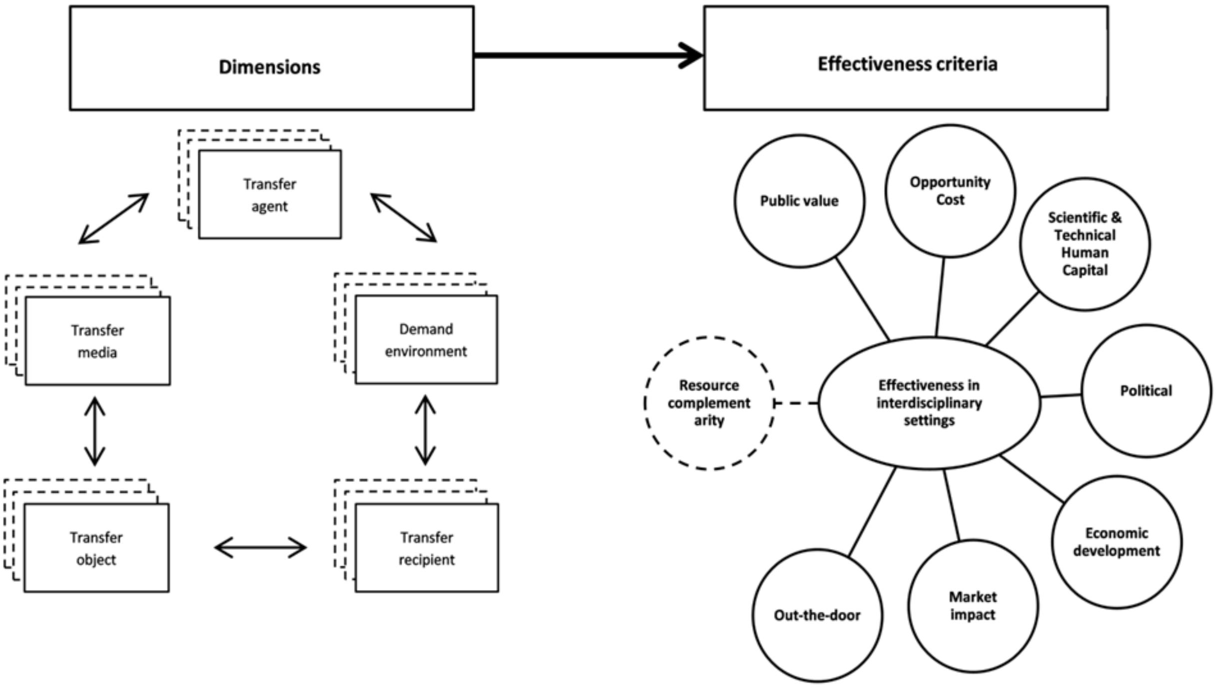

Figure 2-2: Extension of the Contingent Effectiveness Model of Technology Transfer[172]

Concluding remarks

This exploratory study attempted to answer the question of how to assess effectiveness of technology transfer in the interdisciplinary research setting of the bioeconomy. To answer this research question, the "Contingent Effectiveness Model of Technology Transfer" developed by Bozeman (2000) adapted to the particularities of the interdisciplinary setting of the bioeconomy is used. Then, empirical evidence gathered from eight comprehensive case studies is employed to reveal how these interdisciplinary institutions manage technology transfer. Based on the findings of the study, this research contributes in several ways.

Firstly, this research represents an important contribution to the current body of literature on technology transfer by applying Bozeman's (2000) model to the particularities of the emerging and very interdisciplinary field of the bioeconomy. As a consequence, this study extends Bozeman's (2000) model by adding a new effectiveness criterion: *Resource complementarity*. This new criterion assesses the effect of technology transfer on the creation of new knowledge

[172] Source: Own Figure based on Bozeman et al. (2014, p. 36).

and technologies based on the interaction of different disciplines. Thereby, a modified version of the Bozeman's (2000) model to be used for assessing technology transfer effectiveness in interdisciplinary settings is presented.

Secondly, within the multiple case study approach, this research contributes to the current literature on technology transfer, inter-organisational collaboration and the management of innovation across multiple discipline boundaries. In this regard, this study identifies two main categories of factors that lead to enhancing effectiveness of technology transfer in interdisciplinary research settings: *individual characteristics* and *institutional settings*. Networks such as the BioSC provide an excellent framework for fostering interdisciplinary research and technology transfer. By making interdisciplinary collaborations mandatory in research proposals, the BioSC has developed a truly interdisciplinary research that integrates insights across multiple bioeconomy disciplines. Consequently, the creation of networks and funding agencies such as the BioSC can be identified as an exceptional example to allow such opportunities at regional scale.

Therefore, this work argues that such networks could set mandatory requirements for funding in two particular ways. Firstly, by setting mandatory collaboration across different disciplines. Secondly, by making mandatory integration of academic and industry partners in research proposals. This mode, dissemination and transfer of research results could be ensured.

Managerial implications

From a managerial perspective it is a major challenge not only to collaborate across different discipline boundaries, but to be able to transfer the research results developed from interdisciplinary collaborations into viable technologies, processes or products. Thus, companies that aim at benefiting from interdisciplinary research results need to develop specific capabilities to manage these challenges. Firstly, the collaboration of industry partners with centres focusing on interdisciplinary research should be fostered in the future. For instance, via funding research calls that enforce the inclusion of different disciplines as well as industry partners. Secondly, the participation of companies in networks, platforms or clusters to collaborate across different discipline boundaries and with academia should be supported. Finally, as the integration of pilot and scaling-up facilities to demonstrate the feasibility and potential of interdisciplinary technologies is of key importance to achieve successful technology transfer, these facilities should be encouraged. This could also be addressed by considering the development of these facilities in future calls and research projects.

Limitations and future research

The results of this research cannot provide a holistic view of the entire field of interdisciplinarity in the bioeconomy. Although relevant examples of academic research groups and spin-offs in this area were selected, care needs to be taken when attempting to generalise from the findings. Future studies could include the analysis of more academic research groups and spin-offs potentially in other regions or other interdisciplinary research settings.

This case study approach allowed an in depth investigation of research groups and spin-offs working on interdisciplinary research in the bioeconomy. However, the limitations of this study are based on the selection of the case studies approach used. Although careful analysis to inductively reveal the categories was performed, certain degree of subjectivity remains. To mitigate this, the analysis was performed by two independent scientists and the findings were then compared.

Future studies could also consider the application of this conceptual framework to other interdisciplinary research settings like bioinformatics, ICT, nanotechnology, or neurosciences to validate the extension of the conceptual framework.

The present chapter analysed technology transfer from the perspective of different disciplines working together. It provided a conceptual framework on assessing technology transfer in interdisciplinary settings and identified factors that can lead to enhance effectiveness of technology transfer in interdisciplinary settings. It also recognised the need of including stakeholders to study technology transfer and interdisciplinary research, since different stakeholder groups (e.g. academia, industry) have different perceptions and objectives about technology transfer. This difference in perception can hinder the process of technology transfer. Therefore, the next chapter uses a multi-stakeholder perspective to analyse technology transfer and interdisciplinary research. To this end, a bottom-up and participatory method is used to investigate challenges in technology transfer from the point of view of the different stakeholder groups.

3 Evaluation of technology transfer from a stakeholder perspective

Chapter 3 answers Research Question 2 and 3:

R.Q.2: What are perceptions of factors that influence technology transfer in the bioeconomy from the point of view of the key stakeholder groups involved in the technology transfer process (i.e. academic scientists, technology transfer facilitators and firms/entrepreneurs)?

R.Q.3: What is the perceived relative importance and coherence of these factors as identified by the different stakeholder groups?

This chapter is based on the following publication: Laura Borge, Stefanie Bröring (2018): *What affects technology transfer in emerging knowledge areas? A multi-stakeholder concept mapping approach in the bioeconomy***,** Journal of Technology Transfer (in press).

3.1 Introduction

Emerging knowledge areas are recognised as key drivers for innovation, economic growth[173], and to provide solutions to global challenges like climate change or rising world population.[174] In what follows, emerging knowledge areas encompass emerging technologies, regulatory frameworks, industries, markets and sectors. These can be defined as radical innovations[175] with relatively fast growth and with the potential to have considerable socio-economic impact.[176] Its development and commercialisation requires the establishment of further linkages among research and innovation at universities, scientific institutions and industries.[177] This calls for closer cooperation between the overall spectrum of stakeholders that are part of the technology transfer process: academic scientists across different disciplines, technology transfer facilitators and firms/entrepreneurs.[178]

Despite the vast opportunities that emerging knowledge areas present, technology transfer is challenged in several ways. Such challenges are strongly associated with the unique particularities exhibited by emerging knowledge areas. Firstly, emerging knowledge areas are characterised by high technology and market uncertainty.[179] Secondly, emerging knowledge areas need the combination of unrelated and highly interdisciplinary knowledge.[180] Finally, the integration of knowledge and expertise of the three key stakeholder groups that are involved in the technology transfer process is pivotal.[181]

The above-mentioned characteristics imply that emerging knowledge areas require a mixture of cross-disciplinary, inter-sectoral and multi-stakeholder collaborations to ensure successful commercialisation.[182] However, each stakeholder group (i.e. academic scientists, technology transfer facilitators and firms/entrepreneurs) has its own specific objectives, skills and

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[173] Groen and Walsh (2013).

[174] Groen and Walsh (2013); Melkers and Xiao (2012).

[175] Bröring et al. (2006); Garcia and Calantone (2002); Rotolo et al. (2015).

[176] Rotolo et al. (2015).

[177] Hung and Chu (2006).

[178] Siegel et al. (2004).

[179] Day et al. (2004); Rotolo et al. (2015).

[180] Maine et al. (2014); Melkers and Xiao (2012); Porter and Rafols (2009).

[181] Borge and Bröring (2017); Rogers (2003).

[182] Maine et al. (2014).

knowledge that are appropriate and pertinent to their respective role in the technology transfer process.[183] As a result, missing coherence among stakeholders may challenge the technology transfer process.[184] Undoubtedly, the chances of successful technology transfer would be enhanced if all the stakeholders involved in the process were to have similar perceptions about technology transfer, and therefore coherent behaviors and ways of operating.

In the literature, however, little remains known about factors affecting technology transfer from a more integrated and multi-stakeholder perspective. Moreover, the need of more studies that include the examination of the whole spectrum of stakeholders involved in transfer has been emphasised by several authors.[185] Likewise, there is no research on the impact of the level of coherence among key stakeholders on technology transfer, which requires mental models among stakeholders. Consequently, this chapter seeks to contribute to close this gap in the existing literature by combining stakeholder theory[186] and microfoundations.[187] In doing so, this thesis provides the first overview of factors affecting technology transfer through stakeholder groups perceptions.

As a suitable case of an emerging knowledge area founded on different disciplines, the case of the KBBE is selected. This emerging knowledge area proves ideal since: (1) it builds upon the combination of a wide spectrum of academic disciplines and technologies[188]; and (2) it strongly relies on the combination of knowledge and expertise among the key stakeholders involved in technology transfer.[189]

The KBBE includes two of the six Key Enabling Technologies (KETs)[190] which have been selected by the European Commission: industrial biotechnology and nanotechnology. Examples include bioplastics, biopharmaceuticals, biofuels, or biogas that can be used in

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[183] Rogers (2003); Siegel et al. (2004).

[184] Rogers (2003).

[185] See e.g. Ankrah et al. (2013); Bradley et al. (2013); Cunningham and O’Reilly (2018).

[186] Freeman et al. (2010); Harrison and Wicks (2013).

[187] Barney and Felin (2013); Cunningham et al. (2016); Foss and Lindenberg (2013).

[188] European Commission (2012b); OECD (2009).

[189] Boehlje and Bröring (2011); European Commission (2012b); Golembiewski et al. (2015).

[190] KETs are a group of six technologies selected by the European Commission (micro and nanoelectronics, nanotechnology, industrial biotechnology, advanced materials, photonics, and advanced manufacturing technologies) that help tackle grand societal challenges.

agriculture, forestry, fisheries, food, pulp and paper production, as well as parts of chemical, pharmaceutical, biotechnological and energy industries.[191] All these applications can lead to economic growth and help tackle major global challenges.[192] Sectors of the bioeconomy are also noted to have the potential to generate € 2 trillion in annual turnover and more than 22 million jobs in Europe.[193] For such an interdisciplinary, innovative, and promising emerging knowledge area, the transfer of knowledge from academic institutions to industry and firms becomes pivotal to achieve successful commercialisation of ongoing research.[194]

The mixed-method approach (qualitative and quantitative) of group concept mapping[195] is used in this research as its ultimate goal is to integrate and represent the unified mental model of a group of stakeholders in spite of their different expertise and interests.[196] Hence, this article is unique in that it employs a novel methodological approach in the field of technology transfer. Using this approach, factors inhibiting technology transfer in the bioeconomy, from the perspectives of the different stakeholder groups, can be identified. Based on the most important factors as perceived by the key stakeholders, suggestions to foster successful technology transfer can thus be proposed. Consequently, the ultimate aim of this work is to provide managerial and policy recommendations that can be transferred to other interdisciplinary and emerging knowledge areas. In this respect, this thesis contributes more generally to the research of technology transfer and technology transfer in emerging knowledge areas such as the bioeconomy.

The remainder of this chapter is structured as follows: Section 3.2 provides the theoretical background and reviews the challenges associated with technology transfer in emerging knowledge areas in order to understand their implications for the particular setting of the bioeconomy. Section 3.3 provides a description of the chosen research method, i.e. group concept mapping. Section 3.4 presents the main findings with respect to R.Q.2 and R.Q.3.

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[191] European Commission (2012b).

[192] European Commission (2012b).

[193] European Commission (2012b).

[194] Audretsch et al. (2014).

[195] Kane and Trochim (2007).

[196] Kane and Trochim (2007); Trochim and Cabrera (2005).

Finally, Section 3.5 provides conclusions and discusses implications as well as the limitations and suggestions for future research.

3.2 Theoretical background: Microfoundations and stakeholder theory

Technology transfer is a broad field encompassing technology transfer between companies to technology transfer between countries or even technology transfer from academia to industry. In this chapter, technology transfer from academic institutions to industry and firms is on the focus. For the purpose of this thesis, this type of technology transfer is especially relevant as it is vital to commercialise emerging inventions and technologies that are developed in academia at the confluence of different disciplines.

Building upon existing reviews[197], literature about factors affecting technology transfer is classified into three main categories: Individual factors (i.e. characteristics of scientists such as age, previous commercialisation experience, grants awarded), organisational factors (e.g. the quality of university/departments, organisational design, types of processes or existence of incentives), and institutional factors (e.g. one's scientific discipline or the impact of public policies). Whereas empirical research on factors that affect technology transfer has been conducted in the past[198], technology transfer factors in a highly interdisciplinary and emerging knowledge area, such as the bioeconomy, has not yet been analysed. As a consequence, this chapter strives to close this gap in the existing literature through an application to the specific setting of the KBBE.

The knowledge-based bioeconomy is defined as *"the production of renewable biological resources and the conversion of these resources and waste streams into value added products, such as food, feed, bio-based products and bioenergy"*.[199] Thus, it is based on a wide range of diverse academic disciplines and technologies such as life sciences, agronomy, ecology, food science, social sciences, biotechnology, nanotechnology, ICT and engineering.[200] Therefore, in the emerging knowledge area of the bioeconomy, the confluence of the different disciplines is particularly noteworthy. Consequently, integration of knowledge across these diverse

[197] Phan and Siegel (2006); Perkmann et al. (2013).

[198] See e.g. Phan and Siegel (2006); Perkmann et al. (2013).

[199] European Commission (2012b, p. 3).

[200] European Commission (2012b).

disciplines is pivotal for the successful implementation and commercialisation of research findings within this emerging knowledge area.[201]

However, implementing the bioeconomy not only requires collaboration among academic scientists with different backgrounds but also a high degree of collaborations between academic scientists, technology transfer facilitators and firms/entrepreneurs. This is because scientific institutions are the key source of knowledge and innovation in the bioeconomy.[202] Moreover, connections between universities, research institutions, technology transfer facilitators, and industries must be established for value creation and successful commercialisation across bioeconomy sectors to take place.[203]

In this regard, technology transfer represents a complex process that mutually depends on three groups of stakeholders[204]: (1) academic scientists, who discover new technologies; (2) technology transfer facilitators, who act as intermediaries between academic scientists and firms and manage IPR; and (3) firms/entrepreneurs, who adopt and commercialise technologies developed by academic scientists. Examples of academic scientists in the bioeconomy include scientists working within the variety of disciplines related to the bioeconomy and on collaborative research projects with partners from other disciplines. Examples of technology transfer facilitators are technology transfer offices, venture capital firms, or networks operating in the particular field of the bioeconomy. Firms/entrepreneurs in the bioeconomy include the spin-offs, start-ups, firms or large industries working in the diverse sectors that are part of the bioeconomy (e.g. chemical, biotechnology or energy).

A summary of the different mission and objectives of the three key stakeholders building upon Siegel et al. (2004) is presented in **Table 3-1**. Academic scientists, who represent the providers of technology, view technology transfer as a means for serving the community through the increased production and sharing of knowledge. Their main objective is taken to be attaining recognition within the scientific community through publications in top journals, presentations

[201] Golembiewski et al. (2015).

[202] Boehlje and Bröring (2011); Borge and Bröring (2017); European Commission (2012b); Golembiewski et al. (2015).

[203] Maciejczak (2017); Schütte (2017).

[204] Siegel et al. (2004).

at conferences, and research grants.[205] Such an outlook can be expected given the general incentive structure within the academic system.[206] Conversely, firms and entrepreneurs, as the recipients of technology, tend to emphasise profit maximisation and the economic benefits of technologies developed by academic scientists.[207] Meanwhile, the general mission of technology transfer facilitators is to ensure the commercialisation of knowledge by acting as a bridge between academic scientists and industrial firms or entrepreneurs. Their objective is twofold: (1) to protect and manage the IPR of the inventions generated by academic scientists; and (2) to market the IP to firms.

Table 3-1: Key stakeholders in technology transfer in the knowledge-based bioeconomy[208]

Stakeholder	Mission	Objectives	In the Bioeconomy
Academic scientists	Production of new knowledge and technologies	Recognition within the scientific community through publications and grants	Academic scientists working on bioeconomy-related disciplines and involved in interdisciplinary projects
Technology transfer facilitators	Collaborations as intermediaries between public research organisations and firms/entrepreneurs to commercialise knowledge and technologies	Protect inventions, market technologies	Technology transfer offices, venture capital firms and networks specialised in bioeconomy
Firm/ entrepreneurs	Commercialisation of knowledge and technologies	Economic benefits	Spin-offs, start-ups, firms or large industries operating in bioeconomy-related sectors

As indicated in **Table 3-1**, these three groups of stakeholders generally may have different perceptions about both the understanding and the objectives of the technology transfer process.[209] This is because the stakeholder groups all have different organisational cultures, motives, missions, practices[210], as well as ways of communicating.[211] These differences are

[205] Siegel et al. (2004).

[206] Bozeman (2000).

[207] Siegel et al. (2004).

[208] Source: Own Table based on Siegel et al. (2004b, p. 120).

[209] Rogers (2003); Siegel et al. (2004).

[210] Santoro and Chakrabarti (2002); Siegel et al. (2004).

[211] Langford et al. (2006).

rooted in the different mental models that different stakeholder groups have.[212] This thesis therefore argues that the ability to promote coherence across all stakeholder groups in the technology transfer process has the potential to improve technology transfer.

In the domain of management, organisation theory, and strategy, a new strand of research is arising that focuses on microfoundations[213] and stakeholder theory.[214] Research into microfoundations and stakeholder theory is concerned with examining the role of stakeholders, specifically their motivations, cognitive processes, and conceptual understanding of problems, in order to better represent the aggregate concepts or perceptions and/or relationships between these.[215] In this context, microfoundations and stakeholder theory offer a promising approach to study the perceived factors affecting technology transfer, notably from the perspective of the key stakeholders.

In contrast to previous studies, this thesis brings together the three groups of stakeholders by including them in the method and framework of the study. Therefore, the perceived factors influencing technology transfer in the KBBE are simultaneously gathered from the various stakeholders that jointly shape the technology transfer process. Research at the level of microfoundations and stakeholder theory can help improve management practices and strategies for successful technology transfer. Consequently, as an application to the case of the KBBE, this chapter aims to answer the following research questions:

RQ.2: What are perceptions of factors that influence technology transfer in the bioeconomy from the point of view of the key stakeholder groups involved in the technology transfer process (i.e. academic scientists, technology transfer facilitators and firms/entrepreneurs)?

RQ.3: What is the perceived relative importance and coherence of these factors as identified by the different stakeholder groups?

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[212] See definition by Freeman et al. (2010).

[213] Barney and Felin (2013); Cunningham et al. (2016); Foss and Lindenberg (2013).

[214] Freeman et al. (2010); Harrison and Wicks (2013).

[215] Barney and Felin (2013); Foss (2010).

3.3 Materials and methods

3.3.1 Overall study approach

In order to answer R.Q.2 and R.Q.3, the methodology of *group concept mapping* is employed. To this end, the KBBE is selected, given that it represents a highly interdisciplinary and emerging knowledge area that strongly depends on the integration of knowledge and expertise of the key stakeholders that are part of technology transfer.[216] This methodology has been employed in a wide range of topics and disciplines such as value chains[217], entrepreneurship[218], public health[219], psychology[220], psychiatry[221], food access[222], energy efficiency[223], or network formation.[224]

Moreover, group concept mapping was deemed to be especially appropriate to meet the aim of this research objective since it is designed to integrate input from a variety of multiple stakeholders, each with their own different perspectives. Consequently, this study is able to identify relevant factors by considering the full spectrum of stakeholders that are part of the technology transfer process. This research is the first to use group concept mapping to explore stakeholder perceptions about factors influencing technology transfer in a highly interdisciplinary and promising emerging knowledge area- that of the KBBE. The group concept mapping process[225], as depicted in **Table 3-2**, consists of five steps: (1) Preparation (including selection of stakeholders and development of the focus prompt for brainstorming); (2) Generation of ideas around the focus prompt; (3) Structuration and rating of the developed

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[216] Boehlje and Bröring (2011); Borge and Bröring (2017); European Commission (2012b); Golembiewski et al. (2015).

[217] Berg et al. (2018).

[218] Cloutier et al. (2017).

[219] Blackstone et al. (2017); Cloutier and Spooner (2016); Stolk-Vos et al. (2017); van Engen-Verheul et al. (2017); Vives-Cases et al. (2017).

[220] Stack-Cutler et al. (2017).

[221] Janssens et al. (2017).

[222] Johnson et al. (2014).

[223] Schroeter et al. (2012).

[224] Klenk and Hickey (2012).

[225] Kane and Trochim (2007).

ideas; (4) Representation of statements in the form of concept maps (using multidimensional scaling and hierarchical cluster analyses); (5) Interpretation and utilisation of maps.

Table 3-2: Steps of the group concept mapping[226]

Step 1 **Preparation**	**Step 2** **Generation of ideas**	**Step 3** **Structuration of ideas**	**Step 4** **Computation of maps (analysis)**	**Step 5** **Interpretation of maps**
▪ Identify stakeholders ▪ Develop focus prompt: *"Factors that influence technology transfer in the bioeconomy are"*	▪ Group discussion with identified stakeholders (N_{GD} = 13) ▪ Formalise generated "ideas" as statements (*k*=55)	▪ Complete participant questions (N_{PQ}= 52) ▪ Sort statements into piles (N_S= 25) ▪ Rate statements for their relative "importance" (N_R= 52)	▪ Use Multidimensional scaling analysis to generate a point map representing relationship of ideas ▪ Use Hierarchical cluster to group ideas into homogeneous groups of ideas	▪ Interpret results and provide managerial and policy recommendations

Note: N_{GD}= number of stakeholders who took part in the group discussion, k= final number of statements, N_{PQ}= number of stakeholders who completed questions, N_S= number of stakeholders who engaged in sorting the statements and N_R=number of stakeholders who took part in rating the statements.

3.3.2 Preparation

During the *preparation* phase of the project, the stakeholders were identified, the focus prompt for conceptualisation was selected, and a working plan was carried out. Overall, the aim of this step was to select a heterogeneous group of stakeholders that were involved in the process of technology transfer. A broad heterogeneous participation thus helps to ensure that a wide variety of different viewpoints will be reflected.[227] In this regard, 13 stakeholders (N_{GD}=13) with contrasting experiences in technology transfer and the bioeconomy were selected. Among these 13 stakeholders, the sample consisted of academic scientists (n=5), industry actors (n=5), and technology transfer facilitators (n=3). The size of the sample is adequate, given that it falls within the recommended range of 10 to 20 stakeholders.[228] Academic scientists represented the diversity of research areas within the bioeconomy (e.g. biotechnology, chemistry, chemical engineering) and worked in interdisciplinary research projects. Industry actors included stakeholders from large firms and entrepreneurs in the field of bioeconomy. Technology

[226] Source: Own Table based on Kane and Trochim (2007, p. 8).

[227] Harrison and Klein (2007); Kane and Trochim (2007).

[228] Trochim (1989).

transfer facilitators consisted of stakeholders from technology transfer offices or venture capital firms.

The focus prompt to guide conceptualisation was specifically designed to evoke ideas from stakeholders by asking them to describe specific actions regarding the topic of interest. In light of R.Q.2 and R.Q.3, the focus prompt for brainstorming was therefore defined as follows: *"Factors that influence technology transfer in the bioeconomy are…"* a sentence to be completed by the identified stakeholders.

3.3.3 Data collection

3.3.3.1 Generation of ideas

A group discussion with the selected 13 stakeholders was used to *generate ideas* around the aforementioned focus prompt. In specific, a group discussion was employed as it enables the participants to benefit from group processes and enrich ideas.[229] The discussion was transcribed and screened by two independent scientists to obtain a representative list of statements. The analysis of the group discussion yielded an initial list of 78 statements; many of them were conceptually similar or redundant. Therefore, after revision and discussion by two different and independent scientists, the scientists consolidated a final list of 55 unique statements, representing the outcome of the discussion (see **Table 3-4***)*.

3.3.3.2 Structuration of ideas through sorting and rating

Once the list of statements that describes the focus prompt of the given topic was established, the sorting and rating of these statements could begin. An online survey using the Concept System® Global MAX©[230], a dedicated group concept mapping software, was launched for this purpose. Stakeholders from the three aforementioned categories (academic scientists, technology transfer facilitators, and firms/entrepreneurs), all of whom had prior experience in technology transfer or the bioeconomy, were then invited to participate. This online survey was divided into three sections: participant questions, sorting and rating of statements.

In the first section, stakeholders were asked to indicate the type of stakeholder group to which they belonged, given the desire to compare the perceptions of different stakeholder groups. The

[229] Rosas (2005).

[230] Concept System Incorporated (2017).

second section consisted of *sorting the statements* into piles by similarity. In specific, stakeholders were asked to sort the developed statements into piles considered to be related and then assign a label to each pile. Stakeholders could thus click and drag each individual statement from a list on the screen into piles that they created. To facilitate this task, instructions were given to categorise the statements into piles based on perceived similarities of the statements and not to create piles for 'miscellaneous' statements. The purpose of the sorting task was to acquire information about how participants perceived the statements to be related to each other. In the final section, stakeholders were asked to *rate the statements* according to the level of relative importance. Stakeholders could rate each statement on a 5-point Likert scale (with 1 = “very low importance” and 5 = “very high importance”). By classifying the statements in this manner, a score could then be given reflecting its perceived importance.

3.3.4 Data analysis

3.3.4.1 Computation of maps

The responses from stakeholders completing both the sorting and rating formed the input for the generation of the visual maps. Data analysis was conducted using the Concept System® Global MAX© software[231] and comprised three main activities: (1) creating similarity matrix from sorted data; (2) multidimensional scaling analysis; and (3) hierarchical cluster analysis.

Firstly, based on the sorted input of each participant, a *binary similarity matrix* is created for each participant. This individual matrix represents how each participant perceives the relationships between statements, with as many rows and columns generated as there are statements.[232] The cells indicate whether, for any two statements, the sorter put those statements together; i.e. a “1” is entered if the row and column statement pair were sorted by the participant into the same pile, and a “0” if not. These individual matrices are then aggregated across all stakeholders to create an *aggregated similarity matrix*, such that the numbers in each cell represent how many sorters put that pair of statements together in the same pile. Thus, a higher value indicates that more of the stakeholders put that pair of statements together in the same pile, implying that those statements are conceptually more similar.[233]

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[231] Concept System Incorporated (2017).

[232] Kane and Trochim (2007).

[233] Kane and Trochim (2007).

This aggregated similarity matrix constitutes the input for the *multidimensional scaling analysis*. Multidimensional scaling takes the statements as they are sorted across all stakeholders and develops a basic map in two-dimensional (x, y) space, where each statement is a point on the map. [234] This point map indicates how the statements are related to one another. [235] Therefore, statements that are piled together by more stakeholders are placed more closely to each other on the map. In multidimensional scaling, in order to evaluate the validity of the two-dimensional representation and the aggregated matrix, a "stress" value is calculated. The Kruskal and Wish (1978) stress value, which ranges from 0 to 1, measures how well the two-dimensional configuration (of the map) matches the data as represented in the total similarity matrix.[236] A lower stress value (i.e. close to 0) suggests a better overall fit between the input matrix data and the two-dimensional representation, indicating higher reliability. In a meta-analysis of 69 group concept mapping studies, the mean stress value was found to be 0.28, ranging from 0.17 to 0.34.[237]

In the next step, the two-dimensional point map serves as input for the *hierarchical cluster analysis*. Hierarchical cluster analysis partitions the map into groups of statements that reflect similar concepts (**Figure 3-1** and **Figure 3-2**). For this analysis, the coordinates from the multidimensional scaling are used to group concepts in agreement to their proximity by computing their Euclidean distance by using the Ward´s algorithm.[238] Whereas the point map in two-dimensional (x,y) space is fixed, cluster analysis represents a more flexible process that depends on how the map is interpreted.[239] The ratings collected from the Likert-scale responses were then added to the concept maps in order to show the differences in relative importance for each cluster (**Figure 3-3**).

From this rating, a *radar chart* (**Figure 3-4**) and a *scatter chart* (**Figure 3-5***)* were both created to show: (1) the perceived relative importance of factors across stakeholder groups and respective to clusters*;* and (2) the coherence of these perceptions across stakeholder groups and

[234] Kane and Trochim (2007).

[235] Kane and Trochim (2007).

[236] Kane and Trochim (2007).

[237] Rosas and Kane (2012).

[238] Kane and Trochim (2007).

[239] Kane and Trochim (2007).

respective to clusters. The radar chart was developed by first computing the statement averages across each stakeholder group (i.e. academic scientists, technology transfer facilitators and firms/entrepreneurs) and then computing the averages for the respective clusters. On the other hand, the scatter chart was carried out by calculating statement averages across clusters as well as the variance of statement averages by clusters. These charts are powerful in their implications, particularly as measures of stakeholder coherence regarding their relative views of statement importance.

3.3.4.2 Interpretation of the maps

Once the maps were generated, a workshop with a small group of stakeholders was conducted. At this time, the different visual maps (cluster maps, cluster rating maps, radar and scatter charts) were presented and analysed. The aim of this workshop was to allow stakeholders to view, discuss, and interpret the maps that were generated. Stakeholders were asked to discuss the number of clusters to retain on the final map and to then label the clusters.

3.4 Results

3.4.1 Stakeholders

The sample for the sorting consisted of 25 (N_S=25) stakeholders of the 66 invited, equivalent to a response rate of 37.88%. This number is above the minimum recommended number of stakeholders of 15.[240] Within the rating task, the survey was sent to 120 stakeholders, of whom 52 participated (N_R=52), equal to a response rate of 43.33%. Responses were obtained from different stakeholders based in Germany. **Table 3-3** gives an overview of the characteristics of respondents.

Table 3-3: Profile of the respondents[241]

Stakeholders	Sorting statements (n=25)		Rating statements (n=52)	
	n	**%**	**n**	**%**
Interdisciplinary academic scientists	11	44	20	38.46
Technology transfer facilitators	6	24	13	25
Firms/entrepreneurs	8	32	19	36.54

[240] Jackson and Trochim (2002).

[241] Source: Own Table.

3.4.2 Representation of the perceptions of factors influencing technology transfer in the bioeconomy

The 55 statements developed by stakeholders from the three aforementioned groups (academic scientists, technology transfer facilitators, and firms/entrepreneurs) were represented in the form of a point map (see **Figure 3-1**). From a microfoundations perspective and stakeholder theory, the depiction of stakeholder representations can improve the understanding of how different factors underlying technology transfer are perceived by different stakeholders.[242] Each point on the map represents one of the 55 statements from **Table 3-4.** The stress value for the point map was 0.28, well within the acceptable range of 0.17 to 0.34 as indicated by the meta-analytic study and thus indicative of a good fit between the sorted data and the point map.[243]

Table 3-4: List of statements with average importance ratings and variance grouped by cluster[244]

[242] Felin et al. (2012); Freeman et al. (2010).

[243] Kane and Trochim (2007); Rosas and Kane (2012).

[244] Source: Own Table.

Cluster	Statement	Perceived level of importance across all stakeholders (mean)	Perceived level of importance Academia (mean)	Perceived level of importance Facilitators (mean)	Perceived level of importance Firm/ Entrepreneurs (mean)	Coherence of perceptions across all stakeholders (variance)
Interdisciplinary collaborations		3.80	3.83	4.08	3.59	0.04
	8. The extent to which specialists from different disciplines are able to communicate effectively with one another	4.02	4.00	4.23	3.89	0.02
	50. Research collaborations between academic and industry partners	3.98	4.15	4.23	3.63	0.07
	22. Collaboration across scientific fields that the bioeconomy involves	3.96	3.95	4.23	3.79	0.03
	29. Availability of experts from the different bioeconomy-relevant disciplines	3.25	3.20	3.61	3.05	0.06
Support for innovation		3.65	3.70	3.88	3.43	0.03
	49. The availability of financial resources	4.21	4.10	4.38	4.21	0.01
	6. Availability of public funding for testing and scaling-up the production of start-ups	4.00	4.05	4.31	3.74	0.05
	19. Government's strategies in support of innovations	3.79	3.90	3.92	3.58	0.02
	15. The facilitation of more efficient innovation processes	3.65	3.65	3.77	3.58	0.01
	24. The promotion of SMEs' access to new technologies	3.56	3.60	3.85	3.32	0.05
	55. Promotion of incentives to foster technology transfer	3.40	3.50	3.69	3.10	0.06
	54. The degree of bureaucracy that scientists are facing at German universities	3.31	3.45	3.50	3.05	0.04
	48. The professionalization of technology transfer at German universities	3.27	3.35	3.69	2.89	0.11
Consumer role		3.64	3.40	3.81	3.79	0.04
	40. Consumer acceptance of biotechnology	3.71	3.45	3.85	3.89	0.04
	45. Unambiguous communication to consumers regarding biotechnology	3.71	3.45	3.85	3.89	0.04
	9. Consumer demand for bioeconomy products	3.69	3.40	4.00	3.79	0.06
	4. The current forecast of the market potential of the bioeconomy	3.46	3.30	3.54	3.58	0.02
Degree of novelty		3.61	3.72	3.69	3.44	0.02
	51. Proof of the applicability of new technologies	3.94	4.10	3.92	3.79	0.02
	37. Availability of processes and infrastructure to scale-up biotechnology production	3.73	3.75	4.08	3.47	0.06
	20. Missing proof of successful (market) applications in biotechnology	3.15	3.30	3.08	3.05	0.01
Academia - industry interface		3.50	3.54	3.62	3.38	0.01
	39. Early testing of commercial applicability and/or potential with industry partners	3.94	3.95	3.85	4.00	0.00
	7. Technology transfer culture in Germany	3.79	3.85	3.77	3.74	0.00
	16. Communication between academia and industry in general	3.77	3.75	4.00	3.63	0.02
	44. Existence of and access to networks to enable collaborations between the actors involved in the technology transfer process	3.65	3.65	3.92	3.47	0.03
	28. Perception at German universities regarding the potential use of research findings to make a profit	3.31	3.25	3.62	3.16	0.04
	32. Culture of doing research at German companies	3.27	3.40	3.46	3.00	0.04
	5. The valorization of scientific publications in industry related positions	2.79	2.95	2.69	2.68	0.02
Entrepreneurship		3.42	3.39	3.66	3.28	0.03

1. Motivation of individuals to become entrepreneurs	4.08	4.05	4.31	3.95	0.02
3. Promotion and support of business ventures by (interdisciplinary) teams	3.77	3.65	4.08	3.68	0.04
27. Implementation of (basic) business economic education in natural science and engineering courses	3.25	3.15	3.77	3.00	0.11
11. Implementation of entrepreneurial training programs at universities	3.23	3.35	3.46	2.95	0.05
10. Participation in events and fairs that especially target entrepreneurs	2.77	2.75	2.69	2.84	0.00
Individual involvement	3.37	3.53	3.33	3.21	0.02
46. Motivation of individuals to actively push technology transfer forward	4.00	4.10	3.69	4.11	0.04
21. The attitude of individuals toward entrepreneurial failure in Germany	3.37	3.70	3.15	3.16	0.07
42. Access to technology transfer offices	2.73	2.80	3.15	2.37	0.10
Framework conditions	3.36	3.40	3.41	3.29	0.00
26. Companies' investment strategies which only account for short-term profitability or superior quality	3.75	3.65	3.61	3.95	0.02
38. Regulatory barriers for bioeconomic technologies to shorten the time to market	3.69	3.60	3.92	3.63	0.02
33. The generally risk-averse attitude of German companies	3.58	3.65	3.61	3.47	0.01
47. The extent to which governments support technologies differently across biotechnological applications	3.38	3.65	3.31	3.16	0.04
23. Effect of subsidies in slowing down further progress and innovation	3.17	3.20	3.08	3.21	0.00
36. Implementation of harmonized standards for biotech production and products	3.13	2.95	3.46	3.10	0.05
52. The structure of the patenting system (incl.: fees, licenses etc.)	2.83	3.10	2.85	2.53	0.05
Access to market	3.36	3.36	3.33	3.37	0.00
25. The relative competitive advantage demonstration of new technologies over established ones	3.92	3.85	3.85	4.05	0.01
34. The early market introduction of products by shortening the time for R&D and product development	3.56	3.55	3.46	3.63	0.00
2. The focus on consumer preferences in R&D to guarantee the existence of a relevant demand	3.50	3.35	3.61	3.58	0.01
13. The misleading confusion between 'bioeconomy' and 'biotechnology' as referring to the same notions	2.44	2.70	2.38	2.21	0.04
Market readiness	3.34	3.31	3.49	3.26	0.01
14. The demonstration of the benefit of new technologies to consumers	3.79	3.70	3.85	3.84	0.00
43. The degree of public acceptance for products from different biotechnological fields	3.44	3.25	3.61	3.53	0.02
41. The consumer's focus on the price as the most important factor in the buying process	3.33	3.40	3.61	3.05	0.05
31. Market authorization for biotechnology products	3.31	3.40	3.46	3.10	0.02
30. The extent to which the demand for biotechnological products differs across applications	2.83	2.80	2.92	2.79	0.00
Perception of value creation	3.14	3.26	3.26	2.94	0.02
53. Valuation of basic academic research as an important source for innovation	3.38	3.60	3.38	3.16	0.03
35. The investment strategies of German companies	3.33	3.55	3.31	3.10	0.03
17. Conflict(s) of interests/objectives between actors in academia and industry	3.33	3.50	3.61	2.95	0.08
18. The measurement of the excellence of scientists' performance beyond number and quality of scientific publications	2.98	3.00	3.23	2.79	0.03
12. The small number of German green biotech companies	2.69	2.65	2.77	2.68	0.00

Note: Ratings are based on a 5-point Likert scale

Afterwards, the 55 ideas were classified into homogeneous groups representing the perceived factors influencing technology transfer in the bioeconomy. The final selection of clusters emerged by consensus during the group session with the stakeholders who were engaged in the project. In the first step, the cluster analysis considers each point as its own cluster. In subsequent steps, two clusters are merged until finally all the points are combined into just one cluster. Beginning with a 14-cluster solution, the stakeholders evaluated whether each proposed merging of clusters made sense until finally arrived at a 11-cluster solution. **Figure 3-1** depicts the 11 clusters that bring together the 55 statements about technology transfer in the bioeconomy as a spatial distribution of the representation of stakeholders. A brief description of the types of ideas contained in each cluster is explained below, beginning with the cluster at the bottom of the map and following clockwise:

- *'Entrepreneurship':* i.e. the individual motivation to become an entrepreneur and the implementation of education to foster entrepreneurship.
- *'Individual involvement'*: i.e. individual attitudes towards technology transfer and entrepreneurship.
- *'Interdisciplinary collaborations'*: i.e. collaborations between academic scientists from the different disciplines comprising the bioeconomy as well as collaborations between academia and industry.
- *'Perception of value creation'*: i.e. the valuation of academic research as a powerful source of creativity and innovation as well as investment strategies of companies.
- *'Access to market'*: i.e. barriers that firms face when marketing new technologies and innovations.
- *'Consumer role'*: i.e. the role of consumers when it comes to accepting products and technologies in the bioeconomy.
- *'Market readiness'*: i.e. the market environment in which the bioeconomy operates as well as the ability to translate results into market-ready products and technologies.
- *'Degree of novelty'*: i.e. the degree of maturity of new technologies as well as lack of suitable infrastructure to scale-up biotechnology production.
- *'Framework conditions'*: i.e. role of standards, governmental incentives, and regulations in bioeconomy/biotechnology as well as the existence of enabling attitudes of companies.

- *'Support for innovation'*: i.e. availability of public funding and financial resources in support of innovations and new technologies as well as promotion of incentives to foster technology transfer.
- *'Academia-industry interface':* i.e. objectives, incentives, mission, or way of communicating between academia and industry.

Based on the collective representation of ideas and the spatial distribution of clusters on the map, indicative insights for its interpretation can be elicited. As such, the proximity of clusters on the map indicates the level of similarity between concepts. For instance, *'Consumer role'* is between *'Access to market'* and *'Market readiness'*, which emphasises the conceptual connection between those ideas contained in these clusters. Conversely, as *'Market readiness'* and *'Entrepreneurship'* are located further away from each other, this implies a low level of similarity between, e.g., market regulations and the motivation of individuals to become entrepreneurs.

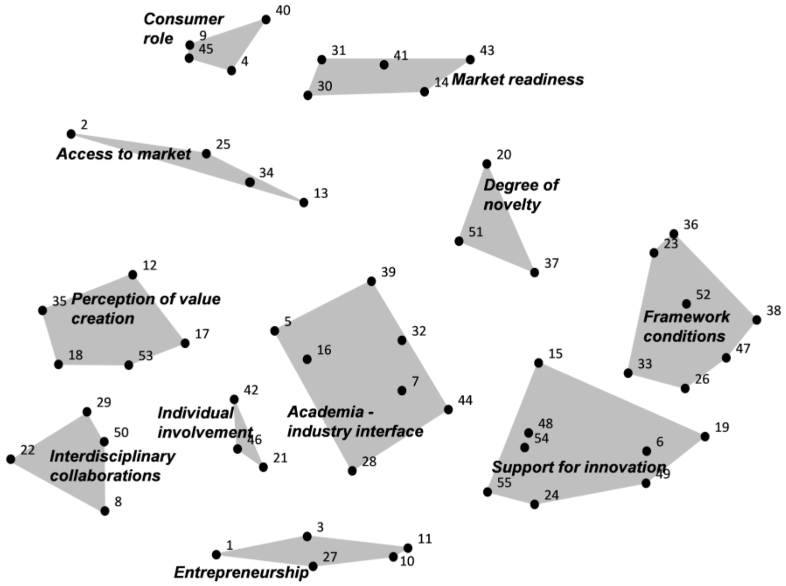

Figure 3-1: Point cluster map for the 11 clusters with their respective labels[245]

In order to get a higher level of abstraction of the map, the clusters were grouped into regions of meaning as shown in **Figure 3-2**. Each region on the map illustrates clusters that can be meaningfully gathered together. Hence, three large areas, each related to a category of factors, can be identified. In the bottom left of the map, there are those factors that relate to the

[245] Source: Own Figure.

individual characteristics of stakeholders to engage in technology transfer, entrepreneurship or collaborations with other disciplines and with industry. The middle and bottom-right parts correspond to factors that reflect the capacity of the organisational and institutional framework to support or inhibit technology transfer. Finally, the top of the map includes market factors influencing the development of technologies in the bioeconomy.

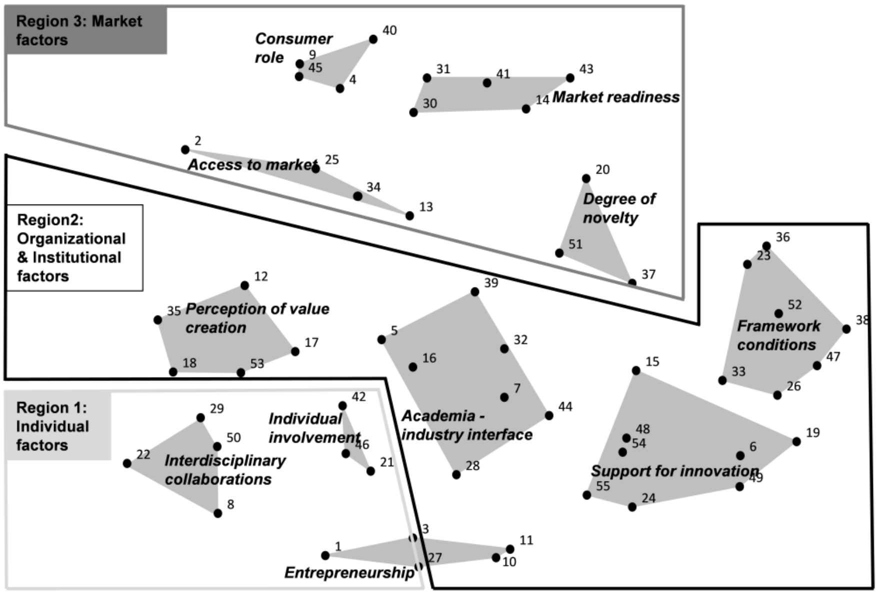

Figure 3-2: Three regions of meaning within the point cluster map[246]

These findings support those of Phan and Siegel (2006) and Perkmann et al. (2013), all of whom recognise that technology transfer is mainly influenced by individual characteristics, organisational and institutional factors. As such, two out of the three regions of meaning are similar to existing conceptual frameworks related to technology transfer. In addition, this study outlines a new region of meaning (*'Market factors'*) that refers to perceptions of the market environment that facilitates or inhibits the transfer of technologies. Moreover, factors such as consumer acceptance or the market authorisation of new technologies appear to play a key role vis-à-vis the perception of technology transfer and the commercialisation of new technologies. This result is in line with other authors, who assert that public knowledge and beliefs are also crucial determinants of successful technology transfer.[247] Based on this, this thesis argues that technology transfer is broadly affected by the way consumers and other market actors perceive

[246] Source: Own Figure.

[247] Bozeman (2000); Costa-Font and Mossialos (2006).

knowledge, technologies and innovations in the bioeconomy. Overall, these findings provide further empirical support for the extant literature on technology transfer factors, while also enriching and extending it in relation to the impact of market factors.

3.4.3 Representation of perceived relative importance and coherence of factors

As depicted in **Figure 3-3**, the cluster map is composed of the stakeholder ratings by the average level of importance. The number of layers for each cluster indicates the relative importance of its statements on average. This implies that the more layers shown, the higher the stakeholders rated the average importance of the statements in a cluster. For instance, the cluster labeled *'Interdisciplinary collaborations'* was perceived to be relatively more important on average (with five layers) than, e.g., the *'Perception of value creation'* cluster (which has only one layer).

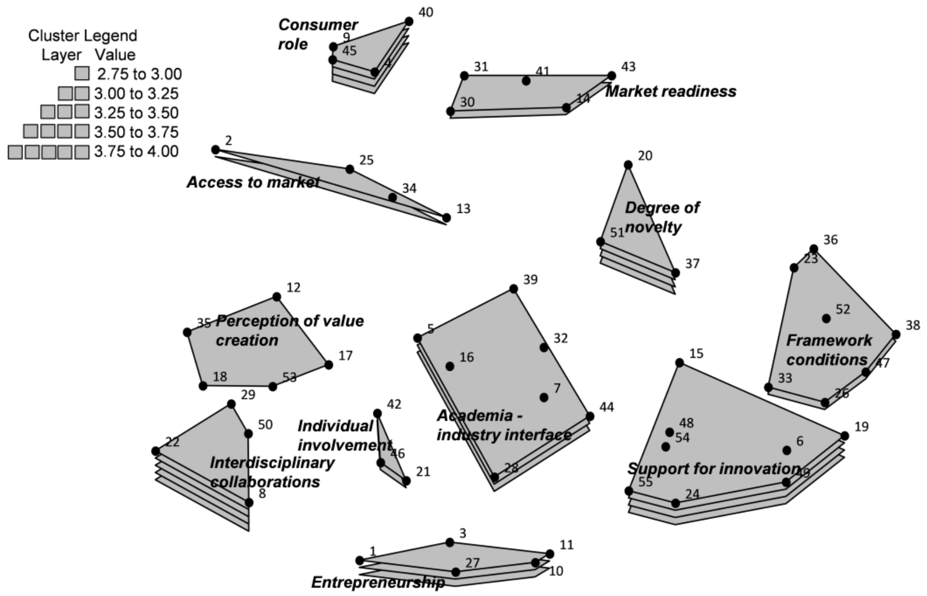

Figure 3-3: Point cluster map with the average ratings of importance.

Note: Ratings are based on a 5-point Likert scale[248]

To gain more detailed insight into the degree of relative importance of factors, **Table 3-4** provides the statement list with both the average level of importance and variance grouped by clusters. This is supported by **Figure 3-4**, which illustrates to what extent the different stakeholder groups perceive certain types of factors to be similarly important. Following the rating from **Table 3-4**, the overall most important cluster was *'Interdisciplinary collaborations'* (average importance=3.80), which refers to collaborations between academics from different

[248] Source: Own Figure.

disciplines as well as collaborations between academic and industry partners. This finding reveals the pivotal importance of collaborations in emerging knowledge areas, given the need to integrate knowledge both from different disciplines[249] and across the key stakeholder groups.[250]

This was followed by *'Support for innovation'* (average importance=3.65), *'Consumer role'* (average importance=3.64), *'Degree of novelty'* (average importance=3.61), and *'Academia-industry interface'* (average importance=3.50). The other six clusters -those containing statements related to, e.g. the role of standards and subsidies, investment strategies of companies for adopting bioeconomy technologies, or technology transfer incentives- are seen to have lower potential on average to affect technology transfer in the bioeconomy. Consequently, this analysis illustrates that stakeholders identify factors such as interdisciplinary collaborations, collaborations between academic and industry partners, the availability of financial resources, consumer acceptance, and the piloting of new technologies as key to achieve successful technology transfer in the emerging knowledge area of the bioeconomy.

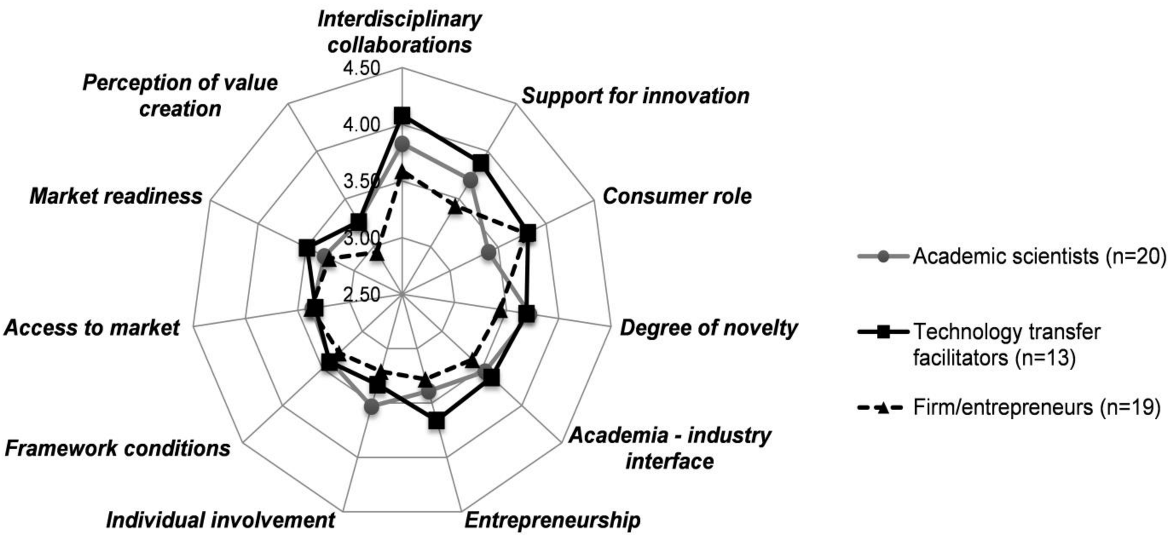

Figure 3-4: Radar chart: relative importance ratings by group of stakeholders.
Note: Ratings are based on a 5-point Likert scale[251]

[249] Maine et al. (2014); Melkers and Xiao (2012); Porter and Rafols (2009).

[250] Maciejczak (2017); Schütte (2017); Rogers (2003).

[251] Source: Own Figure.

Finally, in order to investigate the extent to which perceptions are coherent across the stakeholder groups, the variance as a proxy for coherence was analysed. Toward this end, the variance was calculated for each cluster by taking the average ratings across the three stakeholder groups. Hence, clusters with a lower variance represent smaller differences for the average ratings, and thus indicating a greater coherence of opinions across stakeholder groups. Conversely, clusters with a higher variance illustrate greater disparity within the ratings. From a microfoundations perspective and a stakeholder approach, representations of the level of coherence (variance) across stakeholder groups can improve the understanding of the extent to which perceptions related to technology transfer differ across stakeholders.[252]

The scatter chart in **Figure 3-5** therefore provides a contrast between the ratings of average importance and the level of coherence (variance) across stakeholder groups and respective to cluster. The graph is divided at the mean for each scale, thus resulting in four quadrants. Accordingly, the quadrant where the perceived relative importance is higher and relative coherence is lower, indicates an area where actions should be proposed in order to tackle the lack of coherence across stakeholders and potentially improve technology transfer. Quadrant I and its clusters *'Academia-industry interface'* and *'Degree of novelty'* are rated as being both relatively important and coherent across stakeholder groups. The clusters in quadrant II, i.e. *'Access to market'*, *'Framework conditions'*, *'Individual involvement'*, *'Market readiness'* and *'Perception of value creation'*, are rated as relatively less important though more broadly coherent. Quadrant IV (in the bottom right) illustrates that the clusters *'Consumer role'*, *'Interdisciplinary collaborations'*, and *'Support for innovation'* are characterised as relatively more important but also less coherent.

Overall, these findings support previous empirical research that claims that different stakeholder groups are likely to have different perceptions about technology transfer regarding its mission, objectives and the types of practices that are required.[253] In light of this, clusters within quadrant IV (higher importance-lower coherence) show relatively lower consensus of perceptions across stakeholder groups, delineating the area where managerial and policy implications should be suggested (section 5.1) with the potential to improve technology transfer.

[252] Felin et al. (2012); Freeman et al. (2010).

[253] Langford et al. (2006); Rogers (2003); Santoro and Chakrabarti (2002); Siegel et al. (2004).

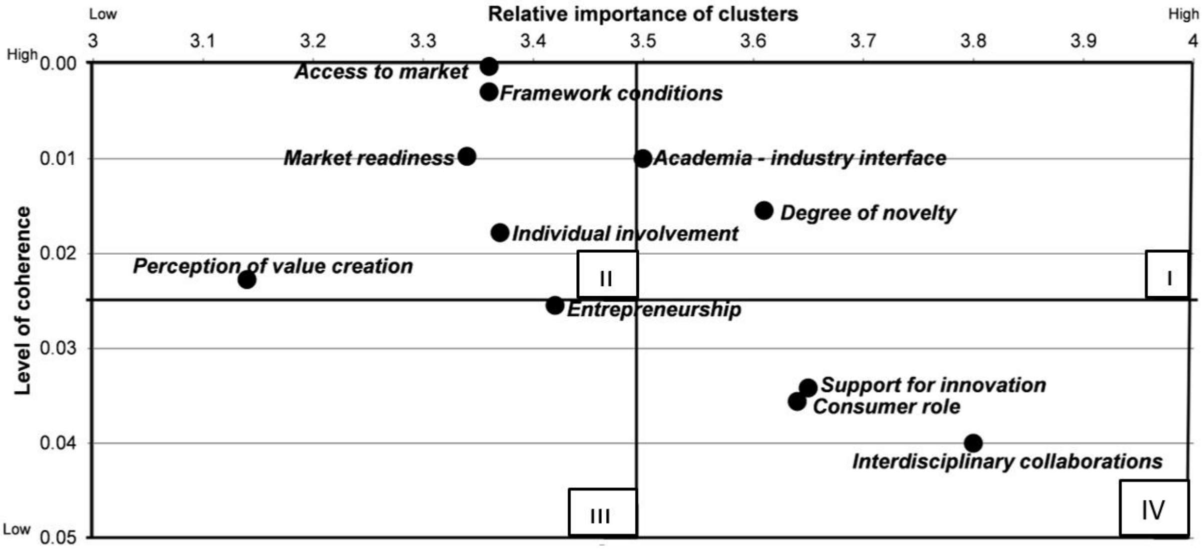

Figure 3-5: Scatter chart: Relative importance of clusters versus level of coherence.

Note: Horizontal line represents mean importance rating; vertical line represents mean variance. Ratings are based on a 5-point Likert scale[254]

3.5 Discussion and conclusion

This exploratory study set itself two main goals: (R.Q.2) to develop a multi-stakeholder representation of the perceived factors affecting technology transfer in the interdisciplinary and emerging knowledge area of the bioeconomy; and (R.Q.3) to examine the degree of relative importance and coherence of the identified factors across stakeholder groups. To answer R.Q.2 and R.Q.3, the method of *group concept mapping* was employed, which constitutes an innovative and novel approach for investigating technology transfer from a microfoundations perspective[255] taking different stakeholders as unit of analysis.[256]

The strength of this bottom-up and multi-stakeholder participatory method was the identification of perceptions of factors from the three key stakeholder groups (i.e. academic scientists, technology transfer facilitators and firms/entrepreneurs) that are part of the technology transfer process. As a result, it is thereby possible to understand the mechanisms of technology transfer at the level of microfoundations, i.e. from the different mental models and

[254] Source: Own Figure.

[255] See definition by Barney and Felin (2013).

[256] Freeman et al. (2010).

perspectives of the different stakeholder groups.[257] By combining microfoundations[258] and stakeholder theory[259], this thesis thus represents an important contribution to the field of technology transfer. Notably, this research enables to investigate the collective perceptions and representations of stakeholder groups. Furthermore, it compares the respective findings regarding the extent to which stakeholders identify perceptions as being equally important (or unimportant). This allows to understand whether different stakeholders have a coherent view on technology transfer, which is known to be an enabling factor for successful technology transfer.[260] Moreover, this is the first study that investigates factors that influence technology transfer in a highly interdisciplinary, emerging, and promising knowledge area such as the bioeconomy.

The study revealed 11 clusters, in order of decreasing importance: *'Interdisciplinary collaborations'*, *'Support for innovation'*, *'Consumer role'*, *'Degree of novelty'*, *'Academia-industry interface'*, *'Entrepreneurship'*, *'Individual involvement'*, *'Framework conditions'*, *'Access to market'*, *'Market readiness'* and *'Perception of value creation'*. These results provide empirical support and enrich extant literature about factors affecting technology transfer.[261] In particular, the main contribution of this study lies in the bottom-up identification of *market-related factors* which are not presently mentioned in the technology transfer literature. This category of factors appears to be especially important for technology transfer in emerging knowledge areas such as the bioeconomy. In addition, the high level of relative importance assigned to *'Interdisciplinary collaborations'* reflects the crucial role that cross-disciplinary and multi-stakeholder collaborations play in the processes of technology transfer in emerging knowledge areas.[262]

This research also illustrated the differing levels of consensus on the relative importance of clusters across the stakeholder groups, being especially notorious for the cluster *'Consumer role'*. This cluster was characterised by a much higher level of average importance for

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[257] Barney and Felin (2013); Freeman et al. (2010).

[258] Barney and Felin (2013).

[259] Freeman et al. (2010).

[260] Langford et al. (2006); Rogers (2003); Santoro and Chakrabarti (2002); Siegel et al. (2004).

[261] Phan and Siegel (2006); Perkmann et al. (2013).

[262] Borge and Bröring (2017); Golembiewski et al. (2015); Maine et al. (2014); Melkers and Xiao (2012); Porter and Rafols (2009); Rogers (2003).

firms/entrepreneurs than, e.g., for academic scientists. Moreover, the clusters *'Consumer role'*, *'Interdisciplinary collaborations'*, and *'Support for innovation'* were assigned the highest average importance across all stakeholders, though these also featured the largest divergence of opinions in ratings of importance. Overall, this combination of a lack of coherence across stakeholders' perceptions and high importance ratings could reflect existing differences vis-à-vis their understanding of objectives and perceptions of technology transfer.[263] These results suggest the presence of different aggregate constructs and mental models around the topic of technology transfer by the different stakeholder groups.[264] This thesis argues that these perceptual differences presumably contribute to hinder technology transfer. For this reason, those managerial and policy implications that are able to improve technology transfer should be prioritised in exactly those clusters which feature a higher relative importance alongside lower relative coherence.

Managerial and policy implications

In light of these findings, various managerial and policy implications can be formulated in relation to the clusters rated as most important but less coherent as perceived by stakeholders. Firstly, since both interdisciplinary collaborations and collaborations between academic scientists and firms/entrepreneurs are deemed to be critical, measures to foster such collaborations should be implemented. These measures should aim at developing deeper relationships between academia and businesses by means of joint research calls and/or dual programs. This could be achieved by, e.g. establishing networks that bring scientists from different disciplines together with industry partners in order to facilitate knowledge exchange and collaborations. In this regard, the organisation of graduate courses that foster interdisciplinary studies or the implementation of funding calls that make interdisciplinary collaborations and the inclusion of industry partners mandatory to obtain funding represent possible solutions.[265]

Secondly, given that the availability of financial resources was also perceived to be of high priority, it is necessary to continue to support spin-offs and commercialisation grants. In a similar vein, funding programs for research and an emphasis on demonstration projects of

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[263] Langford et al. (2006); Rogers (2003); Santoro and Chakrabarti (2002); Siegel et al. (2004).

[264] Barney and Felin (2013); Freeman et al. (2010).

[265] Borge and Bröring (2017).

biotechnology for scale-up activities and/or new production facilities should be implemented. Finally, this work suggests a more widespread need to improve the communication to society about emerging knowledge areas in order to tackle the diminishing trust and lack of acceptance towards new technologies.

Furthermore, this approach enables to identify clusters of non-coherence across stakeholder groups- those that deserve further attention. Based on this, measures with regard to communication can be taken to make factors embedded in these clusters more explicit. As a result, different stakeholder groups can find ways to align their perceptions of technology transfer, which is known to be central to the success of technology transfer.[266] These findings can be used by technology transfer offices to enhance technology transfer in two ways: Firstly, technology transfer offices need to encourage and support mutual beneficial stakeholder relationships. Secondly, technology transfer offices need to adapt their efforts to the needs of the specific stakeholder groups.

Moreover, this method for assessment and mapping technology transfer can serve as a tool for technology transfer offices to scan the external environment for ideas about potential markets for new technologies. For instance, this participatory and bottom-up approach revealed that consumer acceptance of new technologies in the bioeconomy plays a strong role. Hence, technology transfer offices need to develop and disseminate the market-orientation, i.e. the awareness that the role of consumer/societal acceptance needs to be taken into account before investing and providing commercialisation services for new technologies in this field.

Overall, the results generated from this participatory approach can serve to guide the prioritisation of actions and strategies for fostering the success of technology transfer in emerging knowledge areas. In this line, the following broad suggestions can be outlined: (1) foster projects involving multiple disciplines, (2) continue support for commercialisation grants, (3) cultivate education and communication with society about emerging knowledge areas.

Limitations and future research

The limitations of this study are similar to those for exploratory studies, in particular sample size and generalisability. Firstly, the sample size was relatively small and a higher sample size

[266] Rogers (2003); Siegel et al. (2004).

would be advantageous. However, the reliability test (stress value) conducted showed a good fit of the data[267] within the range of stress values identified for group concept mapping studies.[268] In addition, the number of stakeholders in each step of the research process was within the adequate average number of people and within the average number reported in group concept mapping studies.[269] Nevertheless, future research could benefit by increasing the sample of stakeholders who participate in both the sorting and rating tasks.

Secondly, owing to the relatively low number of stakeholders in the study, it is difficult to make generalisations based on the findings of this chapter. However, given that the main objective of this study was to explore the perceived factors affecting technology transfer in the bioeconomy -and not, that is, to test hypotheses- these results make a crucial contribution to the development of a more microfoundational perspective in this domain. Further insights from a micro-level are needed to better contrast these findings as well as to derive implications that can enhance management practices and strategies for technology transfer.

Thirdly, academic stakeholders were selected based on their knowledge and experience in technology transfer. However, this represents a potential selection bias towards actors who are likely to be more market-oriented than the general population scientists. Therefore, the differences across stakeholders could be even greater, which demonstrates the potential gains from considering a more diverse population of stakeholders in future studies of technology transfer in emerging knowledge areas.

Finally, future studies could also consider the application of this method to other interdisciplinary and emerging knowledge areas, like bioinformatics, ICT, nanotechnology, or neurosciences.

This chapter analysed technology transfer from the point of view of the different stakeholder groups that together shape the process of technology transfer. Stakeholders emphasise the need to foster interdisciplinary research. However, little is known about how widespread interdisciplinary research in the bioeconomy is, and hence assessing interdisciplinarity remains somewhat fuzzy. Therefore, the next chapter seeks to elucidate how interdisciplinarity can be

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[267] Kane and Trochim (2007).

[268] Rosas and Kane (2012).

[269] Rosas and Kane (2012).

depicted by drawing upon patents, patent citations and their underlying technology classification. Based on this, a novel patent approach that can be used to assess interdisciplinary research at the level of technological areas is presented.

4 Evaluation of technology transfer from a technology perspective

Chapter 4 answers Research Question 4:

R.Q.4: How can the degree of interdisciplinary research be operationalised by drawing upon patent data?

This chapter is based on the following publication: Laura Borge, Michael Wustmans, Stefanie Bröring (2018): *Assessing interdisciplinarity within an emerging technology network: A novel approach based on patents in the field of bioplastics*, under review in Research Policy.

4.1 Introduction

The need for interdisciplinary research has received a lot of attention from scholars and policy-makers over the last decade. As a result, interdisciplinarity is increasingly considered to represent the major source and the basic instrument for innovation and science-based ventures .[270] It is also acclaimed for having the potential to alleviate the pressing grand challenges of the twenty-first century, e.g. climate change or increasing global population.[271] This has led to broad governmental funding initiatives aiming to promote interdisciplinary research and collaborations, specifically in fields like the bioeconomy, bioinformatics, nanotechnology, or neurosciences, all of which are regarded as emerging between two or more different knowledge fields.[272] Overall, these funding initiatives explicitly emphasise the need of collaborations across different disciplines in their funding conditions. Consequently, the promise of this type of funding has proven to be fundamental for the broader willingness to undertake interdisciplinary collaborations and technology transfer.[273]

As an example of such a highly interdisciplinary and emerging knowledge area, the case of the bioeconomy is selected. The KBBE, guided by the aim to substitute and eventually replace the fossil-based industry with bio-based materials and processes, proves to be an ideal case for interdisciplinarity. This is because, at its core, the notion of the bioeconomy is founded upon the integration of a wide spectrum of scientific disciplines and technologies, for example life sciences, agronomy, ecology, food sciences, social sciences, biotechnology, nanotechnology, ICT and engineering.[274]

Speaking to its transformative potential more generally, the bioeconomy features two of the six KETs which have been selected by the European Commission: industrial biotechnology and nanotechnology. Examples include bioplastics, biopharmaceuticals, biofuels, or biogas, applications all of which can be used in agriculture, forestry, fisheries, food and pulp and paper production, as well as parts of chemical, pharmaceutical, biotechnological and energy

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[270] Bruns (2013); Dahabieh et al. (2018); Dingler and Enkel (2016); Klein (2008); Klein and Falk-Krzesinski (2017); Whalen (2018).

[271] Biancani et al. (2018); Klein (2008); Repko and Szostak (2016).

[272] Mugabushaka et al. (2016); Rafols and Meyer (2009); Rotolo et al. (2016).

[273] Borge and Bröring (2018); Borge and Bröring (2017).

[274] European Commission (2012b); OECD (2009).

industries.[275] Accordingly, the emerging range of bioplastics is highlighted as an example of an application within the bioeconomy that is well-suited to the empirical operationalisation of the concept of interdisciplinarity. The speciality area of bioplastics was chosen given both its explicit interdisciplinary character and, as a result, the large amount of connections and interlinkages among different technological areas.[276]

Despite the growing interest in interdisciplinary research and the increasing number of policies aiming at fostering interdisciplinary research in the bioeconomy, there is however little systematic evidence about how widespread interdisciplinary research is in the bioeconomy. Hence, this also renders assessing the degree of interdisciplinarity a somewhat fuzzy proposition. Research efforts have focused on two strands of literature. The first strand frequently makes use of an approach that investigates general aspects of interdisciplinary research. It focuses, *inter alia*, on the particularities of interdisciplinary research[277], the cognitive barriers associated with interdisciplinary research[278], and the disadvantages of interdisciplinary research for peer-review evaluations.[279] The second approach meanwhile focuses on the results of research (publications) in order to assess the extent to which publications are built upon knowledge from different disciplines. This strand of literature has thus developed a set of bibliometric indicators that help to assess the interdisciplinarity of a paper or research field. Consequently, most of these studies have undertaken the co-citation analysis of journals, a method that uses citations of scientific papers occurring outside their knowledge areas.[280] However, the general topic of how best to evaluate interdisciplinary research by means of patents and patent analysis remains scarce in the existing literature. Furthermore, those previous studies using the co-citation analysis of patents[281] tend to be limited to the visualisation of technological areas in form of network maps and, crucially, without the aim to assess interdisciplinarity.

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[275] European Commission (2012b).

[276] Elvers et al. (2016).

[277] Borge and Bröring (2017).

[278] Yegros-Yegros et al. (2015).

[279] Rafols et al. (2012).

[280] Cassi et al. (2017); Leydesdorff et al. (2018); Leydesdorff and Rafols (2011); Mugabushaka et al. (2016); Porter et al. (2007); Porter and Rafols (2009); Rafols et al. (2010); Rafols and Meyer (2007).

[281] Kay et al. (2014); Yan and Luo (2017).

To close this research gap, this chapter aims at answering the following research question:

R.Q.4: How can the degree of interdisciplinary research be operationalised by drawing upon patent data?

To this end, a patent sample in the emerging domain of bioplastics is used to thereby analyse patents, patent citations, and patent classification codes as proxies for technological knowledge. As such, this chapter presents a first operationalisation of a new approach that uses patents to assess the degree of interdisciplinarity. Thus, the resulting findings provide valuable implications for a wide range of audiences: including academic scientists, firms, and policy-makers. Additionally, the set of network indicators that are calculated here demonstrate for the specific case of bioplastics how network analysis can be used to identify the central technological areas within the network and relationships among technological areas.

In addition to our primary objective of making it possible to depict and assess interdisciplinary research by drawing upon patent data, this chapter also aims at contributing more generally by providing indicators that will enable academic scientists, firms, and policy-makers to better assess the degree of interdisciplinarity within a technology network. For academic scientists and firms, this research could therefore be used to identify experts with the types of knowledge that are relevant and necessary for conducting R&D related to bioplastics. Among other things, this would help these actors to guide and orient efforts to increase their technological capabilities by facilitating better knowledge sharing and transfer across technological areas. For policy-makers, meanwhile, this research can be used to support the design and development of science and innovation policies that better foster interdisciplinary research. In light of the increasing number of governmental funding initiatives that aim to foster interdisciplinary research collaborations, especially in emerging knowledge areas, this goal is therefore becoming ever more relevant.

The remainder of this chapter is structured as follows. Section 4.2 reviews extant studies that have attempted to assess interdisciplinary research and introduces the case of bioplastics as a specific setting where interdisciplinary research is pivotal. Section 4.3 describes the methodological approach. Section 4.4 presents the major findings with respect to R.Q.4. Section 4.5 discusses the findings and concludes the study by highlighting managerial and policy implications as well as limitations and suggestions for future research.

4.2 Theoretical background: Approaches and indicators of interdisciplinary research

Interdisciplinary research can be generally defined as *"a mode of research by teams or individuals that integrates information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines or bodies of specialised knowledge or area of research practice"*.[282] Recent studies suggest closely connected concepts for interdisciplinary research and collaborations, such as "multidisciplinary" (defined as collaboration with a low degree of integration across disciplines or knowledge)[283], or "transdisciplinary" (defined as collaboration between not only disciplines but also integrating non-scientific stakeholders).[284] In what follows, the term interdisciplinary from a technological innovation perspective is used. This is defined as the combination of knowledge from two or more technological areas.[285]

4.2.1 Assessment of interdisciplinary research

A) Analyses based on publications

Publication methods have been predominately applied for the assessment of interdisciplinary research. These methods have used diverse approaches as discussed in Porter et al. (2007). Common approaches have been co-authorship analysis[286], a method that employs departmental/institutional affiliation of authors, or co-classification analysis, a method that classifies publications and journals into categories reflecting disciplines.[287] Additionally, semantic analysis to identify topics across publications, have also been employed.[288] The more recent approaches to assess interdisciplinarity use co-citation analysis, a method that uses citations of publications outside their knowledge areas as an indicator for interdisciplinarity. Co-citations analyses were found to capture the interdisciplinary knowledge more accurately than co-authorship analysis or co-classification analysis.[289]

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[282] Porter et al. (2006, p. 189).

[283] Klein (2008).

[284] Klein (2008).

[285] Su and Moaniba (2017).

[286] Bordons et al. (1999); Porter et al. (2007).

[287] Morooka et al. (2014); Pilar Lagar-Barbosa et al. (2014)

[288] Leydesdorff et al. (2018); Nichols (2014); Whalen (2018); Xu et al. (2016).

[289] Porter et al. (2007); Rafols and Meyer (2007).

Most studies have combined co-citation analysis of publications with additional indicators. For instance, network indicators (e.g. betweenness centrality) were used as a typology to assess interdisciplinarity.[290] Morillo et al. (2001) described relationships among knowledge areas according to the quantity of their links (number of related categories) and their quality (with close or distant categories, diversity, and strength of links) by using co-authorship and co-citations analyses. The Shannon entropy and the Simpson index, indices that reflect the distribution of the cited references in different knowledge areas, were used by several authors as indicators for interdisciplinarity.[291] Porter et al. (2007) developed an integration indicator based on publications that accounts not only for the distribution of the cited references in different knowledge areas but also for the degree to which those knowledge areas are closely related. Porter and Rafols (2009) used several indicators, e.g. variation, integration index, citations within subject category to show how the degree of interdisciplinarity has changed from 1995 to 2005; their research covered six research domains, including long established disciplines and emerging ones (biotechnology; engineering, electrical and electronic; mathematics; medicine; neurosciences; physics).

Furthermore, Rafols and Meyer (2010) built upon Porter et al. (2007) and Stirling (2007) to develop a new set of indicators to assess interdisciplinary research: diversity (it captures disciplinary heterogeneity of the set of knowledge areas), and coherence (it measures similarity between knowledge areas). Moreover, Cassi et al. (2017) or Solomon et al. (2016) used the Rao-Stirling index, a diversity measure that is computed as the relative share of references citing two different knowledge areas and the degree of relatedness between these two knowledge areas, respectively. The Leinster-Cobbold index, as employed by Mugabushaka et al. (2016), is a diversity index similar to Shannon or Simpson indices that also includes a sensitivity parameter (from 0 to infinity) that controls 'the relative emphasise that the user wishes to place on common and rare elements'. [292]

B) Analyses based on patents

Fewer studies have employed patent data to examine interdisciplinary research between technological areas. Studies have used co-classification analysis from International Patent

[290] Leydesdorff et al. (2018); Leydesdorff and Rafols (2011).

[291] Adams et al. (2007); Barjak (2006); Rafols and Meyer (2009); Wang et al. (2017).

[292] Mugabushaka et al. (2016, p. 600).

Classification (IPC) codes[293] of a patent or co-citation analysis from a patent. Co-classification analysis, a method that categorises patents in IPC codes, were used to map technology distance.[294] Additionally, co-citations of patents were applied to map technological areas and distance among these and to locate the relative technological position of an organisation's patent activity[295] or to identify boundary spanning inventions.[296]

Against this backdrop, the topic of evaluation of interdisciplinary research using patents remains rather unexplored in the existing literature. Furthermore, previous studies are limited to the visualisation of technological areas in form of network maps and thus, lack the implementation of indicators that can help identify relationships among technological areas and assess the degree of interdisciplinarity of these. Consequently, this chapter attempts to depict and assess interdisciplinary research in the highly interdisciplinary and emerging field of bioplastics by building upon co-citations and classifications of patents.

4.2.2 Interdisciplinary research: The case of bioplastics

The specific case of bioplastics was chosen for the empirical operationalisation of interdisciplinary indicators since it presents an area consisting of multiple disciplines like Chemistry, Biology and Materials Science.[297] Most commonly bioplastics are defined as plastics derived completely or partially from biomass.[298] The term bioplastics covers three groups of materials. The first and largest group are bio-based or partly bio-based, but not biodegradable materials.[299] The second group is bio-based and biodegradable. The third group is fossil-based but still biodegradable.[300] In the analysis, the focus is exclusively on the three bio-based and biodegradable polymer products (group 2) which show the fastest rates of market

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[293] IPC is a hierarchical system of codes established by World Intellectual Property Organization (WIPO) that matches patents with categories. The IPC structures patents into eight different sections: i.e. from A to H, followed by a sub-structuring into classes, subclasses, groups and sub-groups, ultimately leading to>70,000 different IPC codes.

[294] Aharonson and Schilling (2016); Krafft et al. (2011).

[295] Kay et al. (2014); Yan and Luo (2017).

[296] Whalen (2018).

[297] Elvers et al. (2016); Pilla (2011).

[298] European Bioplastics [www.european-bioplastics.org].

[299] Biodegradable plastics refer to plastics that break down into natural compounds by using the action of microorganisms available on the environment.

[300] European Bioplastics [www.european-bioplastics.org].

growth and have the largest impact on the market.[301] These are polylactic acid (PLA), polyhydroxyalkanoates (PHAs) and polybutylene succinate (PBS).

The diversity of disciplines required for the development and production of bioplastics is also reflected in a wide range of sectoral application areas, i.e. packaging, horticulture and agriculture, medicine and personal care, consumer electronics, automobile and manufacture, textiles, construction and housing.[302] Specifically, PLA is used in several applications such as textile fibres, rigid packaging, and medicine (fibre, implants).[303] PHAs are found in application areas like packaging, moulded products, films, foam and fibre.[304] PBS is used for e.g. film, packaging, foaming or flushable hygienic applications.[305]

Due to the shrinking supply of crude oil and the growing concern of consumers for sustainability, bioplastics are becoming a potential alternative to classical fossil-based plastics, which have recently attracted increasing attention in government policy and industry. Evidence for this are the European Strategy for plastics in a circular economy, which aims at making plastic packaging recyclable by 2030[306]; or the recently proposed European directive aimed at banning single-use plastics.[307]

In fact, bioplastics represent the fastest growing product line in the bio-based products industry.[308] Additionally, the bio-based share is growing at a faster rate than the global plastic market.[309] According to a market study, the worldwide production of bioplastics amounted to 5,2 million tonnes in 2013 corresponding to about 2% of the total plastic market.[310] Until the year 2020, this market study forecasts a triplication of bio-based production to nearly 17 million

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301 Aeschelmann and Carus (2015).

302 European Bioplastics [www.european-bioplastics.org].

303 Elvers et al. (2016).

304 Babu et al. (2013).

305 Babu et al. (2013).

306 European Commission (2018a).

307 European Commission (2018b).

308 Carus et al. (2000); Philp (2014).

309 Aeschelmann and Carus (2015).

310 Aeschelmann and Carus (2015).

tonnes, equivalent to approximately 4.25% of the total plastic market production of 400 million tonnes.[311]

4.3 Materials and methods

This study draws upon patent data to enable stakeholders (academic scientists, firms and policy-makers) to assess and monitor interdisciplinary research. Patents are a reliable source for mapping technology knowledge flows[312], monitoring the emergence of new technological areas[313], or analysing interdisciplinarity and technological distance.[314] Moreover, patent data is regarded as an important indicator to reflect the ability to transfer research results into technological applications.[315] As such, patents are a useful tool for operationalising interdisciplinarity in emerging technologies such as bioplastics.

One advantage of using patents as proxies for technology knowledge flows is their standardised data structure as well as their accessible information over long time periods.[316] We focus on the IPC, however, the IPC has limitations as in some cases a technology may not match a real product or service.[317] In order to better show the technological competence to produce a certain product or service, Schmoch (2008) developed the IPC-Technology Concordance Table, which matches IPC codes (on subclass level) with technological areas.

This study uses the IPC-Technology Concordance Table version 2018. It is divided into five major sectors including Electrical engineering, Instruments, Chemistry, Mechanical engineering, and Other fields. These sectors are subdivided into 35 different technological areas based on IPC codes (on subclass level). For example, the IPC subclass C12Q corresponds to the technological area of Biotechnology. In the following, the data collection and analysis steps are explained in detail according to how they were used in the analysis on bioplastic patents.

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311 Aeschelmann and Carus (2015).

312 Alcacer and Gittelman (2006); Jaffe and Trajtenberg (2002).

313 Berg et al. (2018); Curran et al. (2010); Goeldner et al. (2015).

314 Aharonson and Schilling (2016); Gilsing et al. (2011).

315 Bozeman (2000); Phan and Siegel (2006).

316 Hall (2007).

317 Schmoch (2008).

4.3.1 Data collection and categorisation

The data collection process, as depicted in **Table 4-1**, consisted of extracting the patent sample and the cited patent sample.

Table 4-1: Representation of the data collection and categorisation steps.[318]

I. Patent sample		**II. Cited patent sample**	
1 Sample creation	**2 Sub-sample creation**	**3 Sample creation of cited patents**	**4 Sub-sample creation of cited patents**
Extracting patent sample representative for the field of bioplastics N = 890 patent families from 1995 to 2015	Matching IPC codes of patents with technological areas (based on IPC-Technology Concordance Table) N_{IPC} = 1,705 IPC codes distributed into 29 technological areas	Extracting patents cited by the patent sample N = 8,979 cited patents	Matching IPC codes of cited patents with technological areas (based on IPC-Technology Concordance Table) N_{IPC} = 23,160 IPC codes distributed into 32 technological areas

4.3.1.1 Extraction of the patent sample

In the first step, an overall patent sample was generated. This patent sample has to be representative of the technological field under analysis, i.e. bioplastics. As in previous studies, keywords based on technology names of the field under investigation were selected.[319] This task was carried out in an iterative process whereby different keywords and queries were tested by collecting information from patent databases and validating the results with an expert. Accordingly, patents containing bio-based and biodegradable bioplastics-related keywords in titles, abstracts or claims were searched and extracted using the Derwent Innovation patent database.

In our search, only bio-based and biodegradable bioplastics were covered as these are regarded as one of the technologies driving the innovation and current market growth because they provide an additional end of life option.[320] As such, the search string[321] included the following

[318] Source: Own Table.

[319] Bornkessel et al. (2016); Preschitschek et al. (2013).

[320] Elvers et al. (2016).

[321] CTB=((bioplastic* OR biopolymer* OR bio-plastic* OR bio-polymer* OR biobased ADJ plastic* OR biobased ADJ polymer* OR bio-based ADJ plastic* OR bio-based ADJ polymer*) AND (poly ADJ (lactic ADJ acid) OR polylactic ADJ acid OR polylactide OR polyhydroxyalkanoate* OR poly ADJ (butylenesuccinate) OR polybutylene ADJ succinate)) AND DP>=(19950101) AND DP<=(20151231).

bio-based and biodegradable polymers: PLA, PHAs, PBS. Thereby, biodegradable but fossil-based bioplastics (e.g. polycaprolacton (PCL), polybutylene adipate-co-terephthalate (PBAT)) were excluded in the search. The sample was limited by the publication data and the time frame between 1995 and 2015 was selected. We looked from 1995 since it represents the time where the market and economic importance of bioplastics started to grow.[322] This search resulted in 890 INPADOC patent families.

In the second step, the IPC codes of each patent in the sample were translated into technological areas based on the IPC-Technology Concordance Table.[323] Technological areas were used as unit of analysis, following many other authors that have considered IPC codes the most suitable representation of technological areas.[324] In total, 1,705 IPC codes (on IPC subclass level) distributed into 29 technological areas were obtained in the patent sample.

4.3.1.2 Extraction of the cited patent sample

In the third step, the focus of the analysis was on the backward citations of the patent sample. Backward citations are previous patents (references) on which the new invention is based upon. Backward citations allow to trace back the origin of ideas and identify what ideas are based upon, e.g. if a patent builds on a particular technological area or builds upon the combination of knowledge from two or more technological areas (interdisciplinarity).[325] Hence, the patent applications cited by the patent sample were extracted from the Derwent Innovation patent database. This search resulted in 8,979 patent applications.

In the fourth step, the IPC codes of each cited patent were translated into technological areas based on the IPC-Technology Concordance Table[326] following the same process carried out in the second step. In total, 23,160 IPC codes (on IPC subclass level) distributed into 32 technological areas were obtained.

[322] Queiroz and Collares-Queiroz (2009).

[323] Schmoch (2008).

[324] Kay et al. (2014); Leydesdorff et al. (2014); Nemet and Johnson (2012).

[325] Su and Moaniba (2017).

[326] Schmoch (2008).

4.3.2 Data analysis

The data analysis process, as depicted in **Table 4-2**, followed three main steps: (1) the generation of the matrices, (2) the calculation of indicators based on the matrices, (3) the computation of different visualisations to show interdisciplinary dynamics and relationships among technological areas.

Table 4-2: Representation of the data analysis steps.[327]

I. Matrix generation	II. Calculation of indicators based on matrices		III. Visusalisations
	2.1 Indicators based on citations sent	2.2 Indicators based on citations received	
Generating matrices across time periods. The number in each cell of the matrix is the frequency of citations	Developing and calculating novel interdisciplinary indicators	Calculating centrality indicators to identify central technological areas as well as bridging technological areas within the network	Generating interdisciplinary portfolio Generating network maps that shows relationships among technological areas

4.3.2.1 Matrix generation

In the first step, the matrices were generated following two steps. First, all of the patents were classified into five time periods according to their application year: below 2000, 2001-2005, 2006-2010, 2011-2015, and below 2000-2015. Second, five citing-to-cited matrices corresponding to the five time periods were computed. A depiction of the process of constructing the matrices taking the example of one patent is shown in **Figure 4-1**. For example, $patent_1$ includes two IPC codes classified in two different technological areas, and it cites a patent (Cited $patent_1$) that includes two IPC codes classified in two different technological areas. Each row and column in the matrix represents a technological area. The number in each cell of the matrix indicates how often each technological area in the patent sample cites each technological area in the sample of cited patents. For example, a 1 is placed in a cell of the matrix as TA_1 cites TA_1 and TA_3, however, we place a 0 as TA_1 does not cite TA_2.

Therefore, these matrices represent relationships among technological areas, with 32 rows and columns corresponding to the total number of technological areas extracted from the sample of

[327] Source: Own Table.

cited patents. A higher value in a cell indicates that this pair of technological areas is highly cited, implying that patents rely on knowledge from those technological areas.

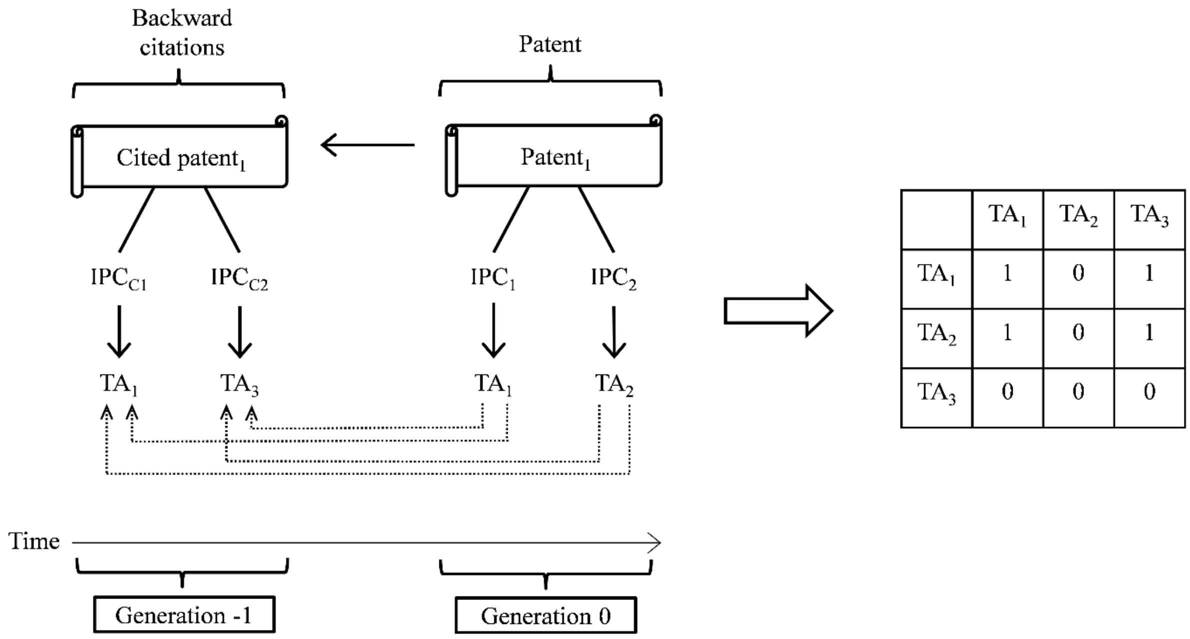

Figure 4-1: Schema for patent citations showing how the matrices are constructed taking the example of one patent.[328]

Note: Dotted arrows indicate where the technological knowledge is originating from.

4.3.2.2 Calculation of indicators based on matrices

In the second step, with the aim of identifying the most interdisciplinary technological areas as well as the most important technological areas, a series of indicators explained below (see **Table 4-3**) were calculated. Moreover, in order to assess and operationalise interdisciplinarity of a technological area, three novel patent indicators are introduced: *Total interdisciplinarity technological area*, *total interdisciplinarity sector*, and *total interdisciplinarity index*. This indicator takes into account (1) number of citations of a technological area stemming from the own technological area (self-citations), (2) number of citations of a technological area stemming from outside the own technological area, and (3) the number of sectors cited (referring to technological diversity following Rafols and Meyer (2007, 2010)).

The *total interdisciplinarity technological area* measures the self-citations relative to the total number of citations. According to this, a higher number of self-citations over the total number

[328] Source: Own Table.

of citations point to less interdisciplinary technological areas. The total interdisciplinarity technological area is defined as follows:

$$I_{(i)} = 1 - \left[\frac{Cs_i}{\sum_i C}\right]$$

where i is the focal technological area, Cs_i is the number of backward citations of the focal technological area stemming from the own technological area and C is the sum of backward citations the focal technological area draws upon. The ratio is subtracted from one (1), so that the closer the value of $I_{(i)}$ is to 1, the more interdisciplinary the focal technological area i is.

The *total interdisciplinarity sector* is calculated as the ratio of the different sectors that a technological area draws upon to five (5), corresponding to the total number of sectors following the IPC-Technology Concordance Table. The total interdisciplinarity sector is defined as follows:

$$Is_{(i)} = \left[\frac{ns_i}{5}\right]$$

where i is the focal technological area, and ns_i is the number of sectors that the focal technological area draws upon. The closer the value of $Is_{(i)}$ is to 1, the higher the number of sectors a technological area draws upon, and thus the more interdisciplinary the focal technological area i is.

In the final step, the total interdisciplinarity technological area is multiplied by the total interdisciplinary sector, yielding the *total interdisciplinarity index* ($TI_{(i)}$).

$$TI_{(i)} = I_{(i)} \text{ x } Is_{(i)}$$

In order to assess the degree of interdisciplinarity of a technological area i, two interdisciplinarity scales are presented in **Figure 4-2** and **Figure 4-3**. **Figure 4-2** shows the interdisciplinarity scale by technological area and **Figure 4-3** displays the interdisciplinarity scale by sector.

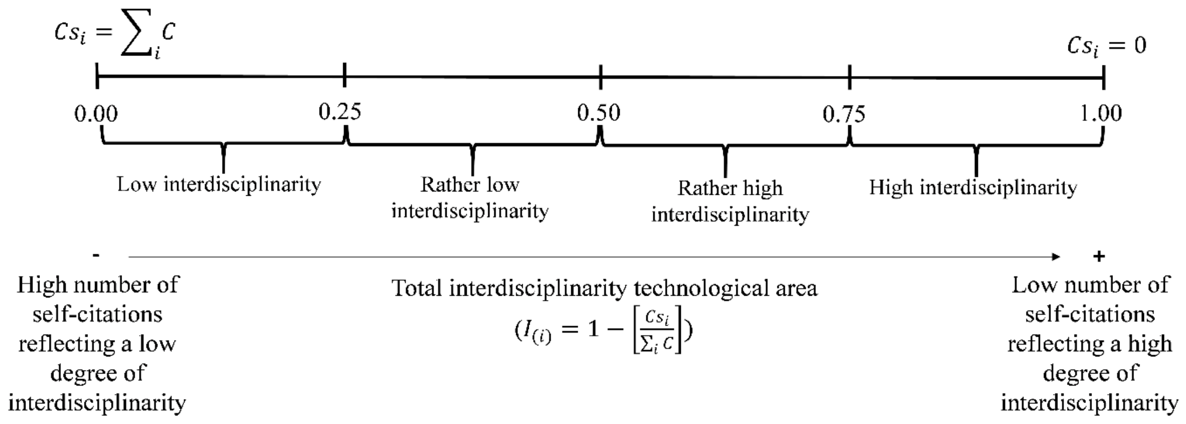

Figure 4-2: Interdisciplinary scale by technological area. [329]

Note: The closer the value of total interdisciplinarity technological area ($I_{(i)}$) *is to 1.00, the more interdisciplinary the technological area is.*

The interdisciplinary scale in **Figure 4-2** is based on the value obtained from the *total interdisciplinarity technological area,* thus it ranges from 0.00 to 1.00. A 0.00 would indicate that the number of self-citations equals the total number of citations, pointing to technological areas with a low degree of interdisciplinarity. Increasing values (closer to 1.00) reflect a high degree of interdisciplinarity. Thus, a 1.00 indicates the point where a technological area does not draw upon citations from the own technological area but it only draws upon citations from other technological areas, pointing to technological areas with a high degree of interdisciplinarity. The scale is divided at its mean ($I_{(i)} = 0.50$), the point where $Cs_i = \frac{\sum_i C}{2}$.

Further, the scale is divided into four intervals indicating four degrees of interdisciplinarity: (1) low interdisciplinarity ($I_{(i)} = [0.00 - 0.25]$), (2) rather low interdisciplinarity ($I_{(i)} = [0.25 - 0.50]$), (3) rather high interdisciplinarity ($I_{(i)} = [0.50 - 0.75]$), (4) high interdisciplinarity ($I_{(i)} = [0.75 - 1.00]$). Overall, a lower value of the *total interdisciplinarity technological area* (i.e. close to 0.00) suggests a lower degree of interdisciplinarity of a technological area. The closer the value of the *total interdisciplinarity technological area* is to 1.00, the more interdisciplinary a technological area is.

[329] Source: Own Figure.

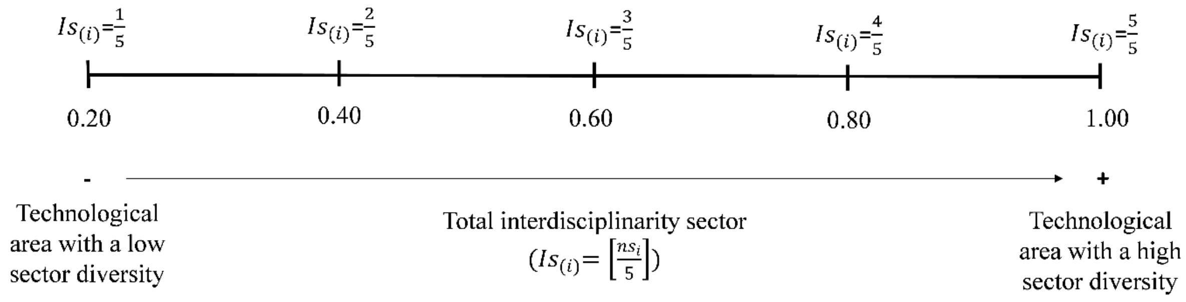

Figure 4-3: Interdisciplinary scale by sector.[330]

Note: The closer the value of total interdisciplinarity sector ($Is_{(i)}$) *is to 1.00, the more sectors are cited and thus, the technological area has a high sector diversity (high interdisciplinarity).*

The interdisciplinary scale in **Figure 4-3** is based on the value obtained from the *total interdisciplinarity sector*. It ranges from 0.20 to 1.00 depending on the number of sectors that a technological area draws upon, i.e. if a technological area draws upon one sector, $Is_{(i)} = 0.20$; if a technological area draws upon two sectors, $Is_{(i)} = 0.40$; $Is_{(i)} = 0.60$ corresponds to three sectors; $Is_{(i)} = 0.80$ corresponds to four sectors; and when a technological area draws upon all of the sectors (max.5) a 1.00 is reached. Thus, a lower value of the *total interdisciplinarity sector* (i.e close to 0.20) suggests low sector diversity. Contrary, a high value of the *total interdisciplinarity sector* (i.e close to 1.00) indicates a high sector diversity.

Furthermore, network analysis indicators were employed to determine the central technological areas within the network. A typical indicator to assess the relative importance of a node is its centrality, which is subdivided into degree centrality, closeness centrality, and betweenness centrality. The degree, closeness or betweenness centrality of a node represent its overall influence on the other nodes[331] but they differ in their definitions and interpretations.[332] To calculate closeness centrality, it is necessary for the technology network maps to be fully connected graphs, i.e. when there is a path from each node to every other node. Therefore, this research only uses degree centrality and betweenness centrality to identify the most important nodes.

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[330] Source: Own Figure.

[331] Lee et al. (2009); Yang et al. (2010); Yang and Heo (2014); Yoon et al. (2014).

[332] Borgatti et al. (2002).

The *degree centrality* of a technological area explains the extent to which a technological area may be integrated in the network and it is defined as follows:

$$Dc_{(i)} = \frac{\sum_{j=1}^{n} a_{ij}}{n-1}$$

where i is the focal technological area, j is another technological area in the network and a_{ij} is the sum of all lines that the focal technological area receives. The numerator is divided by the maximum number of technological areas (n) in the network minus one (1). If a technological area in a technology network has a high degree centrality value, it has a strong power or prestige in the network[333] and, can therefore be considered as a central technological area.

The *betweenness centrality* of a technological area measures the extent to which a technological area lies between the other technological areas in the network. It reflects the technological area's influence as a communication channel between the other technological areas in a network[334] and it is regarded as the extent to which a technological area serves as a bridge.[335] Betweenness centrality is calculated as the shortest paths that contain the node, among all the shortest paths between each pair of the other technological areas in the network and is defined as follows:

$$Bc_{(i)} = \sum_{s \neq t \neq i \epsilon V} \frac{\sigma_{st}(i)}{\sigma_{st}}$$

where i is the focal technological area, V is the set of all technological areas in the network, $\sigma_{st}(i)$ is the total number of shortest paths between technological area s and t that pass through i and σ_{st} is the total number of shortest paths between s and t. A technological area with a high betweenness centrality value has a strong possibility of acting as a bridge in transferring technological knowledge within the network.[336]

[333] Borgatti et al. (2002).

[334] Yoon et al. (2014).

[335] Tseng et al. (2016).

[336] Leydesdorff (2007); Yoon et al. (2014).

Table 4-3: List of indicators used.[337]

Indicator		Description	Interpretation
Based on patent sample	$\boldsymbol{I_{(i)}}$ **(Total interdisciplinarity technological area)**	It measures the number of self-citations a technological area draws upon relative to the total number of citations	A high degree of interdisciplinarity technological area would imply that technological areas build upon technological knowledge from different technological areas.
	$\boldsymbol{Is_{(i)}}$ **(Total interdisciplinarity sector)**	It measures the diversity of sectors involved in the citations a technological area draws upon	A high degree of interdisciplinarity sector would imply that technological areas build upon technological knowledge from different sectors.
	$\boldsymbol{TI_{(i)}}$ **(Total interdisciplinarity index)**	It combines the total interdisciplinary technological area and the total interdisciplinary sector	A high interdisciplinarity index would imply that technological areas build upon technological knowledge from different technological areas and from different sectors.
Based on patent sample and cited patent sample	$\boldsymbol{Dc_{(i)}}$ **(Degree centrality)**	It measures the number of citations a technological area receives	Central technological area: A high degree centrality would imply that technological areas have more power within the network.
	$\boldsymbol{Bc_{(i)}}$ **(Betweenness centrality)**	It measures the capacity of a technological area to serve as a bridge within a network	Bridging technological area: A high betweenness centrality would imply that technological areas are considered to act as ‘bridges’ and thus, have potential to coordinate relations to other technological areas within the network.

4.3.2.3 Visualisation

In the third step, to answer R.Q.4 and further assess the data, different visualisations were computed. Firstly, a *scatter chart* was created to show the evolution of interdisciplinarity by technological areas across time periods: below 2000, 2001-2005, 2006-2010, 2011-2015, and below 2000-2015. Secondly, technological areas and relationships among technological areas involved in the innovative activity in the field of bioplastics were visualised by means of *network analysis*. In doing so, the aggregated matrices constituted the input for the computation of network maps using UCINET 6.[338] These visualisations are based on citing-to-cited relationships among the technological areas derived from the IPC codes of the patent samples. Technological areas are the unit of analysis and are presented as nodes, which are connected by

[337] Source: Own Table.

[338] Borgatti et al. (2002).

lines on the map. The lines represent the citation relationship, which represent that a technological area is related to another technological area. The network of relationships indicates the internal knowledge structure of the technology field under examination, i.e. bioplastics. Therefore, the most connected nodes are on the centre of the map and the least connected nodes are located on the periphery.

4.4 Results

4.4.1 Descriptive analysis

Firstly, selected descriptive analyses regarding the whole patent sample are conducted. **Figure 4-4** displays the evolution over time of bioplastic patents. For this research, keywords were limited to PLA, PHAs, and PBS. This timeline demonstrates that the innovative activity in the field has progressively increased until 2014. A similar trend is found in Elvers et al. (2016), who delineated the research landscape and development trends of some biodegradable plastics (PLA, PHAs, PBS, PCL and PBAT).

Specifically, three distinct phases of innovative activity can be distinguished. A first phase from 1995 to 2000 where the number of patent families were below 10 per year. A second phase between 2001 and 2010 in which the patenting increased. A third phase from 2011 to 2015, where the patenting activity rose significantly exceeding 80 filed patents per year. However, from 2014 the number starts decreasing again which might be due to the fact that it takes considerable time until a patent is granted by a national patent office and then counted as a "member" of a family. Next, the focus was on the average number of IPC subclasses in which each patent was classified in the patent sample. Overall, the average number of IPC codes of patents slightly decreased during the period of analysis. In 2001, on average a patent was assigned to 2.64 IPC codes, whereas in 2015 a patent was classified into 1.84 IPC codes. This finding confirms earlier research depicting a decrease of IPC codes as a result of emerging dominant design.[339]

[339] Berg et al. (2018).

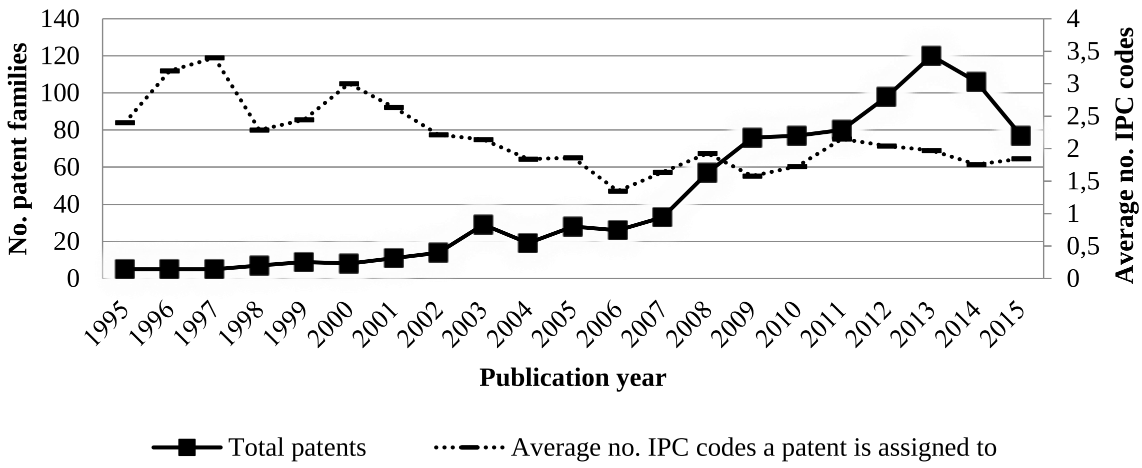
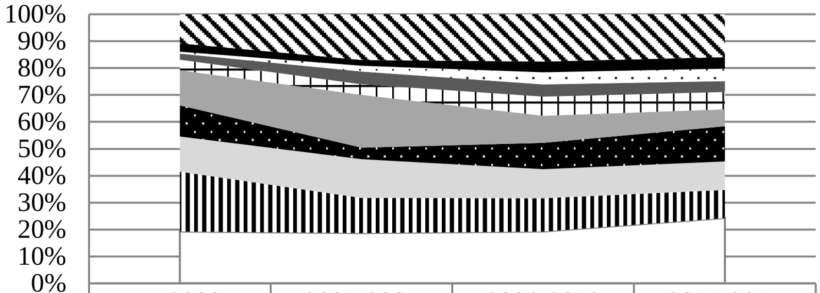


Figure 4-4: Evolution over time of patents on bioplastics and average number of IPC codes.[340]

Figure 4-5 shows the distribution of patents on bioplastics among the top ten technological areas (as reflected by the IPC Technology Concordance Table). Accordingly, the technology network in the field is associated with the following technological areas: ‘Macromolecular chemistry, polymers’, ‘Biotechnology’, ‘Organic fine chemistry’, ‘Other special machines’, ‘Medical technology’, ‘Surface technology, coating’, ‘Basic materials chemistry’, ‘Textile and paper machines’, ‘Handling’, and ‘Other’. The category “other” summarises all those technological areas that were not among the top applied technological areas.

There is a decrease over time in the IPC codes classified in the technological areas of ‘Biotechnology’, ‘Organic fine chemistry’, ‘Medical technology’, ‘Surface technology, coating’ and ‘Basic materials chemistry’. Contrary, the number of IPC codes in the technological areas of ‘Macromolecular chemistry, polymers’ or ‘Other special machines’, has increased over the last decade. This may indicate that bioplastics initially focused on basic research covering a broad spectrum of application fields and that over time the focus has shifted towards manufacturing. The number of IPC codes classified as “Other” has increased after 2000 and has remained relatively stable after 2001. This might imply that new technological inventions associated with bioplastics were classified into IPC codes corresponding to a diverse range of technological areas.

[340] Source: Own Figure.



	<=2000	2001-2005	2006-2010	2011-2015
Other	10,8%	17,0%	17,6%	16,0%
Handling	3,1%	2,2%	4,0%	4,3%
Textile and paper machines	0,8%	2,2%	4,5%	4,5%
Basic materials chemistry	2,3%	4,8%	4,5%	4,0%
Surface technology, coating	3,8%	3,9%	7,1%	6,5%
Medical technology	13,1%	19,6%	10,1%	6,2%
Other special machines	11,5%	4,3%	9,7%	13,1%
Organic fine chemistry	13,1%	14,3%	10,8%	10,6%
Biotechnology	22,3%	13,0%	12,3%	10,4%
Macromolecular chemistry, polymers	19,2%	18,7%	19,3%	24,3%

Figure 4-5: Distribution over time of patents on bioplastics among technological areas.[341]

4.4.2 Matrix

Results from the exploratory data analysis point to a wide variety of technological areas involved in the technology network of bioplastics. The technological areas shown in **Table 4-4** indicate how often technological areas (in the patent sample) cite technological areas in their references (backward citations). The patents in the cited patent sample are categorised into 32 technological areas. These are the 29 technological areas that appeared in the patent sample along with the following technological areas: 'Computer technology', 'Engines, pumps, turbines', 'Information Technology (IT) methods for management'. This is a 32*32 matrix, corresponding to 32 technological areas present in the sample of cited patents. The diagonal indicates the number of self-citations. For example, 'Macromolecular chemistry, polymers' cites itself 2223 times and it cites e.g. 'Pharmaceuticals' 18 times over the entire time frame. 'Biotechnology' cites itself 2037 and it cites 'Pharmaceuticals' 77 times over the entire time frame.

[341] Source: Own Figure.

Table 4-4: Number of citations between technological areas by sectors over the whole time period.[342]

	Sector	Technological area	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)	(28)	(29)	(30)	(31)	(32)
Technological areas in patent sample (890 patents and 1705 IPC codes)	Chemistry	Basic materials chemistry (1)	1107	64	86	8	7	455	100	3	255	21	79	12	0	40	0	10	0	0	12	83	7	4	21	27	4	161	149	1	13	461	13	13
		Biotechnology (2)	361	2037	203	43	387	316	16	4	644	77	44	10	16	11	4	0	1	7	64	363	13	7	33	20	2	165	294	3	2	0	3	24
		Chemical engineering (3)	56	33	86	12	19	155	27	4	37	4	213	3	0	11	0	5	0	3	12	25	12	0	72	18	0	159	51	2	3	2	0	7
		Environmental technology (4)	4	12	14	40	4	3	0	0	3	0	1	1	0	0	0	0	0	0	0	2	2	0	2	1	1	6	0	0	0	1	0	0
		Food chemistry (5)	14	23	32	3	118	71	17	0	39	4	22	0	0	0	0	0	0	0	2	7	0	0	16	6	0	71	10	0	0	8	0	0
		Macromolecular chemistry, polymers (6)	308	141	315	4	42	2223	210	7	239	18	544	15	10	34	1	4	0	4	7	280	36	1	241	71	8	1342	321	2	17	155	17	30
		Materials, metallurgy (7)	3	9	32	5	0	14	28	2	19	1	16	0	0	3	0	3	0	2	11	9	6	0	0	1	2	9	7	2	0	0	0	2
		Micro-structural and nano-technology (8)	5	2	1	0	0	25	8	1	6	1	4	1	0	2	0	1	0	0	0	3	2	0	1	0	0	9	4	0	0	0	0	0
		Organic fine chemistry (9)	105	164	109	2	54	297	66	22	668	128	47	10	27	15	10	19	4	3	51	748	15	6	14	63	6	96	54	31	9	9	2	19
		Pharmaceuticals (10)	14	55	14	0	2	28	0	1	173	56	1	0	2	2	1	1	0	0	9	212	2	0	2	2	0	5	0	0	0	0	0	2
		Surface technology, coating (11)	246	135	176	8	44	1382	112	7	100	24	1396	53	18	46	1	28	5	6	19	418	31	0	440	78	17	1282	387	8	43	131	32	61
	Electrical engineering	Audio-visual technology (12)	6	0	0	0	0	8	0	0	0	0	0	1	1	0	0	0	0	0	0	4	0	0	6	0	1	3	2	0	0	0	0	1
		Computer technology (13)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Electrical machinery, apparatus, energy (14)	20	1	6	1	0	30	21	0	2	0	3	0	0	36	0	0	0	0	6	1	5	0	2	0	5	7	13	8	0	0	0	3
		IT methods for management (15)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Semiconductors (16)	18	60	9	2	4	41	17	52	38	8	67	88	36	40	0	262	5	2	45	155	144	1	9	4	0	56	72	4	2	0	0	8
		Telecommunications (17)	0	0	0	0	0	2	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Instruments	Control (18)	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
		Measurement (19)	6	29	2	0	0	9	1	2	24	4	5	1	3	8	0	5	1	2	54	16	3	0	0	0	0	9	4	0	7	0	0	2
		Medical technology (20)	175	286	136	3	12	615	26	11	664	116	132	32	58	49	10	38	55	33	255	3109	37	10	36	25	25	258	224	1	8	6	87	85
		Optics (21)	7	0	14	2	5	60	3	4	2	0	12	1	0	2	0	0	0	1	2	4	67	0	0	6	0	33	4	0	2	0	0	2

[342] Source: Own Table.

Mechanical engineering	Engines, pumps, turbines (22)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Handling (23)	45	2	23	5	18	207	10	0	11	0	134	10	4	20	1	1	1	1	4	34	10	2	279	11	4	235	113	2	5	6	30	69
	Machine tools (24)	7	1	0	1	0	1	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	3	5	0	1	2	0	0	0	0	0
	Mechanical elements (25)	1	0	0	0	0	3	4	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	6	9	5	2	0	6	0	0
	Other special machines (26)	163	64	88	6	24	900	44	6	90	4	425	20	7	32	1	6	1	3	14	121	20	5	188	34	20	903	175	13	53	79	38	28
	Textile and paper machines (27)	40	21	18	4	2	206	2	0	75	6	50	1	0	14	0	0	1	0	7	140	1	3	25	1	3	87	302	0	2	7	7	21
	Thermal processes and apparatus (28)	1	0	0	0	0	3	4	0	0	0	0	0	0	1	0	3	0	0	1	0	0	3	0	0	6	22	5	12	2	5	1	1
	Transport (29)	18	0	6	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	2	0	2	6	0	1	23	0	0	0
Other fields	Civil engineering (30)	9	0	2	0	0	1	4	0	0	0	3	1	1	0	0	0	0	0	0	0	0	0	0	1	6	7	0	0	0	51	0	0
	Furniture, games (31)	2	0	20	1	28	30	2	0	1	1	21	2	0	8	0	0	0	1	5	9	27	4	163	7	2	86	23	3	4	2	193	9
	Other consumer goods (32)	7	0	6	0	1	21	2	0	5	2	13	11	3	5	0	0	2	4	1	5	2	2	31	1	9	11	15	6	3	1	19	103

4.4.3 Indicators based on matrices

4.4.3.1 Characterisation of the most interdisciplinary technological areas within the network

This section seeks to depict and assess the degree of interdisciplinarity behind the technological knowledge of the patent sample. In order to determine the degree of interdisciplinarity that each technological area related to bioplastics has on the overall network, the interdisciplinary indicators defined in 4.3.2.2 were developed and calculated. The technological areas shown in **Table 4-5** indicate the *Total interdisciplinarity technological area*, the *Total interdisciplinarity sector* and the *Total interdisciplinarity index* classified by sectors within the technology network of bioplastics across time periods: below 2000, 2001-2005, 2006-2010, 2011-2015 and all years.

Table 4-5: Total interdisciplinarity technological area ($I_{(i)}$), total interdisciplinarity sector ($Is_{(i)}$) and total interdisciplinarity index ($TI_{(i)}$).[343]

Note: Grey marked values indicate the top ten interdisciplinarity technological areas based on the total interdisciplinarity technological area and the total interdisciplinarity sector in the particular time frame. Bold values represent the technological areas that have become more interdisciplinary over time.

[343] Source: Own Table.

Sector	Technology area	<=2000			2001-2005			2006-2010			2011-2015			All years		
		$I_{(i)}$	$Is_{(i)}$	$TI_{(i)}$	$I_{(i)}$	$Is_{(i)}$	$TI_{(i)}$	$I_{(i)}$	$Is_{(i)}$	$TI_{(i)}$	$I_{(i)}$	$Is_{(i)}$	$TI_{(i)}$	$I_{(i)}$	$Is_{(i)}$	$TI_{(i)}$
Chemistry	Basic materials chemistry	-	-	-	0.997 (03)	1.000 (01)	0.997 (03)	0.984 (10)	1.000 (01)	0.984 (10)	0.997 (07)	1.000 (01)	0.997 (07)	0.656 (22)	1.000 (01)	0.656 (19)
	Biotechnology	**0.527 (10)**	0.400 (03)	0.211 (11)	**0.990 (06)**	0.800 (02)	0.792 (08)	**0.996 (06)**	1.000 (01)	0.996 (06)	**0.999 (02)**	1.000 (01)	0.999 (02)	0.606 (25)	1.000 (01)	0.606 (21)
	Chemical engineering	0.762 (05)	0.400 (03)	0.305 (09)	1.000 (01)	0.400 (04)	0.400 (11)	1.000 (01)	1.000 (01)	1.000 (01)	0.996 (09)	1.000 (01)	0.996 (09)	0.917 (04)	1.000 (01)	0.917 (02)
	Environmental technology	-	-	-	**0.944 (08)**	0.800 (02)	0.756 (09)	**1.000 (01)**	0.800 (02)	0.800 (12)	**1.000 (01)**	0.400 (03)	0.400 (17)	0.588 (26)	1.000 (01)	0.588 (23)
	Food chemistry	**0.950 (02)**	0.800 (01)	0.760 (02)	**1.000 (01)**	0.600 (03)	0.600 (10)	**1.000 (01)**	0.800 (02)	0.800 (12)	**1.000 (01)**	0.400 (03)	0.400 (17)	0.745 (16)	0.800 (02)	0.596 (22)
	Macromolecular chemistry, polymers	0.713 (06)	0.800 (01)	0.570 (04)	0.996 (04)	1.000 (01)	0.996 (04)	0.997 (05)	1.000 (01)	0.997 (05)	0.998 (05)	1.000 (01)	0.998 (05)	0.666 (21)	1.000 (01)	0.666 (18)
	Materials, metallurgy	-	-	-	**1.000 (01)**	0.400 (04)	0.400 (11)	**1.000 (01)**	1.000 (01)	1.000 (01)	**1.000 (01)**	1.000 (01)	1.000 (01)	0.849 (06)	1.000 (01)	0.849 (04)
	Micro-structural and nano-technology	-	-	-	0.999 (02)	1.000 (01)	0.999 (02)	1.000 (01)	1.000 (01)	1.000 (01)	0.984 (12)	1.000 (01)	0.984 (12)	0.987 (02)	0.800 (02)	0.789 (08)
	Organic fine chemistry	0.615 (09)	0.600 (02)	0.369 (07)	1.000 (01)	0.400 (04)	0.400 (11)	0.994 (07)	1.000 (01)	0.994 (07)	1.000 (01)	1.000 (01)	1.000 (01)	0.767 (14)	1.000 (01)	0.767 (11)
	Pharmaceuticals	**0.884 (04)**	0.400 (03)	0.353 (08)	**1.000 (01)**	1.000 (01)	1.000 (01)	**1.000 (01)**	0.800 (02)	0.800 (12)	**1.000 (01)**	1.000 (01)	1.000 (01)	0.904 (05)	1.000 (01)	0.904 (03)
	Surface technology, coating	1.000 (01)	0.800 (01)	0.800 (01)	0.750 (09)	0.400 (04)	0.300 (12)	0.986 (09)	1.000 (01)	0.986 (09)	0.997 (08)	1.000 (01)	0.997 (08)	0.793 (09)	1.000 (01)	0.793 (06)
Electrical engineering	**Audio-visual technology**	-	-	-	-	-	-	**1.000 (01)**	0.800 (02)	0.800 (12)	**1.000 (01)**	1.000 (01)	1.000 (01)	0.970 (03)	1.000 (01)	0.970 (01)
	Electrical machinery, apparatus, energy	-	-	-	-	-	-	1.000 (01)	0.800 (02)	0.800 (12)	-	-	-	0.788 (11)	1.000 (01)	0.788 (09)
	Semiconductors	-	-	-	-	-	-	0.950 (12)	0.800 (02)	0.760 (13)	0.929 (16)	1.000 (01)	0.929 (15)	0.790 (10)	1.000 (01)	0.790 (07)
	Telecommunications	-	-	-	1.000 (01)	0.400 (04)	0.400 (11)	-	-	-	-	-	-	1.000 (01)	0.400 (03)	0.400 (25)
Instruments	Control	-	-	-	-	-	-	1.000 (01)	0.400 (03)	0.400 (14)	-	-	-	1.000 (01)	0.400 (03)	0.400 (25)
	Measurement	0.400 (11)	0.600 (02)	0.240 (10)	1.000 (01)	0.800 (02)	0.800 (07)	1.000 (01)	1.000 (01)	1.000 (01)	0.964 (14)	0.800 (02)	0.771 (16)	0.726 (17)	1.000 (01)	0.726 (13)
	Medical technology	**0.682 (08)**	0.800 (01)	0.545 (06)	**0.993 (05)**	1.000 (01)	0.993 (05)	**0.998 (03)**	1.000 (01)	0.998 (03)	**0.999 (03)**	1.000 (01)	0.999 (03)	0.530 (27)	1.000 (01)	0.530 (24)
	Optics	-	-	-	-	-	-	1.000 (01)	0.800 (02)	0.800 (12)	0.994 (11)	1.000 (01)	0.994 (11)	0.712 (18)	1.000 (01)	0.712 (14)
Mechanical engineering	Handling	0.940 (03)	0.800 (01)	0.752 (03)	1.000 (01)	0.600 (03)	0.600 (10)	0.998 (02)	1.000 (01)	0.998 (02)	0.984 (13)	1.000 (01)	0.984 (13)	0.785 (12)	1.000 (01)	0.785 (10)
	Machine tools	-	-	-	-	-	-	**1.000 (01)**	0.400 (03)	0.400 (14)	**1.000 (01)**	0.400 (03)	0.400 (17)	0.783 (13)	0.400 (03)	0.313 (27)
	Mechanical elements	-	-	-	-	-	-	**1.000 (01)**	0.800 (02)	0.800 (12)	**1.000 (01)**	0.400 (03)	0.400 (17)	0.842 (07)	0.800 (02)	0.674 (17)
	Other special machines	0.71	0.800	0.568	0.970	1.000	0.970	0.990	1.000	0.990	0.998	1.000	0.998	0.747	1.000	0.747

		0(07)	(01)	(05)	(07)	(01)	(06)	(08)	(01)	(08)	(06)	(01)	(06)	(15)	(01)	(12)
	Textile and paper machines	-	-	-	1.000	0.800	0.800	1.000	1.000	1.000	0.998	1.000	0.998	0.711	1.000	0.711
					(01)	(02)	(07)	(01)	(01)	(01)	(04)	(01)	(04)	(19)	(01)	(15)
	Thermal processes and apparatus	-	-	-	-	-	-	**1.000**	0.800	0.800	**1.000**	1.000	1.000	0.829	1.000	0.829
								(01)	(02)	(10)	**(01)**	(01)	(01)	(08)	(01)	(05)
	Transport	-	-	-	-	-	-	-	-	-	1.000	1.000	1.000	0.617	0.400	0.247
											(01)	(01)	(01)	(24)	(03)	(28)
Other fields	Civil engineering	-	-	-	-	-	-	1.000	0.800	0.800	0.889	0.400	0.356	0.407	0.800	0.326
								(01)	(02)	(12)	(17)	(02)	(18)	(28)	(02)	(26)
	Furniture, games	-	-	-	1.000	1.000	1.000	0.997	1.000	0.997	0.995	1.000	0.995	0.705	1.000	0.705
					(01)	(01)	(01)	(04)	(01)	(04)	(10)	(01)	(10)	(20)	(01)	(16)
	Other consumer goods	-	-	-	1.000	0.800	0.800	0.961	1.000	0.961	0.951	1.000	0.951	0.646	1.000	0.646
					(01)	(02)	(07)	(11)	(01)	(11)	(15)	(01)	(14)	(23)	(01)	(20)

Table 4-5 shows the dynamics of interdisciplinarity by technological areas across time periods, identifying whether these have become more interdisciplinary over time. Overall, according to the *total interdisciplinarity index* ($TI_{(i)}$), the three technological areas showing the highest degree of interdisciplinarity are: 'Audio-visual technology', 'Pharmaceuticals' and 'Chemical engineering'. The first refers to consumer electronics, the second to applications in pharma, and the latter covers technologies at the interface of chemistry and engineering, referring to apparatus and processes for the industrial production of chemicals. Moreover, 10 out of 29 technological areas in the technology network of bioplastics have become more interdisciplinary over time, as the total interdisciplinarity index appears to increase (closer to one) across time periods. The cases of biotechnology and medical technology are interesting in that their *total interdisciplinarity index* ($TI_{(i)}$) has increased to around 370% for biotechnology and around 80% for medical technology in about ten years. Therefore, biotechnology and medical technology can be described as technological areas characterised by a rapid increase of interdisciplinarity, and thus as technological areas that drawn upon technological knowledge from many different technological areas and diverse sectors.

4.4.3.2 Characterisation of the most important technological areas within the network

In order to determine the importance that each technological area related to the technology network of bioplastics has on the overall network, the degree of centrality (**Table 4-6**) and the betweenness centrality (**Table 4-7**) of each technological area were calculated and then classified by sectors across time periods: below 2000, 2001-2005, 2006-2010, 2011-2015 and all years. For both cases, normalised centrality values were calculated. Hence, the dynamics of technological areas over time periods are shown in the above mentioned tables, to help identifying whether technological areas have been central (degree centrality) or acted as bridging (betweenness centrality) across all time periods or only in some periods.

Table 4-6: Normalised degree centrality.[344]

Note: Number between brackets refers to rank compared to all other technological areas in the network in the particular timeframe. Grey marked values indicate the top ten central technological areas in the particular time frame. Bold values represent the technological areas that have increased their importance over time.

[344] Source: Own Table.

Sector	Technology area	<=2000	2001-2005	2006-2010	2011-2015	All years
Chemistry	Basic materials chemistry	0.040 (06)	0.018 (03)	0.019 (09)	0.023 (08)	0.029 (07)
	Biotechnology	0.048 (05)	0.006 (07)	0.026 (06)	0.039 (03)	0.033 (05)
	Chemical engineering	0.061 (04)	0.004 (08)	0.013 (10)	0.014 (10)	0.015 (10)
	Environmental technology	0.001 (19)	0 (12)	0.002 (16)	0.002 (18)	0.002 (17)
	Food chemistry	0.032 (10)	0.002 (10)	0.006 (12)	0.009 (11)	0.008 (12)
	Macromolecular chemistry, polymers	0.161 (01)	0.021 (02)	0.088 (01)	0.064 (01)	0.074 (01)
	Materials, metallurgy	0.022 (13)	0.003 (09)	0.005 (13)	0.008 (12)	0.008 (12)
	Micro-structural and nano-technology	0.001 (19)	0 (12)	0.001 (17)	0.002 (18)	0.001 (18)
	Organic fine chemistry	0.067 (03)	0.013 (04)	0.033 (05)	0.027 (05)	0.032 (06)
	Pharmaceuticals	0.008 (16)	0.002 (10)	0.007 (11)	0.003 (17)	0.005 (14)
	Surface technology, coating	**0.036 (09)**	**0.003 (09)**	**0.045 (04)**	**0.035 (04)**	0.034 (04)
Electrical engineering	Audio-visual technology	0 (20)	0.001 (11)	0.003 (15)	0.003 (17)	0.003 (16)
	Computer technology	0.002 (18)	0 (12)	0.002 (16)	0.002 (18)	0.002 (17)
	Electrical machinery, apparatus, energy	0.002 (18)	0.001 (11)	0.003 (15)	0.004 (16)	0.004 (15)
	IT methods for management	0 (20)	0 (12)	0 (18)	0 (20)	0 (19)
	Semiconductors	0.002 (18)	0.001 (11)	0.002 (16)	0.006 (14)	0.004 (15)
	Telecommunications	0 (20)	0 (12)	0 (18)	0.001 (19)	0.001 (18)
Instruments	Control	0 (20)	0 (12)	0.001 (17)	0.001 (19)	0.001 (18)
	Measurement	0.031 (11)	0.002 (10)	0.005 (13)	0.006 (14)	0.006 (13)
	Medical technology	0.040 (06)	0.045 (01)	0.072 (02)	0.025 (06)	0.06 (02)
	Optics	0.004 (17)	0.001 (11)	0.004 (14)	0.005 (15)	0.005 (14)
Mechanical engineering	Engines, pumps, turbines	0 (20)	0 (12)	0 (18)	0 (20)	0 (19)
	Handling	0.029 (12)	0.001 (11)	0.021 (08)	0.017 (09)	0.016 (09)
	Machine tools	0.011 (15)	0 (12)	0.005 (13)	0.004 (16)	0.004 (15)
	Mechanical elements	0 (20)	0 (12)	0.002 (16)	0.001 (19)	0.001 (18)
	Other special machines	0.157 (02)	0.008 (05)	0.053 (03)	0.056 (02)	0.052 (03)
	Textile and paper machine	0.037 (08)	0.007 (06)	0.022 (07)	0.024 (07)	0.023 (08)
	Thermal processes and apparatus	0 (20)	0 (12)	0.002 (16)	0.001 (19)	0.001 (18)
	Transport	0 (20)	0 (12)	0.002 (16)	0.003 (17)	0.002 (17)
Other fields	Civil engineering	0.015 (14)	0.008 (05)	0.004 (14)	0.007 (13)	0.01 (11)
	Furniture, games	0 (20)	0.001 (11)	0.007 (11)	0.004 (16)	0.005 (14)
	Other consumer goods	0.004 (17)	0.002 (10)	0.007 (11)	0.004 (16)	0.005 (14)

According to the degree centrality index ($Dc_{(i)}$), the three technological areas showing the highest degree centrality are ‘Macromolecular chemistry, polymers’, ‘Medical technology’ and ‘Other special machines’. The first refers to chemical properties of polymers, the second is associated with medical technology, and the latter is associated with patents referring to turning, drilling, grinding, soldering or cutting not focused on metals. ‘Macromolecular chemistry, polymers' appears to have the highest degree centrality over all time periods, with the exception of the period 2001-2005, when 'Medical technology' achieved an important position relative to all other technological areas. Contrary, the timely development of 'Medical technology' and 'Other special machines' is characterised by high fluctuations over time.

Table 4-7: Normalised betweenness centrality.[345]

Note: Number between brackets refers to rank compared to all other technological areas in the network in the particular timeframe. Grey marked values indicate the top ten bridging technological areas in the particular time frame. Bold values represent the technological areas that have increased their importance as bridging over time.

Sector	Technology area	<=2000	2001-2005	2006-2010	2011-2015	All years
Chemistry	**Basic materials chemistry**	**0** (10)	**0.02** (07)	**0.031** (06)	**0.04** (02)	0.026 (06)
	Biotechnology	0.005 (08)	0.055 (03)	0.023 (08)	0.037 (03)	0.014 (09)
	Chemical engineering	0.006 (07)	0.007 (08)	0.012 (10)	0.025 (08)	0.013 (10)
	Environmental technology	0 (10)	0.004 (09)	0.004 (12)	0.001 (19)	0.003 (15)
	Food chemistry	0.040 (04)	0.002 (10)	0.002 (14)	0 (20)	0.001 (17)
	Macromolecular chemistry, polymers	0.026 (06)	0.144 (01)	0.050 (04)	0.035 (04)	0.061 (01)
	Materials, metallurgy	0 (10)	0.001 (11)	0.011 (11)	0.009 (14)	0.01 (12)
	Micro-structural and nano-technology	0 (10)	0 (12)	0.001 (15)	0.004 (17)	0.001 (17)
	Organic fine chemistry	0.076 (01)	0.045 (04)	0.079 (01)	0.014 (11)	0.03 (04)
	Pharmaceuticals	0 (10)	0.001 (11)	0.002 (14)	0.004 (17)	0.004 (14)
	Surface technology, coating	**0.001 (09)**	**0.031 (05)**	**0.061 (03)**	**0.027 (07)**	0.029 (05)
Electrical engineering	Audio-visual technology	0 (10)	0 (12)	0.001 (15)	0 (20)	0.002 (16)
	Computer technology	0 (10)	0 (12)	0 (16)	0 (20)	0 (18)
	Electrical machinery, apparatus, energy	0 (10)	0 (12)	0.001 (15)	0.006 (16)	0.003 (15)
	IT methods for management	0 (10)	0 (12)	0 (16)	0 (20)	0 (18)
	Semiconductors	0 (10)	0 (12)	0.001 (15)	0.018 (09)	0.01 (12)
	Telecommunications	0 (10)	0 (12)	0 (16)	0 (20)	0 (18)
Instruments	Control	0 (10)	0 (12)	0 (16)	0 (20)	0 (18)
	Measurement	0.037 (05)	0.004 (09)	0.011 (11)	0.011 (13)	0.009 (13)
	Medical technology	0.064 (02)	0.096 (02)	0.040 (05)	0.029 (06)	0.034 (03)
	Optics	0 (10)	0 (12)	0.001 (15)	0.007 (15)	0.003 (15)
Mechanical engineering	Engines, pumps, turbines	0 (10)	0 (12)	0 (16)	0 (20)	0 (18)
	Handling	0.006 (07)	0.004 (09)	0.011 (11)	0.017 (10)	0.021 (07)
	Machine tools	0 (10)	0 (12)	0.001 (15)	0.001 (19)	0.001 (17)
	Mechanical elements	0 (10)	0 (12)	0.002 (14)	0.001 (19)	0.003 (15)
	Other special machines	0.051 (03)	0.022 (06)	0.067 (02)	0.051 (01)	0.037 (02)

[345] Source: Own Table.

	Textile and paper machine	**0 (10)**	**0.004 (09)**	**0.024 (07)**	**0.032 (05)**	0.016 (08)
	Thermal processes and apparatus	0 (10)	0 (12)	0.001 (15)	0.012 (12)	0.004 (14)
	Transport	0 (10)	0 (12)	0 (16)	0.002 (18)	0.001 (17)
Other fields	Civil engineering	0 (10)	0 (12)	0.003 (13)	0.001 (19)	0.002 (16)
	Furniture, games	0 (10)	0.002 (10)	0.002 (14)	0.004 (17)	0.002 (16)
	Other consumer goods	0 (10)	0.001 (11)	0.013 (09)	0.009 (14)	0.011 (11)

According to the betweenness centrality index ($Bc_{(i)}$), the three technological areas showing the highest betweenness centrality are again ‘Macromolecular chemistry, polymers’, ‘Other special machines’ and ‘Medical technology’. ‘Macromolecular chemistry, polymers’ and ‘Medical technology’ seem to play a very crucial role as bridging over the time period 2001-2005, decreasing its importance after 2005. Contrary, ‘Other special machines’ gained higher relevance as bridging technologies after 2006.

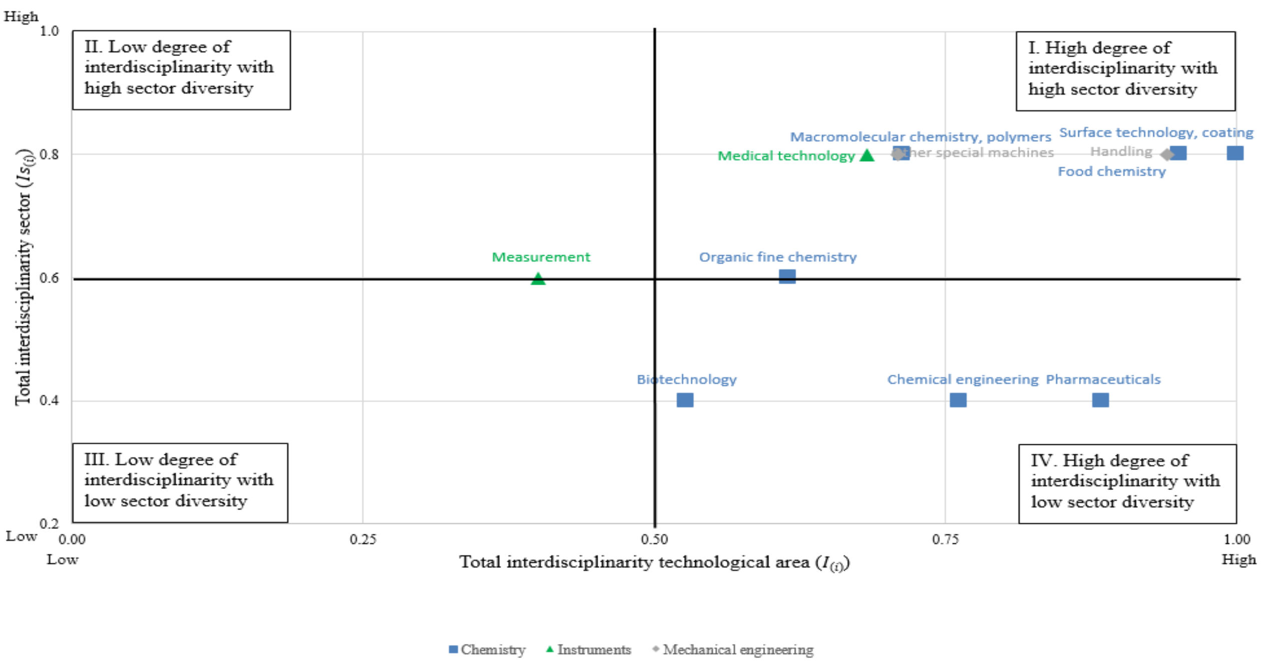
4.4.4 Visualisation

4.4.4.1 Visualisation of interdisciplinarity evolution

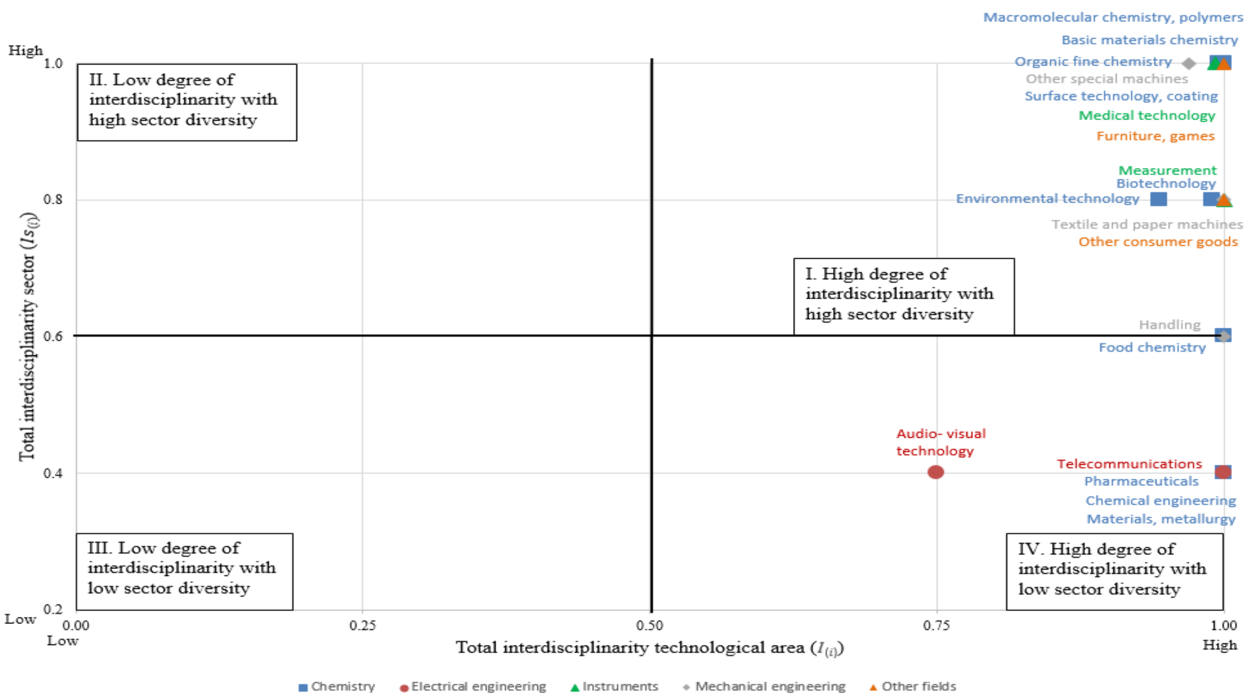
Visualisations of interdisciplinarity allow to identify the most interdisciplinary technological areas within the field of bioplastics as well as their evolution over time. The visualisations of the interdisciplinary evolution of the technological areas over the five time periods (a) ≤2000; (b) 2001-2005; (c) 2006–2010; (d) 2011–2015; (e) all years; are shown in Figure 6. These scatter plots depict the number of citations stemming from outside the own technological area ($I_{(i)}$) on the horizontal axis, and number of sectors that technological areas draw upon ($Is_{(i)}$) on the vertical axis. The graph is divided at the mean values for each scale, $I_{(i)} = 0.50$ and $Is_{(i)} = 0.60$, thus resulting in four quadrants.

Quadrant I (High degree of interdisciplinarity with high sector diversity) displays those technological areas that have a low number of self-citations ($Cs_i \leq \frac{\sum_i C}{2}$) relative to total citations, thus $I_{(i)} \geq 0.50$ and that cite technological areas from four of five different sectors ($Is_{(i)} > 0.60$). The technological areas located in this quadrant are considered as more interdisciplinary than the technological areas positioned on the other quadrants. Quadrant II (Low degree of interdisciplinarity with high sector diversity) shows the technological areas that have high number of self-citations relative to total citations ($I_{(i)} \leq 0.50$) and that cite technological areas from four or five different sectors ($Is_{(i)} > 0.60$). Quadrant III (Low degree of interdisciplinarity with low sector diversity) indicates technological areas that have a high number of self-citations relative to total citations ($I_{(i)} \leq 0.50$) and their technological knowledge (citations) are concentrated in only one or two sectors ($Is_{(i)} < 0.60$). Quadrant IV (High degree of interdisciplinarity with low sector diversity) shows technological areas that have a low share of self-citations relative to total citations ($I_{(i)} \geq 0.50$) and their technological knowledge (citations) are concentrated in only one or two sectors ($Is_{(i)} < 0.60$).

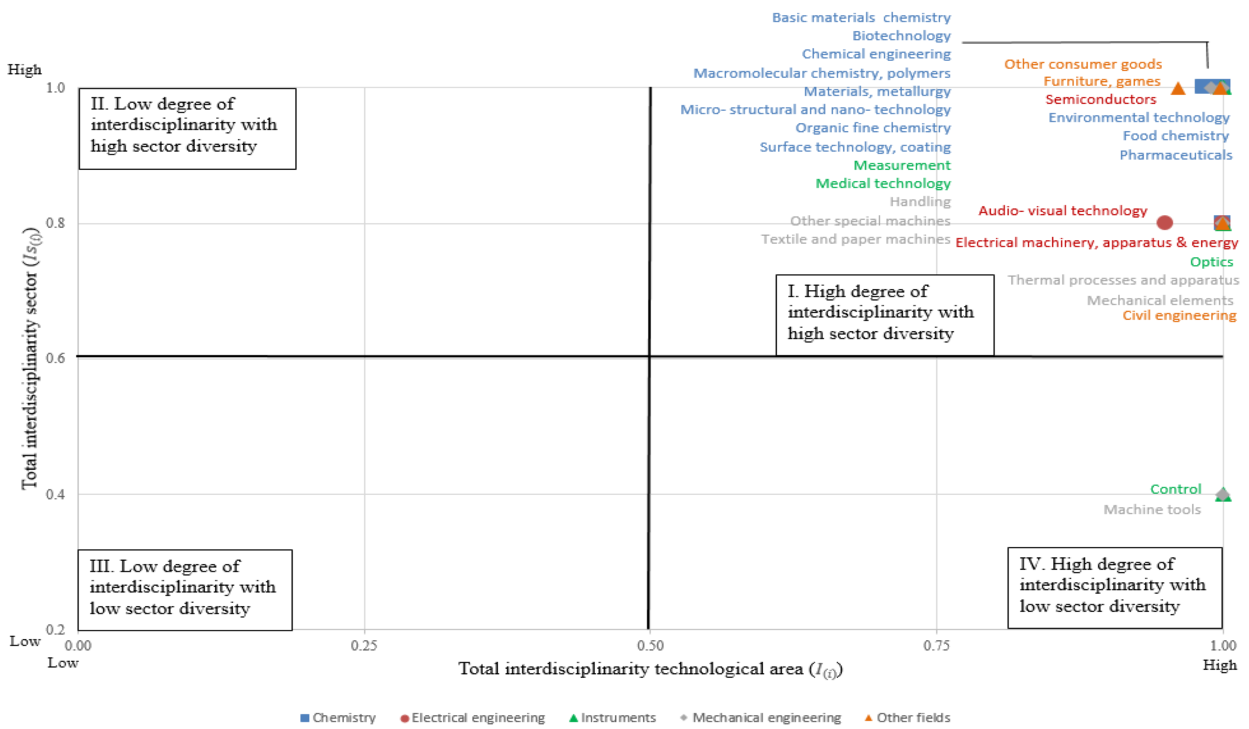
(a) ≤2000



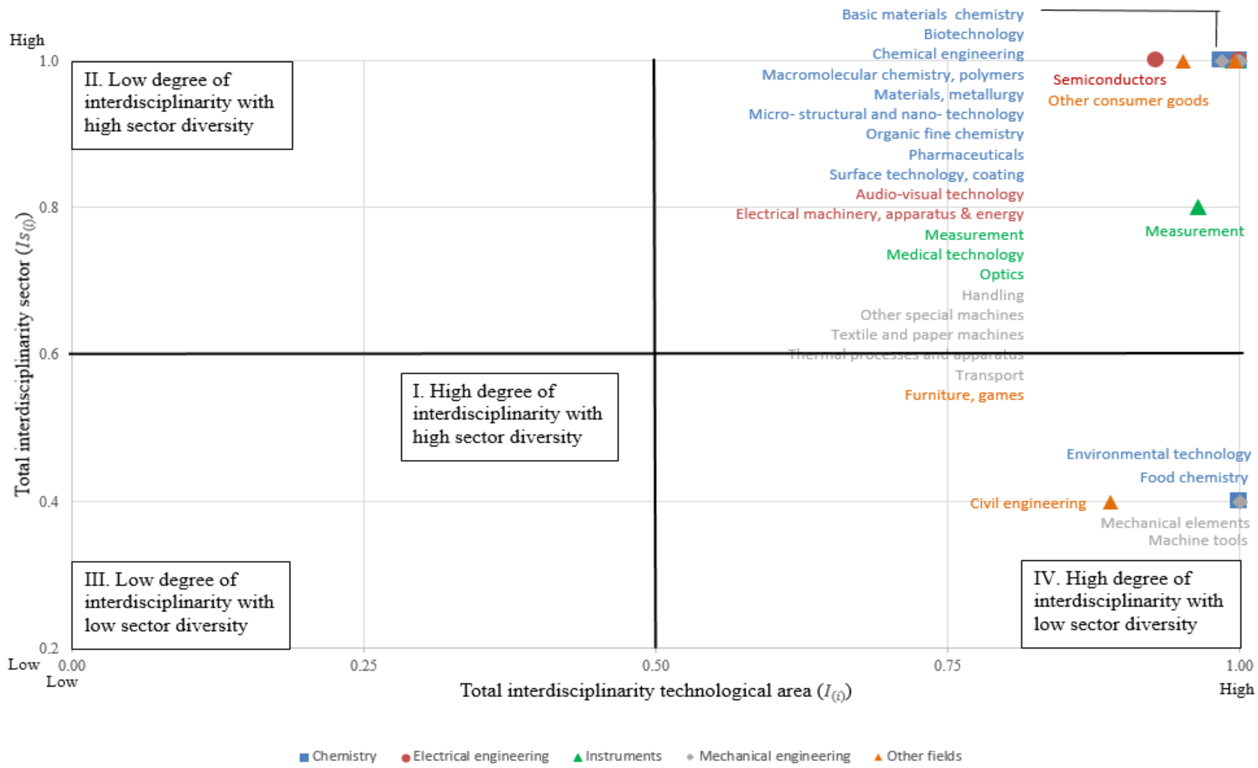
(b) 2001-2005



(c) 2006–2010



(d) 2011–2015



(e) All years

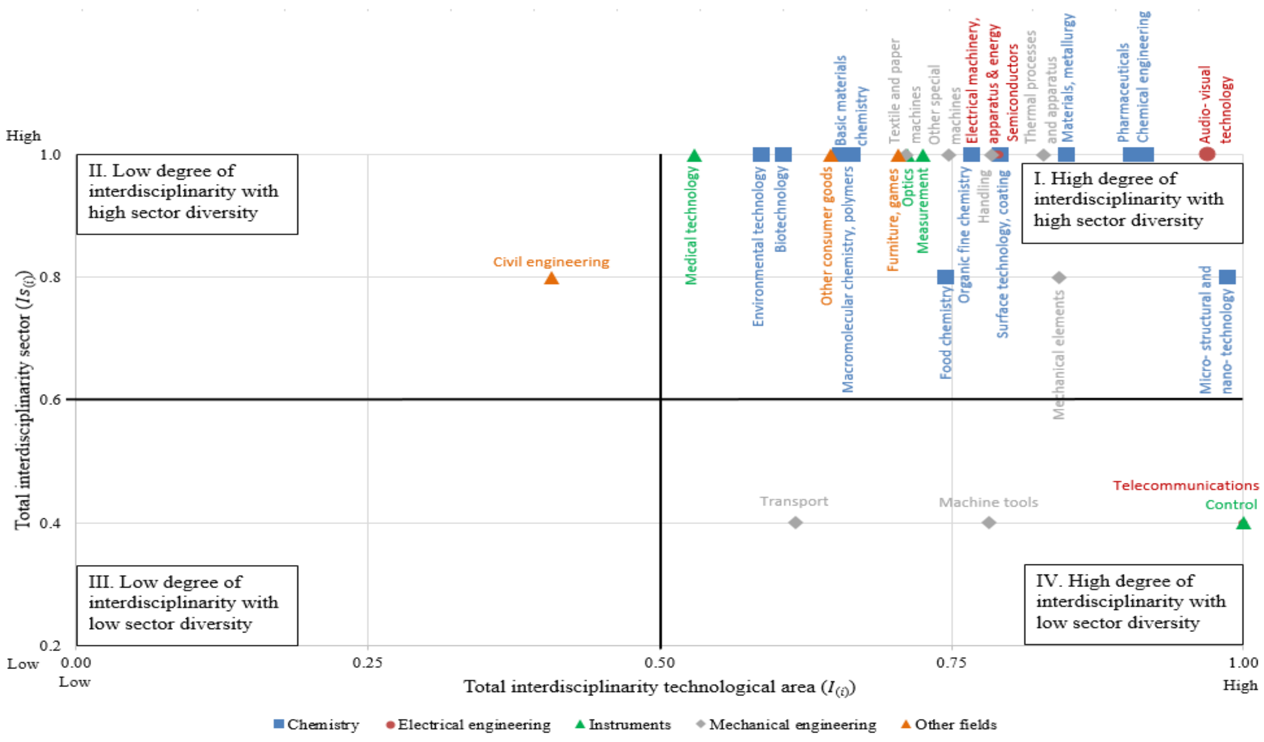


Figure 4-6: Total interdisciplinarity sector vs. total interdisciplinarity technological area for bioplastics, five sub-periods: (a) ≤2000; (b) 2001-2005; (c) 2006–2010; (d) 2011–2015; (e) all years.[346]

Note: The colour and shape of the nodes represent sectors based on the IPC-Technology Concordance Table: Chemistry: blue and square; Electrical engineering: red and circle; Instruments: green and up triangle; Mechanical engineering: grey and diamond; Other fields: orange and up triangle.

Taking into account all time periods, the technological areas located in the ‘High degree of interdisciplinarity with high sector diversity’ quadrant show the lowest shares of self-citations relative to the total number of citations and these draw upon technological knowledge from four or five different sectors (following the IPC-Technology Concordance Table). Thus, these technological areas are highly interdisciplinary. Quadrant II (‘Low degree of interdisciplinarity with high sector diversity’) only contains the technological area of ‘Civil engineering’, characterised by having a high share of self-citations relative to the total number of citations and by drawing upon knowledge from four or five different sectors. There is not any technological area located in the ‘Low degree of interdisciplinarity with low sector diversity’ (Quadrant III), thus there are no technological areas characterised by having a low share of self-citations relative to the total number of citations and by drawing upon knowledge from only two sectors. This might be due to the fact that a five-year accumulation of data is used.

Contrary, the technological areas ‘Control’, ‘Machine tools’, ‘Telecommunications’, and ‘Transport’ (located in the ‘High degree of interdisciplinarity with low sector diversity’ quadrant) display a low share of self-citations relative to the total number of citations and draw upon technological knowledge from only two different sectors (following the IPC-Technology Concordance Table). This indicates that these technological areas appear to rely on knowledge generated in only two sectors, turning to be less interdisciplinary. Generally, it can be observed that across time periods technological areas have moved to the ‘High degree of interdisciplinarity with high sector diversity’ quadrant, implying that technological areas have become more interdisciplinary over time.

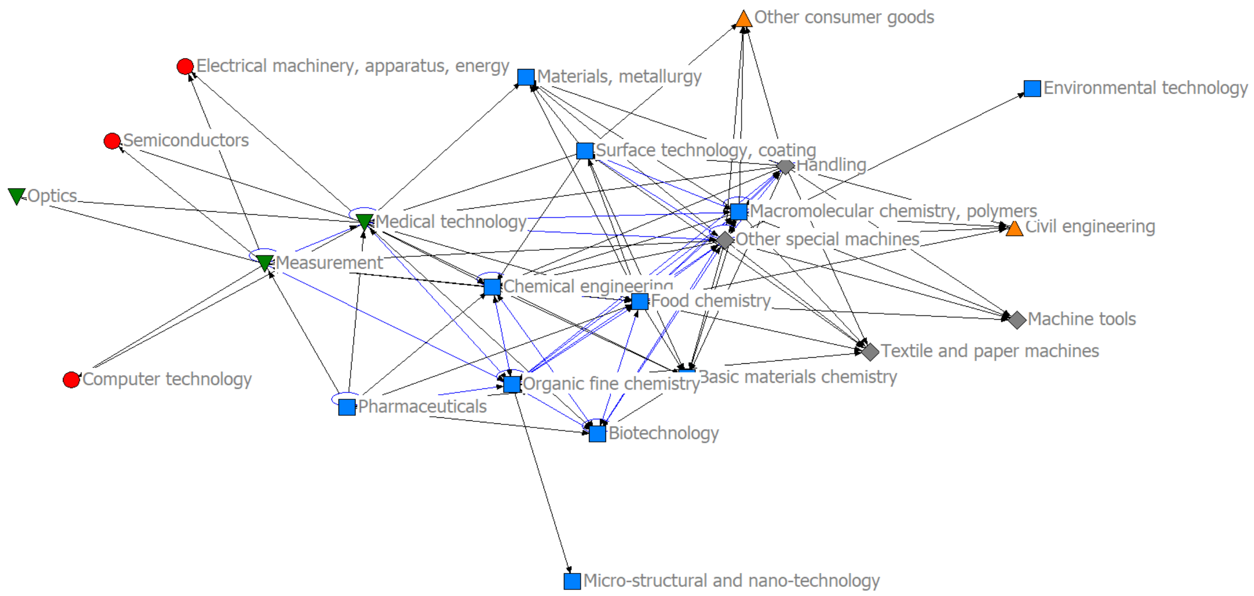
4.4.4.2 Visualisation of technology network maps

In addition to the visualisations of interdisciplinarity by technological areas, technology network maps allow to visualise relationships among the technological areas that constitute the

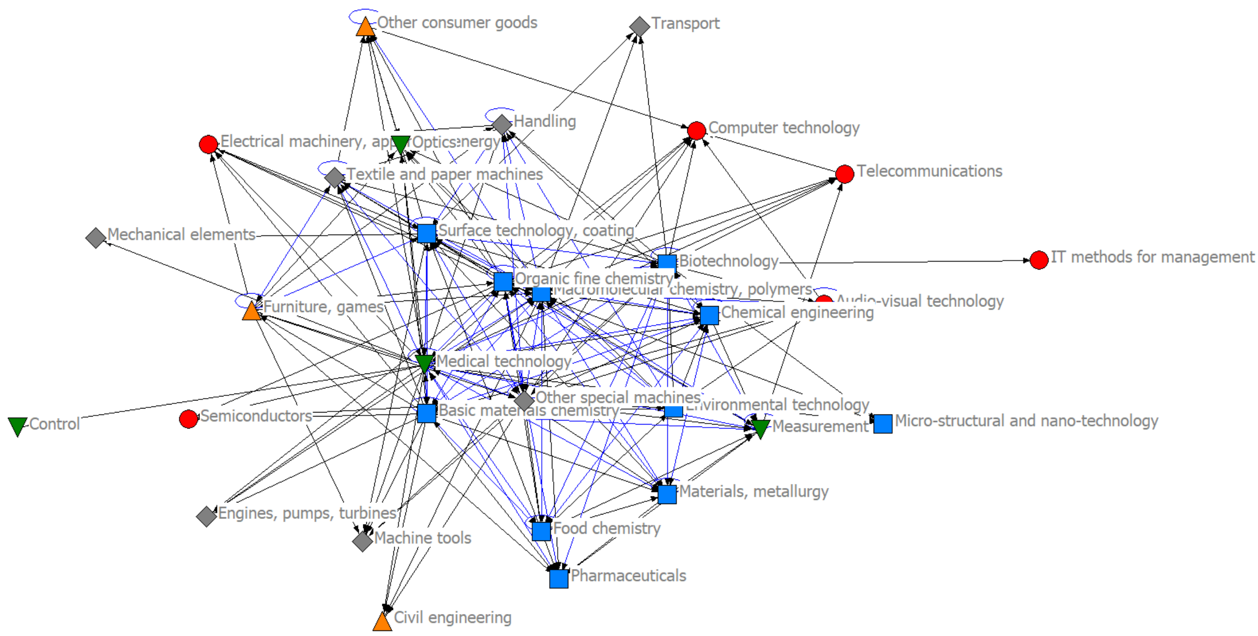
[346] Source: Own Figure.

structure of the technological knowledge behind bioplastics as well as the changes of these relationships over time. The visualisation of the network analyses for the technological areas over five time periods: (a) ≤2000; (b) 2001-2005; (c) 2006–2010; (d) 2011–2015; (e) all years is depicted in Figure 7.

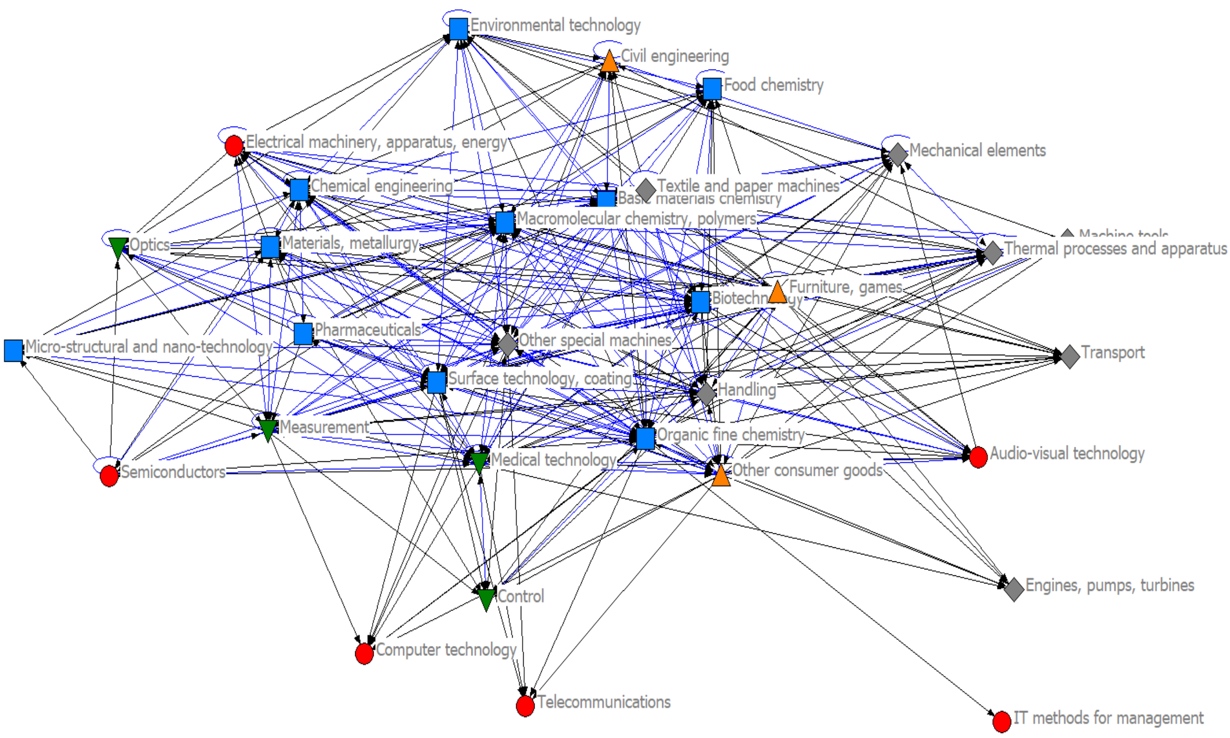
(a) ≤2000



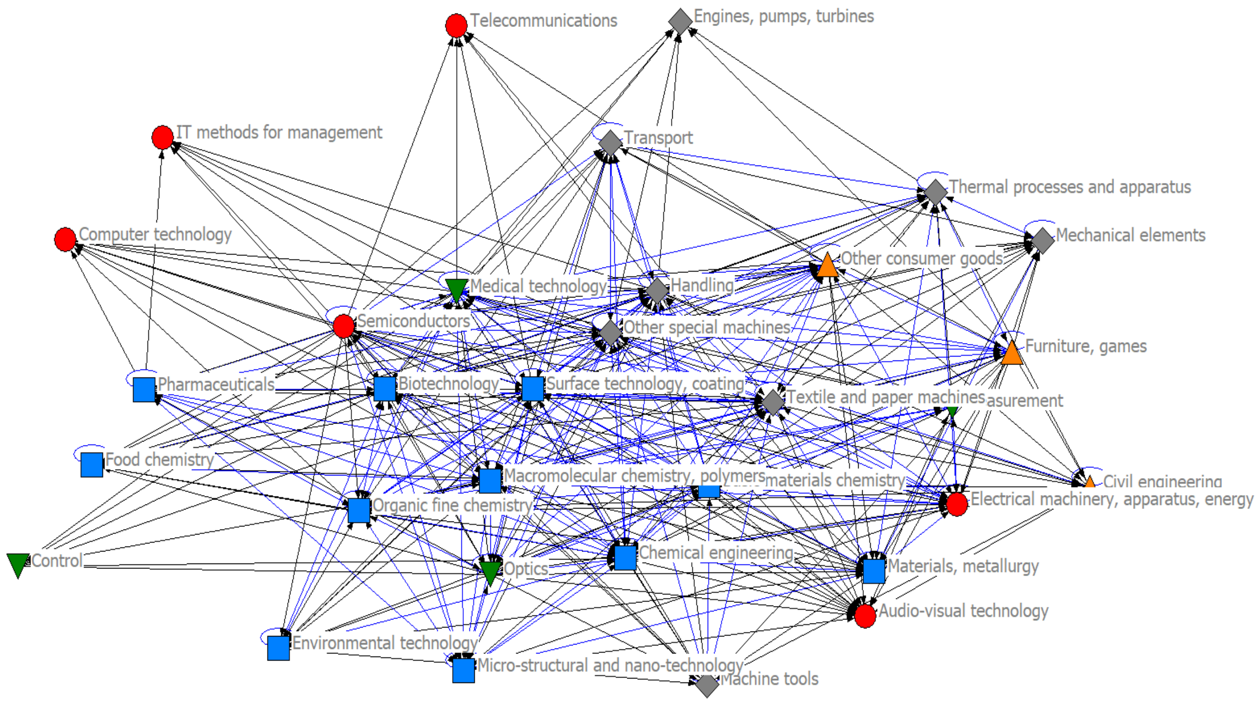
(b) 2001-2005



(c) 2006–2010



(d) 2011–2015



(e) All years

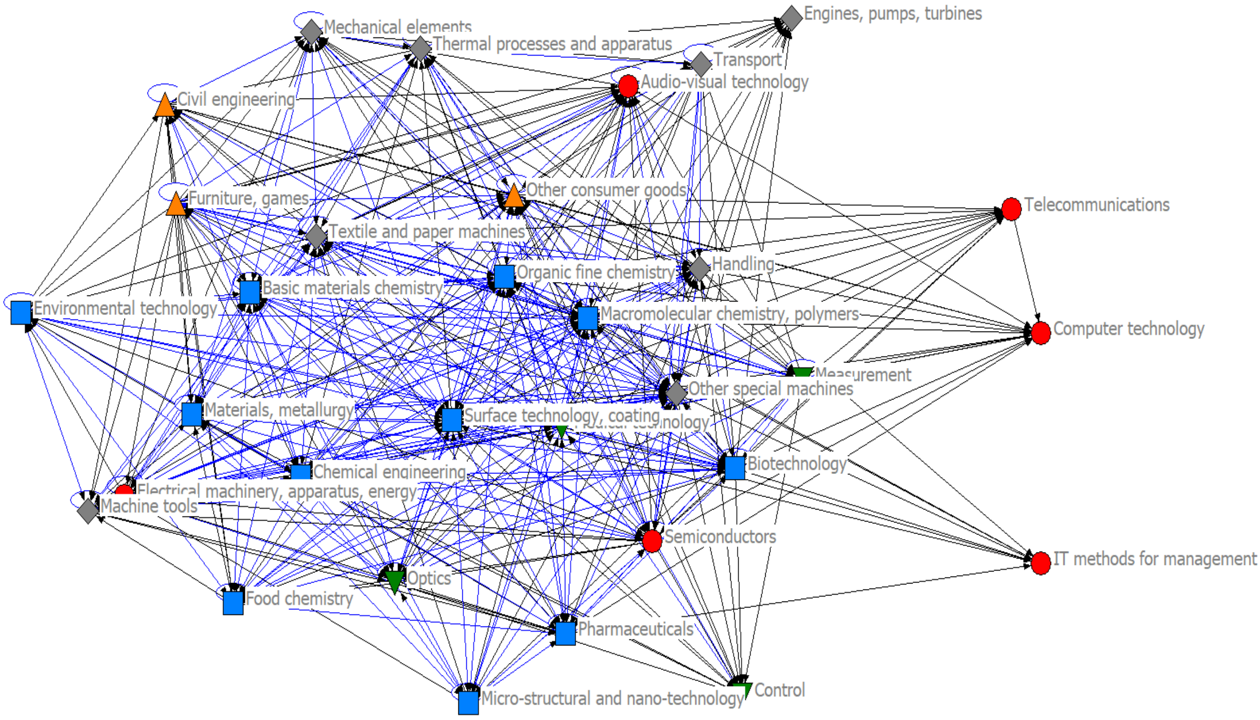


Figure 4-7: Network of technological areas for bioplastics, five sub-periods: (a) <=2000; (b) 2001-2005; (c) 2006–2010; (d) 2011–2015; (e) all years.[347]

Note: The colour and shape of the nodes represent sectors based on the IPC-Technology Concordance Table. Chemistry: blue and square; Electrical engineering: red and circle; Instruments: green and down triangle; Mechanical engineering: grey and diamond; Other fields: orange and up triangle. The colour of the lines represents directions of citations. Blue lines: reciprocal citations; black lines: one way citations.

The first period of the analysis shows a relatively simple network visualisation composed of 23 technological areas and 5 sectors. The core nodes of the map (the most connected ones) correspond to 'Macromolecular chemistry, polymers', 'Other special machines', and 'Organic fine chemistry'.

In the second period of analysis (2001-2005), the network visualisation indicates a more complex structure due to the emergence of more nodes and relationships among them, containing 31 technological areas and 5 sectors. The core nodes of the map are 'Macromolecular chemistry, polymers', 'Medical technology' and 'Basic materials chemistry'. However,

[347] Source: Own Figure.

'Organic fine chemistry' and 'Other special machines' lose importance in the network with respect to the previous period.

The next period of analysis (2006-2010) shows a network which is slightly more complex in terms of relationships among nodes, containing 32 technological areas and 5 sectors. Specifically, the importance of 'Macromolecular chemistry, polymers' and 'Medical technology' persists. In addition, 'Other special machines' gained relevance in this period, recovering the importance achieved in the first period of analysis. Furthermore, 'Surface technology, coating' developed into one of the most strongly connected nodes for the first time. These four nodes can be considered as the central technological areas in this period of analysis.

In the last period of the analysis (2011-2015), the network visualisation contains 32 technological areas and 5 sectors with more relationships among nodes. The core nodes of the map are 'Macromolecular chemistry, polymers', 'Other special machines', and 'Biotechnology'. Interestingly, 'Biotechnology' emerged as a core node of the map, although the patent sample shows a decreasing trend in the number of patents classified in this technological area, indicating the strong role of 'Biotechnology' as bridging technological area. In addition, this might indicate that the patent sample draws upon technological knowledge from outside their own technological areas.

Summing up all the years used for this analysis, the network visualisation contains 32 technological areas and 5 sectors. The five core nodes of the map are 'Macromolecular chemistry, polymers', 'Medical technology', 'Other special machines', 'Surface technology, coating' and 'Biotechnology', which represent the central technological areas in the technology network of bioplastics.

4.5 Discussion and conclusion

This study presents an empirical operationalisation of interdisciplinarity in order to depict and assess interdisciplinary research and its evolution at the level of technological areas within the technology network of bioplastics. By drawing upon patents, patent citations and patent classification codes as proxies for technological knowledge, this study develops a novel approach to assess interdisciplinarity within a technology network. In specific, this chapter constructs three novel patent indicators, namely the *total interdisciplinarity technological area* ($I_{(i)}$), the *total interdisciplinarity sector* ($Is_{(i)}$) and the *total interdisciplinarity index* ($TI_{(i)}$) as well as a typology based on the IPC-Technology Concordance Table.[348] In doing so, this study enables academic scientists and firms to identify key technological areas by facilitating knowledge share and transfer across technological areas. In addition, this study enables academic institutions, funding agencies and policy-makers to understand and manage interdisciplinarity and knowledge collaboration efforts in highly interdisciplinary and emerging knowledge areas.

On the basis of these indicators and the typology, technological areas within a technology network can be classified into four categories (I. High degree of interdisciplinarity with high sector diversity, II. Low degree of interdisciplinarity with high sector diversity, III. Low degree of interdisciplinarity with low sector diversity, IV. High degree of interdisciplinarity with low sector diversity) in relation to the number of citations stemming from a technological area. Applying this framework to the case of bioplastics, this chapter was able to provide an initial demonstration of how these novel patent indicators could be applied to other emerging knowledge areas to assess the degree of interdisciplinarity within a technology network. The development of these novel patent indicators using patents and patent citations and taking technological areas as unit of analysis contributes to previous studies that have developed interdisciplinary indicators using publications.[349]

Our operationalisation of interdisciplinarity shows that the three most interdisciplinary technological areas within the technology network of bioplastics were 'Audio-visual technology', 'Chemical engineering' and 'Pharmaceuticals'. This points out that in order to apply bioplastics in these technological areas, practitioners and companies need technological knowledge from many other technological areas. The *total interdisciplinarity index* ($TI_{(i)}$) and the *typology* also showed that technological areas in the technology network of bioplastics have become more interdisciplinary over time. Thus, in order to further develop the technology field of bioplastics, practitioners and companies require technological knowledge from a wide range of technological areas.

The network indicators (degree centrality and betweenness centrality) as well as the technology network maps were able to capture relationships among technological areas and identify the

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[348] Schmoch (2008).

[349] Cassi et al. (2017); Leydesdorff et al. (2018); Leydesdorff and Rafols (2011); Mugabushaka et al. (2016); Porter et al. (2007); Porter and Rafols (2009); Rafols et al. (2010); Rafols and Meyer (2007).

most important and the bridging technological areas. This contributes to previous studies[350] that were based on the representation of technological areas. Building on the *degree centrality* ($Dc_{(i)}$) and the *betweenness centrality* ($Bc_{(i)}$) indicators, the three technological areas showing the highest degree centrality and thus the most central technological areas in the technology network of bioplastics were ‘Macromolecular chemistry, polymers’, ‘Medical technology’ and ‘Other special machines’. Thus, these technological areas have had the highest importance in the technological development of bioplastics. These technological areas also showed the highest betweenness centrality, referring to their crucial role as bridging and connecting technological knowledge. Interestingly, ‘Other special machines’ appeared on the third position in terms of degree centrality, but is positioned second by betweenness centrality, indicating that despite having a more central location, it seems to play a more crucial role as bridging technological area.

Generally, the technology network maps demonstrate that the technological knowledge behind the technology network of bioplastics draws upon a wide range of technological areas. Furthermore, the technology network maps show that the technological knowledge behind bioplastics undergoes structural changes over time. As such, basic research comprising technological areas linked to pharmaceutical, agrochemical and biotechnology industries (e.g. ‘Macromolecular chemistry, polymers’, ‘Other special machines’, ‘Organic fine chemistry’, and ‘Biotechnology’) prevail their importance over time. From 2001, the technological area related to ‘Medical technology’ emerges and acquires greater importance in the network visualisations. This newer and emerging technological area might indicate that applications of bioplastics in medicine have become more relevant over time.

Managerial and policy implications

In light of these findings, Chapter 4 provides numerous practical implications for a diverse range of relevant stakeholders involved in interdisciplinary research such as the bioeconomy (e.g. academic scientists, firms and policy-makers). Firstly, the novel patent approach offers stakeholders greater opportunities to understanding, accessing, discussing and managing technological knowledge in highly interdisciplinary and emerging knowledge areas. In particular, this study is useful for academic scientists, firms and policy-makers for: (1)

[350] See e.g. Kay et al. (2014); Yan and Luo (2017).

identifying the most interdisciplinary technological areas within a technology network, and (2) identifying the most important and thus the key as well as the bridging technological areas within a technology network. On this basis, this research can help stakeholders to explore the networking and collaboration possibilities between the different technological areas that are involved in a technology network.

Secondly, as research becomes more complex, as it increasingly combines knowledge from two or more disciplines or technologies, we foresee the use of empirically grounded tools for science and technology management by stakeholders, as those presented in this chapter. Thus, this research can be important for potential academic scientists and industry partners to identify experts with relevant technological knowledge to conduct R&D related to e.g. bioplastics. Hence, these novel indicators can serve as a foresight approach for: (1) academic scientists and companies to improve their technological capabilities by facilitating knowledge share and transfer across technological areas, and (2) for interdisciplinary research institutions and funding agencies to understand and manage efforts towards interdisciplinarity and knowledge collaborations.

Finally, this work can also provide important policy implications in light of the growing importance of interdisciplinarity in science and innovation policy. Therefore, policy-makers can use the novel indicators and the network maps to design and develop science and innovation policies in highly interdisciplinary and emerging knowledge areas. The degree centrality indicator can help policy-makers identify technological areas in interdisciplinary settings where investments may pay off (e.g. ‘Macromolecular chemistry, polymers’; ‘Medical technology’; ‘Other special machines’). Similarly, the novel interdisciplinary indicators and the betweenness centrality indicator can be useful to identify technological areas that play a strong role connecting technological areas (bridging technological areas) within a technology network. In this regard, the provision of this novel patent approach may be used by policy-makers to analyse those technological areas that might be mandatorily integrated into research proposals to foster interdisciplinarity (e.g. ‘Macromolecular chemistry, polymers’; ‘Other special machines’; ‘Medical technology’).

Limitations and future research

The limitations of this study are primarily linked to the data used. Firstly, we conducted this analysis using patent families and cited patent applications, therefore including patents from all patent authorities. However, there are differences between the patent systems when it comes to citations. For example, in the US system, the patent applicant and his attorney are obliged to present to the patent examiner a complete list of relevant prior art for inclusion on the patent front page.[351] However, in the European Patent Office (EPO) system, the initial prior art search is carried out by a searcher at the EPO and should only include the most important patent references. That implies that US patents might tend to be more interdisciplinary than patents of other authorities, as the former present a higher number of citations.

A second limitation of this work is that we draw upon frequency of citations of prior patents as a proxy for interdisciplinarity and importance of a technological area. Another limitation is that the IPC-Technology Concordance Table was used as a basis for the analysis to link IPC codes to technological areas and to derive the analysis and indicators. Therefore, there might be some limitations to the use of this table, and more fine-grained indicators may be created by considering IPC groups and sub-groups. In a similar vein, this research is limited to technological areas of patents. However, it does not show the companies R&D efforts to develop bioplastics in these technological areas, nor the innovation strength in the highly interdisciplinary and emerging field of bioplastics. Future research could benefit by extending the current approach, taking into account company data or the information on patent assignees and assessing the innovation impact on technologies developed at the interface of several technological areas. Future studies could also consider the application of the developed approach to other interdisciplinary and emerging settings such as bioinformatics, ICT, nanotechnology or neurosciences.

[351] Michel and Bettels (2001).

5 Discussion and Conclusions

Chapter 5 answers the overall research question:

M.R.Q: How can technology transfer in interdisciplinary settings such as the bioeconomy be assessed from disciplinary, stakeholder and technology perspectives?

5. Discussion and Conclusions

This chapter discusses findings from the previous chapters (section 5.1), highlights the overall theoretical contributions (section 5.2) as well as the practical implications of the study (section 5.3). It concludes the thesis by acknowledging the limitations and proposing promising future research avenues (section 5.4).

5.1 General discussion and conclusions

In this thesis, disciplinary, stakeholder and technology perspectives are used to assess aspects related to technology transfer and interdisciplinary research in emerging knowledge areas. In particular, the case of the bioeconomy as an example of a highly interdisciplinary and emerging knowledge area is selected. This section discusses the overall study with respect to the main research question (M.R.Q) and the perspectives analysed.

> **M.R.Q: How can technology transfer in interdisciplinary settings such as the bioeconomy be assessed from disciplinary, stakeholder and technology perspectives?**

A) Technology transfer from a disciplinary perspective

The aspect of technology transfer from a perspective of collaborative innovation across two or more disciplines is explored in Chapter 2. From this disciplinary perspective, it seems that interdisciplinary research presents barriers. This is because academic disciplines establish boundaries which are deeply rooted within their specific knowledge and cognitive backgrounds.[352] This also implies that knowledge and technologies derived from collaborations across two or more disciplines are more difficult to transfer.[353] The following research question targets this research gap:

> **R.Q.1 (Chapter 2):** How can the effectiveness of technology transfer in the interdisciplinary setting of the bioeconomy be assessed?

Chapter 2 thus offers the first empirical study to understand how the effectiveness of technology transfer in interdisciplinary settings such as the bioeconomy can be assessed. Empirical

[352] Bassett-Jones (2005); MacLeod (2016).

[353] Dingler and Enkel (2016).

evidence is gathered from eight comprehensive case studies (four academic research groups and four spin-offs)[354] and supported by grounded theory.[355] The "Contingent Effectiveness Model of Technology Transfer" developed by Bozeman (2000) is applied to these case studies. This model considers several criteria to assess the effectiveness of the technology transfer process. The study conducted for this thesis indicates a broad consensus drawn from both the interviewees and project documentation that a successful integration of disciplines within the bioeconomy is key to achieve technology transfer. As a result, this chapter extends this model by adding a new effectiveness criterion (*Resource complementarity*) that takes into account the increasing attention paid to interdisciplinary collaborations. Therefore, this study provides a conceptual framework that can be used to assess effectiveness of technology transfer in interdisciplinary and emerging knowledge areas.

In addition, this study identified a set of factors that can lead to enhanced interdisciplinary research and in turn, improve effectiveness of technology transfer. These factors can be grouped into two broad categories: *individual characteristics* and *institutional support*. *Individual characteristics* refer to individual support by academic scientists or CEOs of spin-offs to promote interdisciplinary research. *Institutional support* relates to institutional measures that support interdisciplinary research and technology transfer. In particular, the creation of a network that sets mandatory requirements for funding that enforce interdisciplinary collaborations was highlighted as an exceptional example to foster interdisciplinarity. Furthermore, this chapter also identifies that technology transfer in the setting of the bioeconomy requires linkages between academic institutions and industries. However, these stakeholder groups may have different objectives and perceptions towards technology transfer which might challenge the technology transfer process. This yields to analysing technology transfer from the second perspective.

B) Technology transfer from a stakeholder perspective

The aspect of technology transfer from the perspective of multiple stakeholders is studied in Chapter 3. With respect to the stakeholder perspective, stakeholder groups (i.e. academic scientists from different disciplines, technology transfer facilitators and firms/entrepreneurs)

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[354] Yin (2015).

[355] Glasser and Strauss (1967).

have different perceptions, objectives, values and motivations for technology transfer.[356] Emerging knowledge areas exhibit specific characteristics that demand two particularities. Firstly, the combination of knowledge from different disciplines.[357] Secondly, the integration of knowledge and expertise of the three key stakeholder groups.[358] Consequently, a lack of coherence among stakeholder groups may challenge the technology transfer process.[359] This study reveals the perceived factors affecting technology transfer from the point of view of the key stakeholders by addressing the following research questions:

RQ.2 (Chapter 3): What are perceptions of factors that influence technology transfer in the bioeconomy from the point of view of the key stakeholder groups involved in the technology transfer process (i.e. academic scientists, technology transfer facilitators and firms/entrepreneurs)?

RQ.3 (Chapter 3): What is the perceived relative importance and coherence of these factors as identified by the different stakeholder groups?

Chapter 3 thus presents the first overview of factors influencing technology transfer in the bioeconomy through the aggregate representation of the perceptions of the different stakeholder groups involved in technology transfer. In total, 90 stakeholders comprising the full spectrum of stakeholders involved in technology transfer (36 academic scientists, 22 technology transfer facilitators and 32 firms/entrepreneurs) from Germany participated in the study. The factors generated by the stakeholders using the group concept mapping approach are visualised in the form of maps by means of multidimensional scaling and hierarchical cluster analyses.

Furthermore, a quantitative ranking of the factors is used to demonstrate the degree to which the importance of the perceived factors differs across the stakeholder groups. Results show that factors related to interdisciplinary collaborations and collaborations between academic scientists and firms, as well as those tied to financial issues or consumer acceptance, are assigned the highest level of relative importance. However, these factors are also characterised by the lowest level of relative coherence across the key stakeholder groups. Accordingly, there seems to be a need for *integrating knowledge from different disciplines and across the key*

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[356] Rogers (2003).

[357] Maine et al. (2014); Melkers and Xiao (2012); Porter and Rafols (2009).

[358] Rogers (2003).

[359] Rogers (2003).

stakeholder groups. It is also needed to *support spin-offs* and *commercialisation grants* as well as improving *consumer communication* and acceptance towards new technologies in the bioeconomy. Previous chapters highlighted the importance of fostering interdisciplinary collaborations to enhance technology transfer. Nonetheless, empirical evidence on how interdisciplinarity at technology level can be assessed is limited so far, leading to the third study that looked at the third perspective.

C) Technology transfer from a technology perspective

From disciplinary and stakeholder perspectives, this research reveals the increasingly important role that interdisciplinary research plays to enhance technology transfer. Despite, there is little systematic evidence of how widespread interdisciplinary research is and hence, assessing the degree of interdisciplinary research remains somewhat blurred. Therefore, from a technology perspective, Chapter 4 of this thesis provides the *first empirical operationalisation of interdisciplinarity at the level of technological areas* by targeting the following research question:

R.Q.4 (Chapter 4): How can the degree of interdisciplinary research be operationalised by drawing upon patent data?

This chapter draws upon patents as an example of a technology transfer instrument to investigate knowledge transfer and collaborations across technological areas. Specifically, this thesis constructs three novel patent indicators, namely the *total interdisciplinarity technological area* ($I_{(i)}$), the *total interdisciplinarity sector* ($Is_{(i)}$) and the *total interdisciplinarity index* ($TI_{(i)}$) as well as a *typology* based on the IPC-Technology Concordance Table.[360] This set of indicators enable academic scientists, firms, funding agencies and policy-makers to assess the degree of interdisciplinarity at the level of technological areas. Furthermore, this chapter constructs technology network maps that allow to visualise relationships and knowledge transfer among technological areas. In total, 890 patent families and 8979 patent citations representative of the emerging range of bioplastics were used for the empirical operationalisation of this novel approach.

By applying this framework to the case of bioplastics, these interdisciplinary indicators show that the key technological areas for the innovative activity in the field of bioplastics have

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[360] Schmoch (2008).

become more interdisciplinary over time. Thus, these novel indicators and the typology can help academic scientists and firms improving their technological capabilities by facilitating knowledge sharing and transfer across technological areas. In addition, this approach can serve policy-makers to support the design and development of science and innovation policies that foster interdisciplinary research. By understanding and visualising connections among key technological areas, it is possible for stakeholders participating in the R&D of a technology to plan collaborations with other stakeholders who might be relevant for its development. Moreover, this chapter contributes to advancing the state-of-the-art with regard to the use of interdisciplinary indicators.

Overall, from a disciplinary perspective, this thesis identifies factors that enhance interdisciplinary research and in turn, improve effectiveness of technology transfer. In addition, this thesis shows that the different factors that influence technology transfer are perceived differently from the point of view of the key stakeholder groups. These differences need to be taken into consideration for a successful technology transfer.[361] Furthermore, from a technology perspective, this thesis develops a novel patent approach to evaluate the degree of interdisciplinary research. Understanding how interdisciplinary a certain technological area is might be crucial for identifying relevant disciplines and stakeholders to be involved in R&D. To sum up, collaborations between experts from different disciplines as well as between the key stakeholder groups that jointly shape the technology transfer process is key to achieve successful technology transfer in emerging knowledge areas such as the bioeconomy. The novel approach developed in this thesis, can thus be used to monitor and evaluate collaborations across different disciplines (by taking the IPC codes of patents), or across stakeholders (by taking assignees of patents). **Figure 5-1** illustrates the complete narrative of the thesis.

[361] This is also supported by Rogers (2003); Siegel et al. (2004).

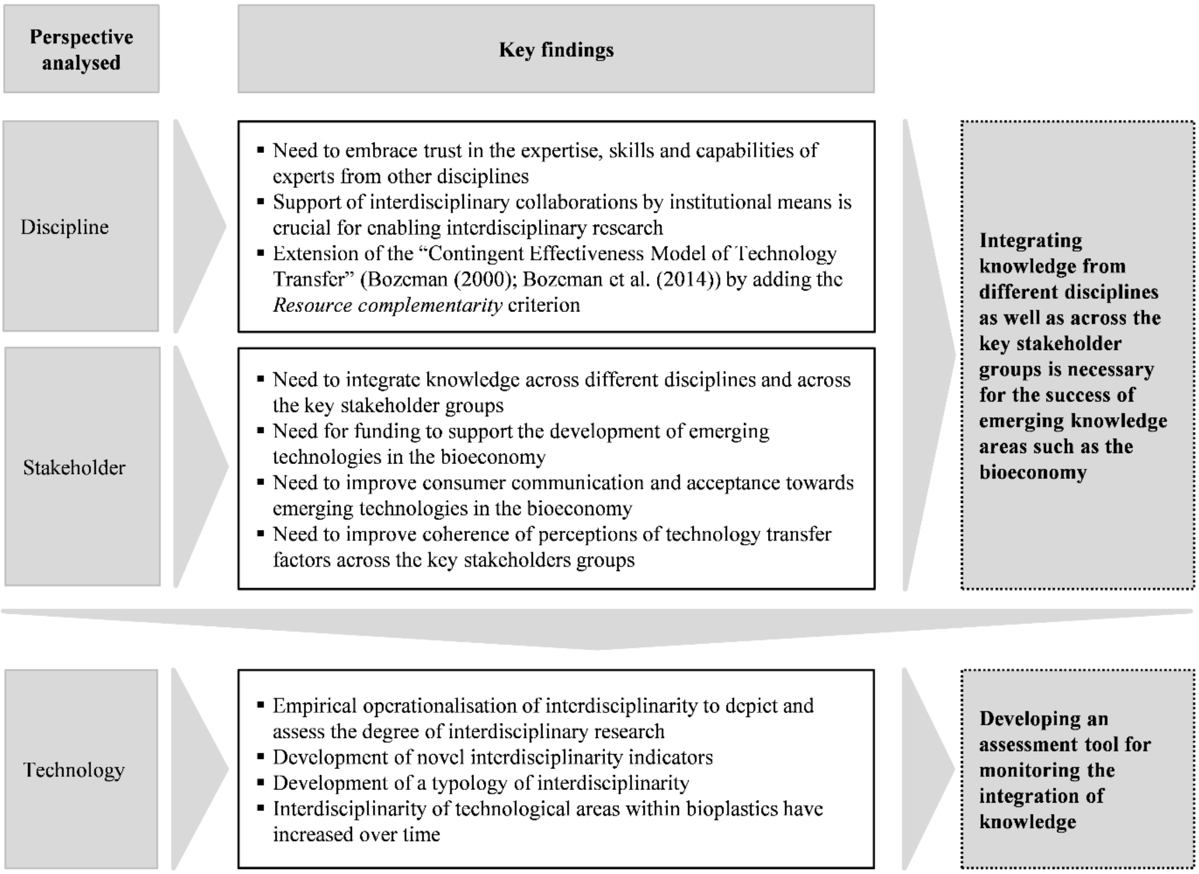

Figure 5-1: Narrative of the thesis[362]

5.2 Theoretical contributions of the thesis

In the following paragraphs the theoretical contributions of the thesis are explained with regard to each of the perspectives analysed: disciplines, stakeholders and technologies. From a theoretical background, the disciplinary perspective is used to derive a conceptual framework to assess effectiveness of technology transfer in interdisciplinary settings. The stakeholder perspective describes perceptions of factors influencing technology transfer from the point of view of the key stakeholder groups involved in technology transfer. The technology perspective develops a novel assessment approach that can be used to depict and assess the degree of interdisciplinarity at the level of technological areas.

[362] Source: Own Figure.

A) Technology transfer from a disciplinary perspective

The present work utilises the RBV to understand how technology transfer in interdisciplinary settings work. During the R&D&I process, firms[363] try to gain competitive advantage.[364] This competitive advantage is based on the combination of new/existing resources and competencies of a firm.[365] Hence, in the context of collaborative innovation across disciplines, experts with different disciplinary backgrounds share their knowledge to develop new knowledge and technologies.[366] In particular, this thesis applies the "Contingent Effectiveness Model of Technology Transfer" developed by Bozeman (2000)[367] as a conceptual framework to investigate how technology transfer in interdisciplinary settings such as the bioeconomy can be assessed.

As a result, this thesis extends this model by adding a new effectiveness criterion: *Resource complementarity*. Resource complementarity refers to the effect of technology transfer on the capacity to create new knowledge and technologies based on the interaction of partners from different disciplines. This complements the RBV as the academic research groups and the spin-offs benefit, and thus gain competitive advantage, by combining knowledge from different disciplines within the bioeconomy.[368] Consequently, the present work presents a modified version of the "Contingent Effectiveness Model of Technology Transfer"[369] to be used for assessing technology transfer in highly interdisciplinary and emerging areas. In this context, this thesis contributes by improving the academic understanding of how technology transfer develops in the specific interdisciplinary setting of the bioeconomy. In this regard, this study indicates that support for interdisciplinary collaborations through institutional and organisational means is crucial to enable interdisciplinary research and technology transfer in the bioeconomy.

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[363] For the context of this thesis, firms refer to academic research groups and spin-offs. This is in line with other studies, see e.g. Mustar er.al (2006), Powers and McDougall (2005) that have considered spin-offs as the unit of analysis.

[364] Penrose (1995).

[365] Barney et al. (2001); Penrose (1995).

[366] Barney (1991); Barney et al. (2001); Penrose (1995).

[367] Bozeman (2000); Bozeman et al. (2014).

[368] Barney (1991); Barney et al. (2001); Penrose (1995).

[369] Bozeman (2000); Bozeman et al. (2014).

B) Technology transfer from a stakeholder perspective

This thesis draws upon microfoundations[370] and stakeholder theory[371] to identify perceptions of factors affecting technology transfer in the interdisciplinary setting of the bioeconomy from the perspective of the key stakeholders that are part of the technology transfer process. In doing so, this work is able to integrate and represent the unified mental model of the key stakeholder groups. In addition, this research compares the findings regarding the extent to which different stakeholder groups identify perceptions as being equally important (or unimportant). Consequently, this thesis presents a novel contribution by incorporating the microfoundations perspective and the stakeholder theory to technology transfer. This contributes to the technology transfer literature, which has emphasised the need for more studies that specifically examine the individual role, behaviours and perceptions of the key stakeholder groups in the technology transfer process. [372]

Furthermore, this thesis enriches and extends previous empirical studies[373] on factors affecting technology transfer. Previous empirical investigations classified factors affecting technology transfer into three main categories[374]: Individual factors (i.e. characteristics of scientists such as age, previous commercialisation experience, grants awarded), organisational factors (e.g. the quality of university/departments, organisational design, types of processes or existence of incentives) and institutional factors (e.g. one's scientific discipline or the impact of public policies). The microfoundations and stakeholder theory perspectives enable the bottom-up identification of market-related factors, which are not presently mentioned in the technology transfer literature. Hence, this emerging category (*Market factors*) refers to perceptions of the market environment that facilities or inhibits technology transfer. This new category appears to be especially important for technology transfer in emerging knowledge areas such as the bioeconomy. From the methodological point of view, this thesis presents a unique contribution by employing a novel methodological approach in technology transfer - that of the group concept mapping.

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[370] Barney and Felin (2013); Felin et al. (2012).

[371] Freeman et al. (2010); Harrison and Wicks (2013).

[372] See e.g. Ankrah et al. (2013); Bradley et al. (2013); Cunningham and O'Reilly (2018).

[373] Phan and Siegel (2006); Siegel et al. (2004).

[374] Phan and Siegel (2006); Siegel et al. (2004).

C) Technology transfer from a technology perspective

This thesis builds upon existing indicators that have been used to assess interdisciplinarity.[375] Thus, the present work delivers a novel assessment approach to depict and assess the degree of interdisciplinarity by using technological areas derived from the IPC-Technology Concordance Table[376] as key units of analysis. By applying this framework to the case of bioplastics, this thesis provides an initial demonstration of how novel patent indicators could be applied to other emerging knowledge areas to assess the degree of interdisciplinarity. This work employs co-citation analysis of patents. This is in line with previous studies[377] that have agreed that co-citation analysis captures the interdisciplinary knowledge more accurately than co-authorship or co-classification analyses.

Previous indicators have drawn upon publications to assess the interdisciplinarity of a scientific paper or a research field.[378] With regard to the use of patents to develop indicators to evaluate interdisciplinarity, the current literature has been limited to visualise technological areas on network maps[379], without the ability to assess the degree of interdisciplinarity. Hence, the present work presents a first operationalisation to assess the degree of interdisciplinarity at the level of technological areas by drawing upon patent data. Specifically, the *total interdisciplinarity technological area* ($I_{(i)}$) extends the study by Porter and Rafols (2009), who construct an indicator that accounts for the number of different knowledge areas a given paper cites. This novel indicator measures the self-citations a technological area draws upon relative to the total number of citations. The *total interdisciplinarity sector* ($Is_{(i)}$) extends previous studies[380] that capture the scale breadth (number of categories) of the knowledge base of a paper. Thus, this indicator measures the number of sectors involved in the citations a technological area draws upon.

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375 Leydesdorff et al. (2018); Leydesdorff and Rafols (2011); Porter et al. (2007); Porter and Rafols (2009); Rafols et al. (2010); Rafols et al. (2012).

376 Schmoch (2008).

377 Porter et al. (2007); Rafols and Meyer (2010).

378 Leydesdorff et al. (2018); Leydesdorff and Rafols (2011); Porter et al. (2007); Porter and Rafols (2009); Rafols et al. (2010); Rafols et al. (2012).

379 Kay et al. (2014); Yan and Luo (2017).

380 Porter et al. (2007); Stirling (2007); Rafols and Meyer (2010).

Furthermore, this thesis constructs a *typology* that combines $I_{(i)}$ and $Is_{(i)}$ and thus is able to capture the degree of interdisciplinarity within a technology network. This extends the study by Porter et al. (2007), who developed a typology that measures on the one hand, the extent to which a publication cites diverse subject categories[381] (Integration). On the other hand, the spread of scientific categories in which the body of research is published (Specialisation). The novel typology measures (1) the extent to which a technological area cites technological areas stemming from outside the own technological area (as Integration[382]), and (2) the diversity of sectors involved in the citations a technological area draws upon. In this way, this thesis contributes to advancing the state-of-the-art with regard to the use of interdisciplinary indicators.

5.3 Practical contributions of the thesis

This thesis presents implications for funding agencies and policy-makers, academic scientists and institutions, technology transfer offices and firms. The empirical study presented in Chapter 2 provides insights into the particularities of interdisciplinary research and into factors that can lead to effectiveness of technology transfer in interdisciplinary settings. This presents implications for academic institutions and firms. Chapter 3 extends these implications to technology transfer offices by including the entire spectrum of stakeholder groups involved in technology transfer. Chapter 4 provides implications for academic scientists, academic institutions, firms, funding agencies and policy-makers on assessing the degree of interdisciplinarity. Hence, practical implications are presented in the following sequential order[383]: funding agencies and policy-makers (as providers of funding), academic scientists and academic institutions (as receivers of funding and producers of knowledge), technology transfer offices (as intermediaries between, on the one hand, academic scientists and academic

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[381] Subject categories are a set of categories established by the Web of Sciences that match journals with disciplines (subject categories). In total, there are more approximately 225 subject categories as of 2010.

[382] See Porter et al. (2007).

[383] This sequential order is similar to the concept of the innovation value chain introduced by Hansen and Birkinshaw (2007). Following this study, innovation across the value chain follows an integrated flow comprising idea generation, conversion of ideas and diffusion of ideas. The first two phases (idea generation and conversion) correspond to the early R&D phase in general value chains. These phases consist of the discovery of new knowledge, which is used to make or improve new products. These phases might resemble the role of funding agencies, policy-makers, academic scientists and academic institutions. The diffusion of ideas corresponds to the commercilisation phase in general value chains and might appear like the role of technology transfer offices and firms, which have a more market-oriented view of technology transfer.

institutions and, on the other hand, firms), and firms (as commercialising and diffusing knowledge).

5.3.1 Implications for funding agencies and policy-makers

This thesis identifies five major implications for funding agencies and policy-makers. Firstly, funding agencies and policy-makers may facilitate cooperation among experts from different disciplines as well as collaboration between academia and industry by providing funding instruments that foster these collaborations. Such funding instruments can make collaborations mandatory (e.g. between different disciplines or between academia and industry) in research proposals in order to obtain funding.

Secondly, funding agencies and policy-makers may also foster the integration of pilot and scaling-up facilities in research proposals to demonstrate the feasibility of interdisciplinary technologies. In a similar vein, funding agencies and policy-makers may also provide commercialisation grants and support business plan contests that require collaborations across different disciplines as well as collaborations with spin-offs or companies.

Fourthly, funding agencies and policy-makers may benefit from using the novel indicators and the network maps to design and develop science and innovation policies in highly interdisciplinary and emerging knowledge areas. Therefore, this novel approach can help funding agencies and policy-makers identify technological areas in interdisciplinary settings where investments may pay off.

Finally, funding agencies and policy-makers may also benefit from using the novel indicators and the network maps to develop and design funding instruments that foster interdisciplinary collaborations. Through these novel indicators, funding agencies and policy-makers may identify those disciplines or technological areas that might be mandatorily integrated in research proposals in order to foster interdisciplinary research.

5.3.2 Implications for academic scientists and academic institutions

The present thesis proposes five implications for academic scientists and institutions. Firstly, academic scientists could benefit from interacting with other academic scientists with different disciplinary backgrounds. In a similar vein, academic institutions may benefit by recruiting staff with different backgrounds and even staff who demonstrate interdisciplinary competencies including team functioning, collaborative leadership, communication and sufficient professional knowledge and experience. Thus, academic scientists and institutions need to embrace trust in the expertise, skills, motivation and capabilities of other experts from different fields.[384] This may enable interdisciplinary research by generating a common ground that integrates information, data, techniques, tools, perspectives, concepts and/or theories to solve global challenges.[385]

Secondly, academic scientists could also benefit from collaborating with industry partners.[386] This collaboration could be developed in two complementary ways: Firstly, by having projects that involve both academia and industry.[387] Secondly, through exchange programmes that allow academic scientists to work in industry.[388]

Thirdly, academic institutions could also benefit from institutionalising interdisciplinary departments at academic institutions. An example of this is the recently implemented Digital Science Center (DiCe) at the University of Bonn. The aim of the DiCe is to centralise all university activities in the field of IT under one umbrella, comprising three research areas: computer science, information science and the humanities.[389] The goal of the DiCe is to master digital structural changes in science, industry and society and thus, to contribute to digitalisation at university level.

Fourthly, as research becomes more complex as it is increasingly combining knowledge from two or more disciplines or technologies, the use of empirically grounded tools for science management and planning is foreseen.[390] Thus, the novel patent approach can be used by academic scientists and institutions to identify key disciplines to conduct research on a particular topic, and thus identify experts with relevant knowledge to conduct research related to that particular field.

Finally, academic scientists and academic institutions may also benefit by using the developed novel approach and the network maps to identify disciplines that are closely related together.

[384] This is also supported by Bassett-Jones (2005); MacLeod (2016).

[385] Following the definition of interdisciplinary research as in Porter et al. (2006, p. 189).

[386] This is in line with Azagra-Caro et al. (2016); Fuentes and Dutrénit (2012); Motohashi and Muramatsu (2012); van Looy et al. (2006).

[387] See e.g. Valentin and Jensen (2007).

[388] See e.g. Autant-Bernard et al. (2013); Azagra-Caro et al. (2016).

[389] Further information about DiCe available at: https://www.uni-bonn.de/neues/255-2018.

[390] Anzai et al. (2012); Ávila-Robinson and Sengoku (2017).

Based on this, these stakeholders can understand and plan collaborations with experts that have the necessary background to conduct research on a specific topic.

5.3.3 Implications for technology transfer offices

Overall, this thesis identifies four major implications for technology transfer offices. Firstly, technology transfer offices may be aware of the different perceptions, objectives, values and motivations between academic scientists and firms. Thus, technology transfer offices may encourage and support mutual benefits of stakeholder relationships and may adapt their efforts to the needs of the specific stakeholder groups.[391]

Secondly, technology transfer offices may facilitate relationships between academia and industry by providing funding for training courses for academic scientists on technology transfer and commercialisation matters. Furthermore, technology transfer offices may provide funding for exchange programmes between academia and industry (e.g. academic scientists who work in industry for a period of time). In a similar vein, technology transfer offices may foster collaborations across academic scientists from different disciplines by providing funding for scientists to work in another field.

Finally, resulting from the study of technology transfer from a stakeholder perspective, technology transfer offices may take into account the consumer acceptance of new technologies in emerging knowledge areas such as the bioeconomy when scanning new ideas. Hence, technology transfer offices need to develop and disseminate the market-orientation, i.e. the awareness that the role of consumer/societal acceptance needs to be taken into account before investing and providing commercialisation services for new technologies in this field.

5.3.4 Implications for firms

Three major implications of this thesis for firms could be identified. Firstly, industry would benefit from collaborating with academic scientists.[392] This collaboration could be developed in two complementary ways: First, by having projects that involved both industry and academic scientists.[393] Second, by having exchange programmes that allow industrial partners to work in

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[391] This is also supported by Rogers (2003); Siegel et al. (2004).

[392] This is in line with Azagra-Caro et al. (2016); Fuentes and Dutrénit (2012); Motohashi and Muramatsu (2012); van Looy et al. (2006).

[393] See e.g. Valentin and Jensen (2007).

an academic institution. Secondly, along with academic institutions, firms may also benefit by recruiting staff with different disciplinary backgrounds and even staff who demonstrate interdisciplinary competencies.

Finally, along with academic scientists and academic institutions, firms may benefit from using the novel approach and the network maps to manage and plan the staff recruitment with the needed knowledge and expertise to conduct R&D&I on a specific technology or product.

To sum up, it can be said that in order to achieve successful technology transfer in emerging knowledge areas such as the bioeconomy, there seems to be a need for establishing institutional framework conditions that foster interdisciplinary research and technology transfer. Such frameworks can facilitate collaborations among academic scientists from different disciplines and between academia and industry. Stakeholders may use empirically grounded tools for R&D planning and management, such as the novel approach presented in this thesis, in order to develop strategies and policies aimed at fostering interdisciplinary research and technology transfer.

5.4 Limitations and directions for future research

First of all, the present studies focus on the particular case of the bioeconomy as an example of an emerging and highly interdisciplinary knowledge area. As such, this thesis delivers approaches to be validated in future studies analysing other emerging knowledge areas. In doing so, these frameworks can be extended to the particularities of other interdisciplinary and emerging settings, such as bioinformatics, ICT, nanotechnology, or neurosciences. The limitations and research avenues with respect to the perspectives analysed are presented in the following paragraphs.

Technology transfer from a disciplinary perspective: The multiple case study research along with grounded theory presented in Chapter 2 of this thesis cannot provide a holistic view of the entire field of interdisciplinarity in the bioeconomy. Future studies can increase the sample size by including the analysis of more academic research groups and spin-offs. This study also presents a certain degree of subjectivity in the analysis of the case studies with regard to the coding system. To mitigate this potential bias, a careful analysis to inductively reveal the categories was performed by two independent scientists. Future research could extend the analysis to universities and spin-offs located in other regions of Germany or to other countries for comparative purposes. Longitudinal case studies could be conducted to evaluate whether and how universities and spin-offs change technology transfer and interdisciplinary practices in the long run.

Technology transfer from a stakeholder perspective: The study from the perspective of stakeholders presented in Chapter 3 of this thesis has limitations regarding sample size and generalisability. This work can be expanded by using a larger sample size of stakeholders who participate in sorting and rating to improve its validity. In addition, academic stakeholders were selected based on their knowledge and experience in technology transfer. This may present a potential bias, as these stakeholders are likely to be more market-oriented than the general population of academic scientists. Future research could benefit from considering a more diverse population of stakeholders to analyse whether different perceptions of factors affecting technology transfer emerge.

Technology transfer from a technology perspective: The methodological limitation to the study in Chapter 4 is primarily related to the use of patent families. This study was carried out using patent families and cited patent applications, thus including patents from all patent authorities. However, there are differences between the patent systems when it comes to citations. For example, in the US system, the patent applicant and his attorney are obliged to present to the patent examiner a complete list of relevant prior art for inclusion on the patent front page.[394] But in the EPO system the initial prior art search is carried out by a searcher at the EPO and should only include the most important patent references. That implies that US patents might tend to be more interdisciplinary than patents from other authorities, as the former presents a higher number of citations.

A second limitation of this study is that the frequency of citations of prior patents is used as a proxy for interdisciplinarity and importance of a technological area. Another limitation is that the IPC-Technology Concordance Table[395] was used as a basis for the analysis to link IPC codes with technological areas and to derive the indicators. Therefore, there might be some limitations to the use of this table, and one could create even finer-grained indicators by considering IPC groups and sub-groups. In the same line, this research is limited to technological areas of patents. However, it does not show companies R&D efforts to develop bioplastics in these technological areas, nor the innovation strength in the highly interdisciplinary and emerging

[394] Michel and Bettels (2001).

[395] Schmoch (2008).

field of bioplastics. Future research could benefit by extending this current approach by taking into account company data or assignees of patents to assess the innovation impact on technologies developed at the interface of several technological areas.

Overall, this thesis proposes to test the derived frameworks to other interdisciplinary and emerging settings to deliver empirical demonstrations of their applicability in other interdisciplinary and emerging knowledge areas. Furthermore, a comprehensive review of strategies fostering interdisciplinary research in the bioeconomy could improve the understanding of how different strategies have developed and how these have promoted interdisciplinarity. This could contribute to recommend best practices to foster interdisciplinary research and technology transfer.

References

Adams, J., Jackson, L. and Marshall, S. (2007) ‘Bibliometric analysis of interdisciplinary research’, *Report to Higher Education Funding Council for England*.

Aeschelmann, F. and Carus, M. (2015) ‘Biobased building blocks and polymers in the world: capacities, production, and applications–status quo and trends towards 2020’, *Industrial Biotechnology*, vol. 11, no. 3, pp. 154–159.

Aharonson, B. S. and Schilling, M. A. (2016) ‘Mapping the technological landscape: Measuring technology distance, technological footprints, and technology evolution’, *Research Policy*, vol. 45, no. 1, pp. 81–96.

Albors-Garrigos, J., Hervas-Oliver, J. L. and Hidalgo, A. (2009) ‘Analysing high technology adoption and impact within public supported high tech programs: An empirical case’, *The Journal of High Technology Management Research*, vol. 20, no. 2, pp. 153–168 [Online]. DOI: 10.1016/j.hitech.2009.09.006.

Alcacer, J. and Gittelman, M. (2006) ‘Patent citations as a measure of knowledge flows: The influence of examiner citations’, *The Review of Economics and Statistics*, vol. 88, no. 4, pp. 774–779.

Alves, J., Marques, M. J., Saur, I. and Marques, P. (2007) ‘Creativity and innovation through multidisciplinary and multisectoral cooperation’, *Creativity and Innovation Management*, vol. 16, no. 1, pp. 27–34.

Ankrah, S. N., Burgess, T. F., Grimshaw, P. and Shaw, N. E. (2013) ‘Asking both university and industry actors about their engagement in knowledge transfer: What single-group studies of motives omit’, *Technovation*, vol. 33, no. 2, pp. 50–65.

Anzai, T., Kusama, R., Kodama, H. and Sengoku, S. (2012) ‘Holistic observation and monitoring of the impact of interdisciplinary academic research projects: An empirical assessment in Japan’, *Managing Technology*, vol. 32, no. 6, pp. 345–357.

Audretsch, D. B., Lehmann, E. E. and Wright, M. (2014) ‘Technology transfer in a global economy’, *The Journal of Technology Transfer*, vol. 39, no. 3, pp. 301–312.

Autant-Bernard, C., Fadairo, M. and Massard, N. (2013) ‘Knowledge diffusion and innovation policies within the European regions: Challenges based on recent empirical evidence’, *Research Policy*, vol. 42, no. 1, pp. 196–210.

AUTM *AUTM* [Online]. Available at http://www.autm.net/autm-info/about-tech-transfer/about-technology-transfer/. Last accessed: 16.12.2018

Azagra-Caro, J. M., Barberá-Tomás, D., Edwards-Schachter, M. and Tur, E. M. (2016) ‘Dynamic interactions between university-industry knowledge transfer channels: A case study of the most highly cited academic patent’, *Research Policy*, vol. 46, no. 2, pp.463–474.

Ávila-Robinson, A. and Sengoku, S. (2017) ‘Multilevel exploration of the realities of interdisciplinary research centers for the management of knowledge integration’, *Technovation*, vol. 62, pp. 22–41.

Babu, R. P., O’connor, K. and Seeram, R. (2013) ‘Current progress on bio-based polymers and their future trends’, *Progress in Biomaterials*, vol. 2, no. 1, p. 8.

Barjak, F. (2006) *Team diversity and research collaboration in life sciences teams: Does a combination of research cultures pay off?*, Fachhochschule Nordwestschweiz, Hochschule für Wirtschaft.

Barney, J. (1991). ‘Firm resources and sustained competitive advantage’, *Journal of management*, vol. 17, no. 1, pp. 99–120.

Barney, J., Wright, M. and Ketchen Jr, D.J. (2001). 'The resource-based view of the firm: Ten years after 1991', *Journal of management*, vol. 27, no. 6, pp. 625–641.

Barney, J. and Felin, T. (2013) 'What are microfoundations?', *The Academy of Management Perspectives*, vol. 27, no. 2, pp. 138–155.

Bassett-Jones, N. (2005) 'The paradox of diversity management, creativity and innovation', *Creativity and Innovation Management*, vol. 14, no. 2, pp. 169–175.

Berg, S., Cloutier, L. M. and Bröring, S. (2018) 'Collective stakeholder representations and perceptions of drivers of novel biomass-based value chains', *Journal of Cleaner Production*, vol. 200, pp. 231–241.

Berg, S., Wustmans, M. and Bröring, S. (2018) 'Identifying first signals of emerging dominance in a technological innovation system: A novel approach based on patents', *Technological Forecasting and Social Change*.

Biancani, S., Dahlander, L., McFarland, D. A. and Smith, S. (2018) 'Superstars in the making? The broad effects of interdisciplinary centers', *Research Policy*, vol. 47, no. 3, pp. 543–557 [Online]. DOI: 10.1016/j.respol.2018.01.014.

Blackstone, S., Iwelunmor, J., Plange-Rhule, J., Gyamfi, J., Quakyi, N. K., Ntim, M. and Ogedegbe, G. (2017) 'Sustaining Nurse-Led Task-Shifting Strategies for Hypertension Control: A Concept Mapping Study to Inform Evidence-Based Practice', *Worldviews on Evidence-Based Nursing*.

Boehlje, M. and Bröring, S. (2011) 'The increasing multifunctionality of agricultural raw materials: Three dilemmas for innovation and adoption', *International Food and Agribusiness Management Review*, vol. 14, no. 2, pp. 1–16.

Bordons, M., Zulueta, M. A., Romero, F. and Barrigón, S. (1999) 'Measuring interdisciplinary collaboration within a university: The effects of the multidisciplinary research programme', *Scientometrics*, vol. 46, no. 3, pp. 383–398.

Borgatti, S. P., Everett, M. G. and Freeman, L. C. (2002) 'Ucinet for Windows: Software for social network analysis'.

Borgatti, S. P., Mehra, A., Brass, D. J. and Labianca, G. (2009) 'Network analysis in the social sciences', *science*, vol. 323, no. 5916, pp. 892–895.

Borge, L. and Bröring, S. (2017) 'Exploring effectiveness of technology transfer in interdisciplinary settings: The case of the bioeconomy', *Creativity and Innovation Management*, vol. 26, no. 3, pp. 311–322.

Borge, L. and Bröring, S. (2018) 'What affects technology transfer in emerging knowledge areas? A multi-stakeholder concept mapping study in the bioeconomy', *The Journal of Technology Transfer*, in press pp. 1–31.

Bornkessel, S., Bröring, S. and Omta, S.W.F. (2016) 'Crossing industrial boundaries at the pharma-nutrition interface in probiotics: A life cycle perspective', *PharmaNutrition*, vol. 4, no. 1, pp. 29–37.

Bozeman, B. (2000) 'Technology transfer and public policy: a review of research and theory', *Research Policy*, vol. 29, 4-5, pp. 627–655.

Bozeman, B., Rimes, H. and Youtie, J. (2014) 'The evolving state-of-the-art in technology transfer research: Revisiting the contingent effectiveness model', *Research Policy*, vol. 44, no. 1, pp. 34–49 [Online]. DOI: 10.1016/j.respol.2014.06.008.

Bradley, S. R., Hayter, C. S. and Link, A. N. (2013) 'Models and methods of university technology transfer', *Foundations and Trends® in Entrepreneurship*, vol. 9, no. 6, pp. 571–650.

Brandes, U., Robins, G., McCranie, A. and Wasserman, S. (2013) 'What is network science?', *Network Science*, vol. 1, no. 1, pp. 1–15.

Bröring, S. (2005) 'The front end of innovation in converging industries. The case of nutraceuticals and functional foods', Gabler Edition Wissenschaft: Betriebswirtschaftliche Studien in forschungsintensiven Industrien, Dt. Univ', *Verl., Wiesbaden*.

Bröring, S. (2010) 'Developing innovation strategies in times of market convergence', *International Journal of Technology Management*, Special Issue on Technology Convergence, vol. 49, no. (1/2), pp. 272–294.

Bröring, S., Cloutier, L. M. and Leker, J. (2006) 'The front end of innovation in an era of industry convergence: evidence from nutraceuticals and functional foods', *R&D Management*, vol. 36, no. 5, pp. 487–498.

Bruns, H. C. (2013) 'Working alone together: Coordination in collaboration across domains of expertise', *Academy of management journal*, vol. 56, no. 1, pp. 62–83.

Butts, C. T. (2009) 'Revisiting the foundations of network analysis', *Science*, vol. 325, no. 5939, pp. 414–416.

Carus, M., Kamp, M. and Lohmeyer, D. (2000) 'Study on Markets and Price Situation of Natural Fibres (Germany and EU)', *Nova Institute, Germany*.

Cassi, L., Champeimont, R., Mescheba, W. and Turckheim, É. de (2017) 'Analysing Institutions Interdisciplinarity by Extensive Use of Rao-Stirling Diversity Index', *PLOS ONE*, vol. 12, no. 1, e0170296.

Chesbrough, H. W. (2003) *Open Innovation: The New Imperative for Creating and Profiting from Technology*, Harvard Business School Press, Boston.

Clarysse, B., Wright, M., Lockett, A., Van de Velde, E. and Vohora, A. (2005). 'Spinning out new ventures: a typology of incubation strategies from European research institutions', *Journal of Business venturing*, vol. 20, no. 2, pp.183–216.

Cloutier, L. M., Cueille, S. and Recasens, G. (2017) '5. Entrepreneurs' perspectives on the structuring phase of the entrepreneurial team', in Ben-Hafaïedh C. and Cooney T. M. (Eds.), *Research Handbook on Entrepreneurial Teams: Theory and Practice*, pp. 96–120, Edward Elgar Publishing, Cheltenham.

Cloutier, L. M. and Spooner, M. P., eds. (2016) '*Closing Gaps in Professional Service Delivery Processes: A Mixed Method-Based Analysis of Clinical Research Project Budget Management*', in DiMauro C., Ancarani, A. and Vastag G. (Eds.), *Research in the decision sciences for the service economy*, pp. 33–52, Pearson Inc., New York.

Concept System Incorporated (2017) *Concept System Incorporated: Concept System Incorporated* [Computer program].

Costa-Font, J. and Mossialos, E. (2006) 'The public as a limit to technology transfer: the influence of knowledge and beliefs in attitudes towards biotechnology in the UK', *The Journal of Technology Transfer*, vol. 31, no. 6, pp. 629–645.

Cunningham, J. A., Menter, M. and Young, C. (2016) 'A review of qualitative case methods trends and themes used in technology transfer research', *The Journal of Technology Transfer*, pp. 1–34.

Cunningham, J. A., O'Reilly, P. (2018) 'Macro, meso and micro perspectives of technology transfer', *The Journal of Technology Transfer*, vol.43, pp. 545–557.

Curran, C.-S., Bröring, S. and Leker, J. (2010) 'Anticipating converging industries using publicly available data', *Technological Forecasting and Social Change*, vol. 77, no. 3, pp. 385–395.

Dahabieh, M. S., Bröring, S. and Maine, E. (2018) 'Overcoming barriers to innovation in food and agricultural biotechnology', *PathogenCombat – Unique achievements in the fight against pathogens*, vol. 79, pp. 204–213.

Dalgaard, T., Hutchings, N. J. and Porter, J. R. (2003) 'Agroecology, scaling and interdisciplinarity', *Agriculture, Ecosystems & Environment*, vol. 100, no. 1, pp. 39–51.

Day, G. S., Schoemaker, P. J. H. and Gunther, R. E. (2004) *Wharton on managing emerging technologies*, John Wiley & Sons.

Derwent Innovation [Online]. Available at https://clarivate.com/products/derwent-world-patents-index/. Last accessed: 14.10.2018

Dingler, A. and Enkel, E. (2016) 'Socialization and innovation: Insights from collaboration across industry boundaries: (Aspects of socialization for innovation)', *Technological Forecasting and Social Change*, vol. 109, pp.50–60.

Ehrlich, K. and Carboni, I. (2005) 'Inside social network analysis', *Boston College*.

Eisenhardt, K. M. (1989) 'Building theories from case study research', *Academy of management review*, vol. 14, no. 4, pp. 532–550.

Elvers, D., Song, C. H., Steinbüchel, A. and Leker, J. (2016) 'Technology Trends in Biodegradable Polymers: Evidence from Patent Analysis', *Polymer Reviews*, vol. 56, no. 4, pp. 584–606.

Etzkowitz, H., Webster, A., Gebhardt, C. and Terra, Branca Regina Cantisano (2000) 'The future of the university and the university of the future: evolution of ivory tower to entrepreneurial paradigm', *Research Policy*, vol. 29, no. 2, pp. 313–330.

European Bioplastics [Online]. Available at https://www.european-bioplastics.org/. Last accessed: 16.10.2018

European Commission (2007) *Improving Knowledge Transfer Between Research Institutions and Industry across Europe: Embracing open innovation. Implementing the Lisbon Agenda.* [Online], Brussels, Publications Office of the European Union.

European Commission (2008a) *Commission Recommendation on the Management of Intellectual Property In Knowledge Transfer Activities and Code of Practice for Universities and Other Public Research Organizations* [Online], Brussels, Publications Office of the European Union.

European Commission (2008b) *Commission urges Member States and public research organizations to better convert knowledge into socio-economic benefits* [Online], Brussels, Publications Office of the European Union.

European Commission (2012a) *Entrepreneurship 2020 Action Plan* [Online], Brussels, Publications Office of the European Union.

European Commission (2012b) *Innovating for sustainable growth: a bioeconomy for Europe*, Brussels, Publications Office of the European Union.

European Commission (2013) *Regulation no. 1290/2013 of the European Parliament and of the council of 11 December 2013 laying down the rules for participation and dissemination in "Horizon 2020 — The framework Programme for research and innovation (2014-2020)"*, L347, pp. 81–103.

European Commission (2018a) *A European Strategy for plastics in a circular economy*, Brussels.

European Commission (28/05/2018b) *Single-use plastics: New EU rules to reduce marine litter*, Brussels.

Everitt, B. (1980) *Cluster analysis (2nd)* [Online], New York: Halsted Press.

Felin, T., Foss, N. J., Heimeriks, K. H. and Madsen, T. L. (2012) ‘Microfoundations of routines and capabilities: Individuals, processes, and structure’, *Journal of Management Studies*, vol. 49, no. 8, pp. 1351–1374.

Foss, N. J. (2010) ‘Micro-foundations for management research: What, why, and whither?’, *Cuadernos de Economía y Dirección de la Empresa*, vol. 13, no. 42, pp. 11–34.

Foss, N. J. and Lindenberg, S. (2013) ‘Microfoundations for strategy: A goal-framing perspective on the drivers of value creation’, *The Academy of Management Perspectives*, vol. 27, no. 2, pp. 85–102.

Freeman, R. E., Harrison, J. S., Wicks, A. C., Parmar, B. L. and Colle, S. de (2010) *Stakeholder theory: The state of the art*, Cambridge university press.

Fuentes, C. de and Dutrénit, G. (2012) ‘Best channels of academia–industry interaction for long-term benefit’, *Research Policy*, vol. 41, no. 9, pp. 1666–1682.

Garcia, R. and Calantone, R. (2002) ‘A critical look at technological innovation typology and innovativeness terminology: a literature review’, *Journal of Product Innovation Management*, vol. 19, no. 2, pp. 110–132.

Gilbert, M. and Cordey-Hayes, M. (1996) ‘Understanding the process of knowledge transfer to achieve successful technological innovation’, *Technovation*, vol. 16, no. 6, pp. 301–312 [Online]. DOI: 10.1016/0166-4972(96)00012-0.

Gilsing, V., Bekkers, R., Bodas Freitas, I. M. and van der Steen, M. (2011) ‘Differences in technology transfer between science-based and development-based industries: Transfer mechanisms and barriers’, *Technovation*, vol. 31, no. 12, pp. 638–647.

Glasser, S., Strauss, A. L. (1967) *The Discovery of Grounded Theory. Strategies for Qualitative Research*. Aldine Transaction.

Goeldner, M., Herstatt, C. and Tietze, F. (2015) ‘The emergence of care robotics — A patent and publication analysis’, *Technological Forecasting and Social Change*, vol. 92, pp. 115–131.

Golembiewski, B., Sick, N. and Bröring, S. (2015) ‘The emerging research landscape on bioeconomy: What has been done so far and what is essential from a technology and innovation management perspective?’, *Innovative Food Science & Emerging Technologies*, vol. 29, pp. 308–317 [Online]. DOI: 10.1016/j.ifset.2015.03.006.

Gopalakrishnan and Santoro (2004) ‘Distinguishing between knowledge transfer and technology transfer activities: the role of key organizational factors’, *Engineering Management*, vol. 51, pp. 57–69.

Groen, A. J. and Walsh, S. T. (2013) ‘Introduction to the field of emerging technology management’, *Creativity and Innovation Management*, vol. 22, no. 1, pp. 1–5.

Hall, B. H. (2007) ‘Patents and patent policy’, *Oxford Review of Economic Policy*, vol. 23, no. 4, pp. 568–587.

Hansen, M. T. and Birkinshaw J. (2007) ‘The Innovation Value Chain’, *Harvard Business Review*, vol. 85, no. 6, pp. 121-130.

Harrison, D. A. and Klein, K. J. (2007) ‘What'’ the difference? Diversity constructs as separation, variety, or disparity in organizations’, *Academy of management review*, vol. 32, no. 4, pp. 1199–1228.

Harrison, J. S. and Wicks, A. C. (2013) ‘Stakeholder theory, value, and firm performance’, *Business ethics quarterly*, vol. 23, no. 1, pp. 97–124.

Heinze, T., Shapira, P., Rogers, J. D. and Senker, J. M. (2009) 'Organizational and institutional influences on creativity in scientific research', *Research Policy,* vol. 38, no. 4, pp. 610–623 [Online]. DOI: 10.1016/j.respol.2009.01.014.

Hendriks, J. (2012) 'Technology transfer in human vaccinology: a retrospective review on public sector contributions in a privatizing science field', *Vaccine*, vol. 30, no. 44, pp. 6230–6240.

Hung, S.-C. and Chu, Y.-Y. (2006) 'Stimulating new industries from emerging technologies: challenges for the public sector', *Technovation*, vol. 26, no. 1, pp. 104–110.

Huutoniemi, K., Klein, J. T., Bruun, H. and Hukkinen, J. (2010) 'Analyzing interdisciplinarity: Typology and indicators', *Research Policy*, vol. 39, no. 1, pp. 79–88.

Jackson, K. M. and Trochim, W. M. K. (2002) 'Concept Mapping as an Alternative Approach for the Analysis of Open-Ended Survey Responses', *Organizational Research Methods*, vol. 5, no. 4, pp. 307–336.

Jaffe, A. B. and Trajtenberg, M. (2002) *Patents, citations, and innovations: A window on the knowledge economy*, MIT Press.

Janssens, K. A.M., Houtveen, J. H., Tak, L. M., Bonvanie, I. J., Scholtalbers, A., van Gils, A., Geenen, R. and Rosmalen, J. G.M. (2017) 'A concept mapping study on perpetuating factors of functional somatic symptoms from clinicians' perspective', *General Hospital Psychiatry*, vol. 44, pp. 51–60.

Johnson, D. B., Quinn, E., Sitaker, M., Ammerman, A., Byker, C., Dean, W., Fleischhacker, S., Kolodinsky, J., Pinard, C. and Pitts, Stephanie B Jilcott (2014) 'Developing an agenda for research about policies to improve access to healthy foods in rural communities: a concept mapping study', *BMC public health*, vol. 14, no. 1, p. 1.

Kane and Trochim (2007) *Concept Mapping for Planning and Evaluation*, Sage Publications.

Kay, L., Newman, N., Youtie, J., Porter, A. L. and Rafols, I. (2014) 'Patent overlay mapping: Visualizing technological distance', *Journal of the Association for Information Science and Technology*, vol. 65, no. 12, pp. 2432–2443.

Kitagawa, F. and Lightowler, C. (2012) 'Incentivising Knowledge Exchange: A Comparison of Vision, Strategies', *Policy and Practice in English and Scottish Higher Education*.

Klein, J. T. (2008) 'Evaluation of Interdisciplinary and Transdisciplinary Research: A Literature Review', *The Science of Team ScienceAssessing the Value of Transdisciplinary Research*, vol. 35, 2, Supplement, S116-S123 [Online]. DOI: 10.1016/j.amepre.2008.05.010.

Klein, J. T. and Falk-Krzesinski, H. J. (2017) 'Interdisciplinary and collaborative work: Framing promotion and tenure practices and policies', *Research Policy*, vol. 46, no. 6, pp.1055–1061.

Klenk, N. L. and Hickey, G. M. (2012) 'Improving the social robustness of research networks for sustainable natural resource management: Results of a Delphi study in Canada', *Science and Public Policy*, vol. 39, no. 3, pp. 357–372.

Krafft, J., Quatraro, F. and Saviotti, P. P. (2011) 'The knowledge-base evolution in biotechnology: a social network analysis', *Economics of Innovation and New Technology*, vol. 20, no. 5, pp. 445–475.

Kruskal, J. B. and Wish, M. (1978) *Multidimensional scaling. Number 07–011 in Sage University Paper series on quantitative applications in the social sciences* [Online], Sage Publications, Beverly Hills.

Langford, C. H., Hall, J., Josty, P., Matos, S. and Jacobson, A. (2006) 'Indicators and outcomes of Canadian university research: Proxies becoming goals?', *Research Policy*, vol. 35, no. 10, pp. 1586–1598.

Larsen, M. T. (2011) 'The implications of academic enterprise for public science: An overview of the empirical evidence', *Special Section on Heterogeneity and University-Industry Relations*, vol. 40, no. 1, pp. 6–19 [Online]. DOI: 10.1016/j.respol.2010.09.013.

Lee, H., Kim, C., Cho, H. and Park, Y. (2009) 'An ANP-based technology network for identification of core technologies: A case of telecommunication technologies', *Expert Systems with Applications*, vol. 36, no. 1, pp. 894–908.

Leydesdorff, L. (2007) 'Betweenness centrality as an indicator of the interdisciplinarity of scientific journals', *Journal of the American Society for Information Science and Technology*, vol. 58, no. 9, pp. 1303–1319.

Leydesdorff, L., Kushnir, D. and Rafols, I. (2014) 'Interactive overlay maps for US patent (USPTO) data based on International Patent Classification (IPC)', *Scientometrics*, vol. 98, no. 3, pp. 1583–1599.

Leydesdorff, L. and Rafols, I. (2011) 'Indicators of the interdisciplinarity of journals: Diversity, centrality, and citations', *Journal of informetrics*, vol. 5, no. 1, pp. 87–100 [Online]. DOI: 10.1016/j.joi.2010.09.002.

Leydesdorff, L., Wagner, C. S. and Bornmann, L. (2018) 'Betweenness and diversity in journal citation networks as measures of interdisciplinarity—A tribute to Eugene Garfield', *Scientometrics*, vol. 114, no. 2, pp. 567–592.

Link, A. N., Siegel, D. S. and Bozeman, B. (2007) 'An empirical analysis of the propensity of academics to engage in informal university technology transfer', *Industrial and Corporate Change*, vol. 16, no. 4, pp. 641–655.

Löfsten, H. and Lindelöf, P. (2002) 'Science Parks and the growth of new technology-based firms—academic-industry links, innovation and markets', *Research Policy*, vol. 31, no. 6, pp. 859–876 [Online]. DOI: 10.1016/S0048-7333(01)00153-6.

Maciejczak, M. (2017) 'Bioeconomy as a Complex Adaptive System of Sustainable Development', *Marketing*, vol. 2, no. 2.

MacLeod, M. (2016) 'What makes interdisciplinarity difficult? Some consequences of domain specificity in interdisciplinary practice', *Synthese*, pp. 1–24.

Maine, E., Thomas, V. J. and Utterback, J. (2014) 'Radical innovation from the confluence of technologies: Innovation management strategies for the emerging nanobiotechnology industry', *Special Issue on Emergence of Technologies: Methods and Tools for Management*, vol. 32, pp. 1–25.

Mansfield, E. (1983) *Technology Transfer, Productivity, and Economic Policy*, W. W. Norton &Co. Inc, New York.

McCormick, K. and Kautto, N. (2013) 'The bioeconomy in Europe: An overview', *Sustainability*, vol. 5, no. 6, pp. 2589–2608.

McMillan, G. S., Narin, F. and Deeds, D. L. (2000) 'An analysis of the critical role of public science in innovation: the case of biotechnology', *Research Policy*, vol. 29, no. 1, pp. 1–8 [Online]. DOI: 10.1016/S0048-7333(99)00030-X.

Melkers, J. and Xiao, F. (2012) 'Boundary-spanning in emerging technology research: Determinants of funding success for academic scientists', *The Journal of Technology Transfer*, vol. 37, no. 3, pp. 251–270.

Michel, J. and Bettels, B. (2001) 'Patent citation analysis. A closer look at the basic input data from patent search reports', *Scientometrics*, vol. 51, no. 1, pp. 185–201.

Miles, M. B. and Huberman, A. M. (1984) *Qualitative data analysis: A sourcebook of new methods*, Sage Publications.

Mohammed, Y., Sax, U., Dickmann, F., Lippert, J., Solodenko, J., Voigt, G. von, Smith, M. and Rienhoff, O. (2010) 'On transferring the grid technology to the biomedical community', *HealthGrid*, pp. 28–39.

Morillo, F., Bordons, M., and Gómez, I. (2001) 'An approach to interdisciplinarity through bibliometric indicators', *Scientometrics* vol. 51, no.1, pp. 203–222.

Morooka, K., Ramos, M. M. and Nathaniel, F. N. (2014) 'A bibliometric approach to interdisciplinarity in Japanese rice research and technology development', *Scientometrics*, vol. 98, no. 1, pp. 73–98.

Motohashi, K. and Muramatsu, S. (2012) 'Examining the university industry collaboration policy in Japan: Patent analysis', *Technology in Society*, vol. 34, no. 2, pp. 149–162 [Online]. DOI: 10.1016/j.techsoc.2012.02.006.

Mugabushaka, A.-M., Kyriakou, A. and Papazoglou, T. (2016) 'Bibliometric indicators of interdisciplinarity: The potential of the Leinster–Cobbold diversity indices to study disciplinary diversity', *Scientometrics*, vol. 107, no. 2, pp. 593–607.

Mustar, P., Renault, M., Colombo, M.G., Piva, E., Fontes, M., Lockett, A., Wright, M., Clarysse, B. and Moray, N., 2006. 'Conceptualising the heterogeneity of research-based spin-offs: A multi-dimensional taxonomy', *Research policy*, vol. 35, no. 2, pp. 289–308.

Nemet, G. F. and Johnson, E. (2012) 'Do important inventions benefit from knowledge originating in other technological domains?', *Research Policy*, vol. 41, no. 1, pp. 190–200 [Online]. DOI: 10.1016/j.respol.2011.08.009.

Nichols, L. G. (2014) 'A topic model approach to measuring interdisciplinarity at the National Science Foundation', *Scientometrics*, vol. 100, no. 3, pp. 741–754.

OECD (2009) *The Bioeconomy to 2030 Designing a Policy Agenda*, Paris, OECD Publications.

Parmar, B. L., Freeman, R. E., Harrison, J. S., Wicks, A. C., Purnell, L. and Colle, S. de (2010) 'Stakeholder theory: The state of the art', *The academy of management annals*, vol. 4, no. 1, pp. 403–445.

Penrose E. T. (1959). *The theory of the growth of the firm*. Wiley, New York.

Perkmann, M., Tartari, V., McKelvey, M., Autio, E., Broström, A., D'Este, P., Fini, R., Geuna, A., Grimaldi, R., Hughes, A., Krabel, S., Kitson, M., Llerena, P., Lissoni, F., Salter, A. and Sobrero, M. (2013) 'Academic engagement and commercialisation: A review of the literature on university–industry relations', *Research Policy*, vol. 42, no. 2, pp. 423–442 [Online]. DOI: 10.1016/j.respol.2012.09.007.

Phan, P. and Siegel, D. S. (2006) 'The effectiveness of university technology transfer', *Foundations and Trends in Entrepreneurship*, vol. 2, no. 2.

Philp, J. (2014) 'OECD Policies for Bioplastics in the Context of a Bioeconomy, 2013', *Industrial Biotechnology*, vol. 10, no. 1, pp. 19–21.

Pilar Lagar-Barbosa, M., Isabel Escalona-Fernandez, M. and Pulgarin, A. (2014). 'Analysis of Interdisciplinarity in Chemical Engineering in Spanish Universities'. *Revista Espanola De Documentacion Cientifica*, *37*(1).

Pilla, S. (2011) *Handbook of bioplastics and biocomposites engineering applications*, John Wiley & Sons.

Pinto, H. (2017) 'Connecting the Triple Helix space: actor-network creation and institutionalisation of knowledge transfer offices', *Triple Helix*, vol. 4, no. 1, p. 2.

Porter, A. L., Cohen, A. S., Roessner, J. D. and Perreault, M. (2007) ‘Measuring researcher interdisciplinarity’, *Scientometrics*, vol. 72, no. 1, pp. 117–147.

Porter, A. and Rafols, I. (2009) ‘Is science becoming more interdisciplinary? Measuring and mapping six research fields over time’, *Scientometrics*, vol. 81, no. 3, pp. 719–745.

Porter, A. L., Roessner, J. D., Cohen, A. S. and Perreault, M. (2006) ‘Interdisciplinary research: meaning, metrics and nurture’, *Research evaluation*, vol. 15, no. 3, pp. 187–195.

Power, J. B. and McDougall, P. P. (2005). ‘University start-up formation and technology licensing with firms that go public: a resource-based view of academic entrepreneurship’, *Journal of business venturing*, vol. 20, no. 3, pp. 291–311.

Preschitschek, N., Niemann, H., Leker, J. and G. Moehrle, Martin (2013) ‘Anticipating industry convergence: semantic analyses vs IPC co-classification analyses of patents’, *Foresight*, vol. 15, no. 6, pp. 446–464.

Pyka, A., Buchmann, T. and Vermeulen, B. (2016) ‘Biosimilars in Germany: the emergence of a new industry in the light of the varieties of capitalism approach’, *Technology Analysis & Strategic Management*, pp. 1–14.

Queiroz, A. U. B. and Collares-Queiroz, F. P. (2009) ‘Innovation and industrial trends in bioplastics’, *Polymer Reviews*, vol. 49, no. 2, pp. 65–78.

Rafols, I., Leydesdorff, L., O’Hare, A., Nightingale, P. and Stirling, A. (2012) ‘How journal rankings can suppress interdisciplinary research: A comparison between Innovation Studies and Business & Management’, *Research Policy*, vol. 41, no. 7, pp. 1262–1282 [Online]. DOI: 10.1016/j.respol.2012.03.015.

Rafols, I. and Meyer, M. (2007) ‘How cross-disciplinary is bionanotechnology? Explorations in the specialty of molecular motors’, *Scientometrics*, vol. 70, no. 3, pp. 633–650.

Rafols, I. and Meyer, M. (2010) ‘Diversity and network coherence as indicators of interdisciplinarity: Case studies in bionanoscience’, *Scientometrics*, vol. 82, no. 2, pp. 263–287.

Rafols, I., Porter, A. L. and Leydesdorff, L. (2010) ‘Science overlay maps: A new tool for research policy and library management’, *Journal of the Association for Information Science and Technology*, vol. 61, no. 9, pp. 1871–1887.

Ramakrishnan, S. (2004) ‘An industrial ecology framework to assist transferring environmental technologies’, *International journal of technology transfer and commercialisation*, vol. 3, no. 2, pp. 147–165.

Repko, A. F. and Szostak, R. (2016) *Interdisciplinary research: Process and theory*, Sage Publications.

Ritter, T. and Gemünden, H. G. (2004) ‘The impact of a company’s business strategy on its technological competence, network competence and innovation success’, *Journal of business research*, vol. 57, no. 5, pp. 548–556.

Rogers, E. M. (2003) *Diffusions of Innovations*, 5th edn, Free Press, New York.

Rogers, E. M., Takegami, S. and Yin, J. (2001) ‘Lessons learned about technology transfer’, *Technovation*, vol. 21, no. 4, pp. 253–261 [Online]. DOI: 10.1016/S0166-4972(00)00039-0.

Rosas, S. R. (2005) ‘Concept Mapping as a Technique for Program Theory Development. An Illustration Using Family Support Programs’, *American Journal of Evaluation*, vol. 26, no. 3, pp. 389–401.

Rosas, S. R. and Kane, M. (2012) ‘Quality and rigor of the concept mapping methodology: A pooled study analysis’, *Safer Schools and Healthier Students: Findings from the National Evaluation of the Safe Schools and Healthy Students*, vol. 35, no. 2, pp. 236–245 [Online]. DOI: 10.1016/j.evalprogplan.2011.10.003.

Rothaermel, F. T., Agung, S. D. and Jiang, L. (2007) ‘University entrepreneurship: a taxonomy of the literature’, *Industrial and Corporate Change*, vol. 16, no. 4, pp. 691–791.

Rotolo, D., Hicks, D. and Martin, B. R. (2015) ‘What is an emerging technology?’, *Research Policy*, vol. 44, no. 10, pp. 1827–1843 [Online]. DOI: 10.1016/j.respol.2015.06.006.

Rotolo, D., Rafols, I., Hopkins, M. M. and Leydesdorff, L. (2016) ‘Strategic intelligence on emerging technologies: Scientometric overlay mapping’, *Journal of the Association for Information Science and Technology*, vol. 68, no. 1, pp.214–233.

Rowley, J. (2002) ‘Using case studies in research’, *Management research news*, vol. 25, no. 1, pp. 16–27.

Sandén, B. A., & Pettersson, K. (2013). Systems Perspectives on Biorefineries 2013.

Santoro, M. D. and Chakrabarti, A. K. (2002) ‘Firm size and technology centrality in industry–university interactions’, *Research Policy*, vol. 31, no. 7, pp. 1163–1180.

Schmoch, U. (2008) ‘Concept of a technology classification for country comparisons’, *Final report to the world intellectual property organisation (wipo), WIPO*.

Schroeter, D. C., Coryn, Chris L. S., Cullen, A., Robertson, K. N. and Alyami, M. (2012) ‘Using concept mapping for planning and evaluation of a statewide energy efficiency initiative’, *Energy Efficiency*, vol. 5, no. 3, pp. 365–375.

Schütte, G. (2017) ‘What kind of innovation policy does the bioeconomy need?’, *New Biotechnology*, vol. 40, pp.82–86.

Shane, S. (2002) ‘Executive Forum: University technology transfer to entrepreneurial companies’, *Journal of Business Venturing*, vol. 17, no. 6, pp. 537–552 [Online]. DOI: 10.1016/S0883-9026(01)00084-2.

Shane (2004) *Academic entrepreneurship: university spinoffs and wealth creation*, Northampton, M.A, Edward Elgar Publishing, Cheltenham, UK.

Siegel, D. S., Waldman, D. A., Atwater, L. E. and Link, A. N. (2004) ‘Toward a model of the effective transfer of scientific knowledge from academicians to practitioners: qualitative evidence from the commercialization of university technologies’, *Journal of engineering and technology management*, vol. 21, no. 1-2, pp. 115–142.

Smart, J. and Benaroya, H. (2016) ‘An examination of non-linear and passive technology transfer in the space sector: Consideration of the Contingent Effectiveness Model as a basis for formal modeling’, *Space Policy*, vol. 38, pp. 39–47.

Solomon, G.E.A., Carley, S., Porter, A.L. (2016) ‘How multidisciplinary are the multidisciplinary journals Science and Nature?’, *PLOS ONE* vol. 11, no. 4, e0152637.

Stack-Cutler, H., Schnirer, L. and Dare, L. (2017) ‘Engaging populations living with vulnerable conditions in community-based research: A concept mapping approach to understanding positive practices’, *Journal of Community Psychology*, vol. 45, no. 5, pp. 601–616.

Staffas, L., Gustavsson, M. and McCormick, K. (2013) ‘Strategies and Policies for the Bioeconomy and Bio-Based Economy: An Analysis of Official National Approaches’, *Sustainability*, vol. 5, no. 6, pp. 2751–2769.

Stake, R. E. (2008) ‘Qualitative case studies’.

Stirling, A. (2007) ‘A general framework for analysing diversity in science, technology and society’, *Journal of The Royal Society Interface* vol. 4, no. 15, pp. 707–719.

Stolk-Vos, A. C., van de Klundert, J. J., Maijers, N., Zijlmans, B. L. M. and Busschbach, J. J. V. (2017) ‘Multi-stakeholder perspectives in defining health-services quality in cataract care’, *International Journal for Quality in Health Care*, vol. 29, no. 4, pp. 470–476.

Su, H.-N. and Moaniba, I. M. (2017) ‘Investigating the dynamics of interdisciplinary evolution in technology developments’, *Emerging Trends in Science and Technology Policy*, vol. 122, pp. 12–23.

Tatikonda, M. V. and Stock, G. N. (2003) ‘Product technology transfer in the upstream supply chain’, *Journal of Product Innovation Management*, vol. 20, no. 6, pp. 444–467.

Trochim, William M. K. (1989) ‘An introduction to concept mapping for planning and evaluation’, *Special Issue: Concept Mapping for Evaluation and Planning*, vol. 12, no. 1, pp. 1–16 [Online]. DOI: 10.1016/0149-7189(89)90016-5.

Trochim, William M. K. and Cabrera, D. (2005) ‘The complexity of concept mapping for policy analysis’, *Emergence: complexity and organization*, vol. 7, no. 1, pp. 11–22.

Tseng, C.-Y., Lin, S.-C., Pai, D.-C. and Tung, C.-W. (2016) ‘The relationship between innovation network and innovation capability: A social network perspective’, *Technology Analysis & Strategic Management*, vol. 28, no. 9, pp. 1029–1040.

Valentin, F. and Jensen, R. L. (2007) ‘Effects on academia-industry collaboration of extending university property rights’, *The Journal of Technology Transfer*, vol. 32, no. 3, pp. 251–276.

van der Steen, Marianne and Enders, J. (2008) ‘Universities in evolutionary systems of innovation’, *Creativity and Innovation Management*, vol. 17, no. 4, pp. 281–292.

van Engen-Verheul, M. M., Peek, N., Haafkens, J. A., Joukes, E., Vromen, T., Jaspers, M. W. M. and Keizer, N. F. de (2017) ‘What is needed to implement a web-based audit and feedback intervention with outreach visits to improve care quality: a concept mapping study among cardiac rehabilitation teams’, *International Journal of Medical Informatics*, vol. 97, pp. 76–85.

van Looy, B., Callaert, J. and Debackere, K. (2006) ‘Publication and patent behavior of academic researchers: Conflicting, reinforcing or merely co-existing?’, *Research Policy*, vol. 35, no. 4, pp. 596–608.

Vandermeulen, V., Van der Steen, Marijke, Stevens, C. V. and van Huylenbroeck, G. (2012) ‘Industry expectations regarding the transition toward a biobased economy’, *Biofuels, Bioproducts and Biorefining*, vol. 6, no. 4, pp. 453–464.

Vinig, T. and Lips, D. (2015) ‘Measuring the performance of university technology transfer using meta data approach: the case of Dutch universities’, *The Journal of Technology Transfer*, vol. 40, no. 6, pp.1034–1049.

Vives-Cases, C., Goicolea, I., Hernández, A., Sanz-Barbero, B., Davó-Blanes, M. and La Parra-Casado, D. (2017) ‘Priorities and strategies for improving Roma women’s access to primary health care services in cases on intimate partner violence: a concept mapping study’, *International Journal for Equity in Health*, vol. 16, no. 1, p. 96.

Vom Stein, N., Sick, N. and Leker, J. (2015) ‘How to measure technological distance in collaborations—the case of electric mobility’, *Technological Forecasting and Social Change*, vol. 97, pp. 154–167.

Wagner, C. S., Roessner, J. D., Bobb, K., Klein, J. T., Boyack, K. W., Keyton, J., Rafols, I. and Börner, K. (2011) 'Approaches to understanding and measuring interdisciplinary scientific research (IDR): A review of the literature', *Journal of informetrics*, vol. 5, no. 1, pp. 14–26.

Wang, J., Veugelers, R. and Stephan, P. (2017) 'Bias against novelty in science: A cautionary tale for users of bibliometric indicators', *Research Policy*, vol. 46, no. 8, pp. 1416–1436 [Online]. DOI: 10.1016/j.respol.2017.06.006.

Weerd-Nederhof, P. de (2001) 'Qualitative case study research. The case of a PhD research project on organising and managing new product development systems', *Management Decision*, vol. 39, no. 7, pp. 513–538.

Whalen, R. (2018) 'Boundary spanning innovation and the patent system: Interdisciplinary challenges for a specialized examination system', *Research Policy*, vol. 47, no. 7, pp. 1334–1343 [Online]. DOI: 10.1016/j.respol.2018.04.017.

Xu, H., Guo, T., Yue, Z., Ru, L. and Fang, S. (2016) 'Interdisciplinary topics of information science: a study based on the terms interdisciplinarity index series', *Scientometrics*, vol. 106, no. 2, pp. 583–601.

Yan, B. and Luo, J. (2017) 'Measuring technological distance for patent mapping', *Journal of the Association for Information Science and Technology*, vol. 68, no. 2, pp. 423–437.

Yang, C. H. and Heo, J. (2014) 'Network analysis to evaluate cross-disciplinary research collaborations: The Human Sensing Research Center, Korea', *Science and Public Policy*, vol. 41, no. 6, pp. 734–749.

Yang, C. H., Park, H. W. and Heo, J. (2010) 'A network analysis of interdisciplinary research relationships: The Korean government's R&D grant program', *Scientometrics*, vol. 83, no. 1, pp. 77–92.

Yegros-Yegros, A., Rafols, I. and D'Este, P. (2015) 'Does interdisciplinary research lead to higher citation impact? The different effect of proximal and distal interdisciplinarity', *PLOS ONE*, vol. 10, no. 8, e0135095.

Yin, R. K. (2015) 'Case Studies', in Wright, J. D. (ed) *International Encyclopedia of the Social & Behavioral Sciences (Second Edition),* Oxford, Elsevier, pp. 194–201.

Yoon, J., Park, Y., Kim, M., Lee, J. and Lee, D. (2014) 'Tracing evolving trends in printed electronics using patent information', *Journal of Nanoparticle Research*, vol. 16, no. 7, p. 2471.

Zhao, L. M. and Reisman, A. (1992) 'Toward meta resarch on Technology-Tansfer', *IEEE Transactions on Engineering Management*, vol. 39, no. 1, pp. 13–21.

Appendices

Appendix A: Expert Interview Guidelines with academic scientists

City, Date:
Interviewee:
Interviewer:

General description

Firstly, I would like to thank you for your participation in this expert interview. These expert interviews are part of the White Paper: “Assessing Science to Business (S2B) Technology Transfer in the emerging Bioeconomy”

The objective of the interviews is to find out (1) what scientists think about technology transfer, (2) what factors influence the science to business technology transfer in the bioeconomy, (3) what instruments scientists use to transfer inventions in the bioeconomy. The results of these interviews will help us to clarify the conceptual framework which is currently being developed.

The interview will last about 30 to 45 minutes. All the information will be treated confidentially and the findings will be made available after analysis.

Before starting the interview, I would like to kindly ask you if I could record the interview. This is to ensure that all the information is accurately reported.

A. General technology transfer questions

1. What is your **understanding of technology transfer**?
2. What are your **experiences** (positive and negative)?
3. **Researchers and firms** are interested in different things: one group is in search and production of knowledge, the other focuses on profit maximization. How can these interests be brought together?
4. Do you have **projects with industry** or had or planned for the future?
5. How do you look **for partners in industry**? Do you find it difficult? By what means (e.g. conferences, workshops) do you get in touch?
6. **Do technology transfer offices help you to establish collaborations with industry? What are your experiences with technology transfer offices?**
7. Some **instruments to transfer new technologies** are patents, licensing, and spin-offs. Do you make use of these or other instruments? Can you say which one you prefer – in how far does this depend on the status quo (maturity) of your research?

B. Bioeconomy-related technology transfer questions

1. What will be the **biggest technological challenge(s)** related to bioeconomy in the next years?
2. **What are the drivers that are fostering the development of the bioeconomy, and in particular, technology transfer in the bioeconomy?**
3. **What are the barriers that are restricting the development of the bioeconomy, and in particular, technology transfer in the bioeconomy?**
4. **To what extent do regulations on biotechnology affect the development of the bioeconomy?**
5. **Does the transdisciplinary approach of the bioeconomy involving many different novel knowledge areas and industries, with, yet, only emerging value chains, present a barrier for technology transfer?**
6. One of the **aims of the BioSC is to foster cooperation between academia and industry**. What role does the BioSC play in this regard? What do you expect from it?

D. Additional questions

1. Any other comments not covered by the questions of the interview which you think are important to make regarding technology transfer in the bioeconomy?

Wrap up

Thank you very much for your time in participating in this expert interview.

Appendix B: Expert Interview Guidelines with spin-offs

City, Date:
Interviewee:
Interviewer:

General description

Firstly, I would like to thank you for your participation in this expert interview. These expert interviews are part of the White Paper: "Assessing Science to Business (S2B) Technology Transfer in the emerging Bioeconomy".

The objective of the interviews is to find out (1) how the process of technology transfer took place from sciences to business, and (2) what factors influence the science to business technology transfer in the bioeconomy. The results of these interviews will help us to clarify the conceptual framework which is currently being developed.

The interview will last about 45 to 60 minutes. All the information will be treated confidentially and the findings will be made available after analysis.

Before starting the interview, I would like to kindly ask you if I could record the interview. This is to ensure that all the information is accurately reported.

General information

- Name of the organisation:
- Current position at the organisaton:
- Years of experience at the organisation:
- Number of employees:
- Educational background:
- Years of experience in academia:
- Years of experience in industry:

A. General questions

2. Which **technology is the basis** of your business and who **initiated** the business?
3. What is the **current stage of your business** according to the following process? *(Describe figure)*
4. Why did you **decide to commercialize** your technology? How was the **process of commercializing** your technology? Which instruments did you make use of?
5. How do you define **successful commercialization** or technology transfer of your technology?
6. How important do you think is/was **networking** for your business' success? Which ways of networking do/did you use?

7. Did you have any **support from the university/research center or technology transfer office** in commercializing your technology? How would you characterize the support from the university/ research center or technology transfer office?
8. How important are the **scientists/inventors** for the commercialization process? Were they included in the beginning of the commercialization phase?
9. **Researchers and firms** are interested in different things: one group is in search and production of knowledge, the other focuses on profit maximization. How can these interests be brought together? Did you encounter any barrier in this context?
10. Is your business located **near** where the technology was developed? If so, to what extent do you think this was important?
11. What do you think was the **biggest barrier** when started to commercialize your technology?
12. What do you think was the **most important driver** when started to commercialize your technology?
13. Which **organizational or institutional factors** did you face when commercializing your technology/ starting your business? Did you consider them in the transfer process?
14. **To what extent do regulations on biotechnology affect the development of your business?**
15. Which **policies/legislations** had influences on your technology transfer decisions? What kind of influence?
16. Where did you get the **managerial expertise** in your firm from?
17. Are you actively **looking for new technologies** to commercialize? If yes, how? What are your future plans regarding the future commercialization of your technology?

B. Additional questions

1. Any other comments not covered by the questions of the interview which you think are important to make regarding technology transfer in the bioeconomy?

Wrap up

Thank you very much for your time in participating in this expert interview.

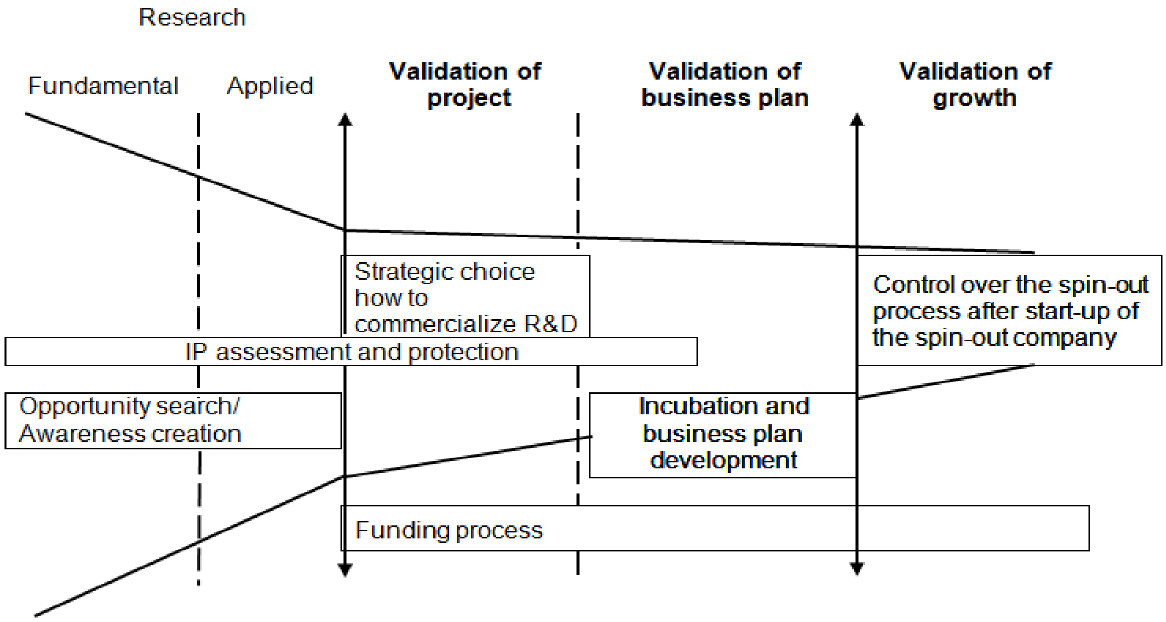

Figure: The spin-off funnel
Source: Adopted from Clarysse et al. (2005, p.187)

Appendix C: Group concept mapping questionnaire to stakeholders

1. Which of the following stakeholder group would you assign yourself to?
   - ☐ Academia (university, research center)
   - ☐ Industry (spin-off, SME, large company)
   - ☐ Technology transfer intermediary (technology transfer office, funding investor, business incubator, government)
   - ☐ Other

2. What is your educational background?
   - ☐ Engineering
   - ☐ Humanities and arts
   - ☐ Natural/life sciences
   - ☐ Social sciences, business and law
   - ☐ Other

3. What is your current job?
   - ☐ Academic Researcher
   - ☐ Administrative
   - ☐ Chief Executive Officer (CEO)
   - ☐ Consultant
   - ☐ Full time student
   - ☐ Industry researcher
   - ☐ Professor
   - ☐ Project manager
   - ☐ Technical assistant
   - ☐ Other

4. Do you have experience in entrepreneurship?
   - ☐ Yes, I have founded a company.
   - ☐ Yes, I have founded a company more than once.
   - ☐ No experience, but I am planning to found a company in the future.
   - ☐ No experience at all.

5. Are you currently actively involved in the bioeconomy? (Please comply with the definition below).

Bioeconomy: "Comprises the economic sectors that are involved in the production of renewable biological resources and the conversion of these resources and waste streams into value added products, such as food, feed, bio-based products and bioenergy" (European Commission, 2012, p.3).

- ☐ Yes and I am intending to increase current activities.
- ☐ Yes, I am currently actively involved.
- ☐ No, but I have been actively involved in the past.
- ☐ No, but I am planning to be actively involved in the future.
- ☐ No, but I am thinking of becoming actively involved in the future.
- ☐ No, I am not actively involved.
- ☐ Other

Appendix D: WIPO IPC-Technology Concordance Table

IPC Code	Sector	Field
F21H	Electrical engineering	Electrical machinery, apparatus, energy
F21K	Electrical engineering	Electrical machinery, apparatus, energy
F21L	Electrical engineering	Electrical machinery, apparatus, energy
F21S	Electrical engineering	Electrical machinery, apparatus, energy
F21V	Electrical engineering	Electrical machinery, apparatus, energy
F21W	Electrical engineering	Electrical machinery, apparatus, energy
F21Y	Electrical engineering	Electrical machinery, apparatus, energy
H01B	Electrical engineering	Electrical machinery, apparatus, energy
H01C	Electrical engineering	Electrical machinery, apparatus, energy
H01F	Electrical engineering	Electrical machinery, apparatus, energy
H01G	Electrical engineering	Electrical machinery, apparatus, energy
H01H	Electrical engineering	Electrical machinery, apparatus, energy
H01J	Electrical engineering	Electrical machinery, apparatus, energy
H01K	Electrical engineering	Electrical machinery, apparatus, energy
H01M	Electrical engineering	Electrical machinery, apparatus, energy
H01R	Electrical engineering	Electrical machinery, apparatus, energy
H01T	Electrical engineering	Electrical machinery, apparatus, energy
H02B	Electrical engineering	Electrical machinery, apparatus, energy
H02G	Electrical engineering	Electrical machinery, apparatus, energy
H02H	Electrical engineering	Electrical machinery, apparatus, energy
H02J	Electrical engineering	Electrical machinery, apparatus, energy
H02K	Electrical engineering	Electrical machinery, apparatus, energy
H02M	Electrical engineering	Electrical machinery, apparatus, energy
H02N	Electrical engineering	Electrical machinery, apparatus, energy
H02P	Electrical engineering	Electrical machinery, apparatus, energy
H02S	Electrical engineering	Electrical machinery, apparatus, energy
H05B	Electrical engineering	Electrical machinery, apparatus, energy
H05C	Electrical engineering	Electrical machinery, apparatus, energy
H05F	Electrical engineering	Electrical machinery, apparatus, energy
H99Z	Electrical engineering	Electrical machinery, apparatus, energy
G09F	Electrical engineering	Audio-visual technology
G09G	Electrical engineering	Audio-visual technology
G11B	Electrical engineering	Audio-visual technology
H04N	Electrical engineering	Audio-visual technology
H04N	Electrical engineering	Audio-visual technology
H04N	Electrical engineering	Audio-visual technology
H04N	Electrical engineering	Audio-visual technology
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H04N	Electrical engineering	Audio-visual technology
H04N	Electrical engineering	Audio-visual technology
H04N	Electrical engineering	Audio-visual technology
H04N	Electrical engineering	Audio-visual technology
H04R	Electrical engineering	Audio-visual technology
H04S	Electrical engineering	Audio-visual technology
H05K	Electrical engineering	Audio-visual technology
G08C	Electrical engineering	Telecommunications
H01P	Electrical engineering	Telecommunications
H01Q	Electrical engineering	Telecommunications

H04B	Electrical engineering	Telecommunications
H04H	Electrical engineering	Telecommunications
H04J	Electrical engineering	Telecommunications
H04K	Electrical engineering	Telecommunications
H04M	Electrical engineering	Telecommunications
H04N	Electrical engineering	Telecommunications
H04Q	Electrical engineering	Telecommunications
H04L	Electrical engineering	Digital communication
H04N	Electrical engineering	Digital communication
H04W	Electrical engineering	Digital communication
H03B	Electrical engineering	Basic communication processes
H03C	Electrical engineering	Basic communication processes
H03D	Electrical engineering	Basic communication processes
H03F	Electrical engineering	Basic communication processes
H03G	Electrical engineering	Basic communication processes
H03H	Electrical engineering	Basic communication processes
H03J	Electrical engineering	Basic communication processes
H03K	Electrical engineering	Basic communication processes
H03L	Electrical engineering	Basic communication processes
H03M	Electrical engineering	Basic communication processes
G06C	Electrical engineering	Computer technology
G06D	Electrical engineering	Computer technology
G06E	Electrical engineering	Computer technology
G06F	Electrical engineering	Computer technology
G06G	Electrical engineering	Computer technology
G06J	Electrical engineering	Computer technology
G06K	Electrical engineering	Computer technology
G06M	Electrical engineering	Computer technology
G06N	Electrical engineering	Computer technology
G06T	Electrical engineering	Computer technology
G10L	Electrical engineering	Computer technology
G11C	Electrical engineering	Computer technology
G06Q	Electrical engineering	IT methods for management
H01L	Electrical engineering	Semiconductors
G02B	Instruments	Optics
G02C	Instruments	Optics
G02F	Instruments	Optics
G03B	Instruments	Optics
G03C	Instruments	Optics
G03D	Instruments	Optics
G03F	Instruments	Optics
G03G	Instruments	Optics
G03H	Instruments	Optics
H01S	Instruments	Optics
G01B	Instruments	Measurement
G01C	Instruments	Measurement
G01D	Instruments	Measurement
G01F	Instruments	Measurement
G01G	Instruments	Measurement
G01H	Instruments	Measurement
G01J	Instruments	Measurement
G01K	Instruments	Measurement

G01L	Instruments	Measurement
G01M	Instruments	Measurement
G01N	Instruments	Measurement
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G01N	Instruments	Measurement
G01N	Instruments	Measurement
G01N	Instruments	Measurement
G01P	Instruments	Measurement
G01Q	Instruments	Measurement
G01R	Instruments	Measurement
G01S	Instruments	Measurement
G01V	Instruments	Measurement
G01W	Instruments	Measurement
G04B	Instruments	Measurement
G04C	Instruments	Measurement
G04D	Instruments	Measurement
G04F	Instruments	Measurement
G04G	Instruments	Measurement
G04R	Instruments	Measurement
G12B	Instruments	Measurement
G99Z	Instruments	Measurement
G01N	Instruments	Analysis of biological materials
G05B	Instruments	Control
G05D	Instruments	Control
G05F	Instruments	Control
G07B	Instruments	Control
G07C	Instruments	Control
G07D	Instruments	Control
G07F	Instruments	Control
G07G	Instruments	Control
G08B	Instruments	Control
G08G	Instruments	Control
G09B	Instruments	Control
G09C	Instruments	Control
G09D	Instruments	Control
A61B	Instruments	Medical technology

A61C	Instruments	Medical technology
A61D	Instruments	Medical technology
A61F	Instruments	Medical technology
A61G	Instruments	Medical technology
A61H	Instruments	Medical technology
A61J	Instruments	Medical technology
A61L	Instruments	Medical technology
A61M	Instruments	Medical technology
A61N	Instruments	Medical technology
H05G	Instruments	Medical technology
G16H	Instruments	Medical technology
A61K	Chemistry	Organic fine chemistry
A61Q	Chemistry	Organic fine chemistry
C07B	Chemistry	Organic fine chemistry
C07C	Chemistry	Organic fine chemistry
C07D	Chemistry	Organic fine chemistry
C07F	Chemistry	Organic fine chemistry
C07H	Chemistry	Organic fine chemistry
C07J	Chemistry	Organic fine chemistry
C40B	Chemistry	Organic fine chemistry
C07G	Chemistry	Biotechnology
C07K	Chemistry	Biotechnology
C12M	Chemistry	Biotechnology
C12N	Chemistry	Biotechnology
C12P	Chemistry	Biotechnology
C12Q	Chemistry	Biotechnology
C12R	Chemistry	Biotechnology
C12S	Chemistry	Biotechnology
A61K	Chemistry	Pharmaceuticals
A61K	Chemistry	Pharmaceuticals
A61K	Chemistry	Pharmaceuticals
A61K	Chemistry	Pharmaceuticals
A61K	Chemistry	Pharmaceuticals
A61K	Chemistry	Pharmaceuticals
A61K	Chemistry	Pharmaceuticals
A61K	Chemistry	Pharmaceuticals
A61K	Chemistry	Pharmaceuticals
A61K	Chemistry	Pharmaceuticals
A61K	Chemistry	Pharmaceuticals
A61K	Chemistry	Pharmaceuticals
A61K	Chemistry	Pharmaceuticals
A61K	Chemistry	Pharmaceuticals
A61K	Chemistry	Pharmaceuticals
A61K	Chemistry	Pharmaceuticals
A61K	Chemistry	Pharmaceuticals
A61K	Chemistry	Pharmaceuticals
A61K	Chemistry	Pharmaceuticals
A61K	Chemistry	Pharmaceuticals
A61K	Chemistry	Pharmaceuticals
A61K	Chemistry	Pharmaceuticals
A61K	Chemistry	Pharmaceuticals
A61P	Chemistry	Pharmaceuticals

C08B	Chemistry	Macromolecular chemistry, polymers
C08C	Chemistry	Macromolecular chemistry, polymers
C08F	Chemistry	Macromolecular chemistry, polymers
C08G	Chemistry	Macromolecular chemistry, polymers
C08H	Chemistry	Macromolecular chemistry, polymers
C08K	Chemistry	Macromolecular chemistry, polymers
C08L	Chemistry	Macromolecular chemistry, polymers
A01H	Chemistry	Food chemistry
A21D	Chemistry	Food chemistry
A23B	Chemistry	Food chemistry
A23C	Chemistry	Food chemistry
A23D	Chemistry	Food chemistry
A23F	Chemistry	Food chemistry
A23G	Chemistry	Food chemistry
A23J	Chemistry	Food chemistry
A23K	Chemistry	Food chemistry
A23L	Chemistry	Food chemistry
C12C	Chemistry	Food chemistry
C12F	Chemistry	Food chemistry
C12G	Chemistry	Food chemistry
C12H	Chemistry	Food chemistry
C12J	Chemistry	Food chemistry
C13B	Chemistry	Food chemistry
C13B	Chemistry	Food chemistry
C13B	Chemistry	Food chemistry
C13B	Chemistry	Food chemistry
C13B	Chemistry	Food chemistry
C13B	Chemistry	Food chemistry
C13B	Chemistry	Food chemistry
C13D	Chemistry	Food chemistry
C13F	Chemistry	Food chemistry
C13J	Chemistry	Food chemistry
C13K	Chemistry	Food chemistry
A01N	Chemistry	Basic materials chemistry
A01P	Chemistry	Basic materials chemistry
C05B	Chemistry	Basic materials chemistry
C05C	Chemistry	Basic materials chemistry
C05D	Chemistry	Basic materials chemistry
C05F	Chemistry	Basic materials chemistry
C05G	Chemistry	Basic materials chemistry
C06B	Chemistry	Basic materials chemistry
C06C	Chemistry	Basic materials chemistry
C06D	Chemistry	Basic materials chemistry
C06F	Chemistry	Basic materials chemistry
C09B	Chemistry	Basic materials chemistry
C09C	Chemistry	Basic materials chemistry
C09D	Chemistry	Basic materials chemistry
C09F	Chemistry	Basic materials chemistry
C09G	Chemistry	Basic materials chemistry
C09H	Chemistry	Basic materials chemistry
C09J	Chemistry	Basic materials chemistry
C09K	Chemistry	Basic materials chemistry

C10B	Chemistry	Basic materials chemistry
C10C	Chemistry	Basic materials chemistry
C10F	Chemistry	Basic materials chemistry
C10G	Chemistry	Basic materials chemistry
C10H	Chemistry	Basic materials chemistry
C10J	Chemistry	Basic materials chemistry
C10K	Chemistry	Basic materials chemistry
C10L	Chemistry	Basic materials chemistry
C10M	Chemistry	Basic materials chemistry
C10N	Chemistry	Basic materials chemistry
C11B	Chemistry	Basic materials chemistry
C11C	Chemistry	Basic materials chemistry
C11D	Chemistry	Basic materials chemistry
C99Z	Chemistry	Basic materials chemistry
B22C	Chemistry	Materials, metallurgy
B22D	Chemistry	Materials, metallurgy
B22F	Chemistry	Materials, metallurgy
C01B	Chemistry	Materials, metallurgy
C01C	Chemistry	Materials, metallurgy
C01D	Chemistry	Materials, metallurgy
C01F	Chemistry	Materials, metallurgy
C01G	Chemistry	Materials, metallurgy
C03C	Chemistry	Materials, metallurgy
C04B	Chemistry	Materials, metallurgy
C21B	Chemistry	Materials, metallurgy
C21C	Chemistry	Materials, metallurgy
C21D	Chemistry	Materials, metallurgy
C22B	Chemistry	Materials, metallurgy
C22C	Chemistry	Materials, metallurgy
C22F	Chemistry	Materials, metallurgy
B05C	Chemistry	Surface technology, coating
B05D	Chemistry	Surface technology, coating
B32B	Chemistry	Surface technology, coating
C23C	Chemistry	Surface technology, coating
C23D	Chemistry	Surface technology, coating
C23F	Chemistry	Surface technology, coating
C23G	Chemistry	Surface technology, coating
C25B	Chemistry	Surface technology, coating
C25C	Chemistry	Surface technology, coating
C25D	Chemistry	Surface technology, coating
C25F	Chemistry	Surface technology, coating
C30B	Chemistry	Surface technology, coating
B81B	Chemistry	Micro-structural and nano-technology
B81C	Chemistry	Micro-structural and nano-technology
B82B	Chemistry	Micro-structural and nano-technology
B82Y	Chemistry	Micro-structural and nano-technology
B01B	Chemistry	Chemical engineering
B01D	Chemistry	Chemical engineering
B01D	Chemistry	Chemical engineering
B01D	Chemistry	Chemical engineering
B01D	Chemistry	Chemical engineering
B01D	Chemistry	Chemical engineering

B01D	Chemistry	Chemical engineering
B01D	Chemistry	Chemical engineering
B01D	Chemistry	Chemical engineering
B01D	Chemistry	Chemical engineering
B01D	Chemistry	Chemical engineering
B01D	Chemistry	Chemical engineering
B01D	Chemistry	Chemical engineering
B01D	Chemistry	Chemical engineering
B01D	Chemistry	Chemical engineering
B01D	Chemistry	Chemical engineering
B01D	Chemistry	Chemical engineering
B01D	Chemistry	Chemical engineering
B01D	Chemistry	Chemical engineering
B01D	Chemistry	Chemical engineering
B01D	Chemistry	Chemical engineering
B01D	Chemistry	Chemical engineering
B01D	Chemistry	Chemical engineering
B01D	Chemistry	Chemical engineering
B01D	Chemistry	Chemical engineering
B01D	Chemistry	Chemical engineering
B01D	Chemistry	Chemical engineering
B01D	Chemistry	Chemical engineering
B01D	Chemistry	Chemical engineering
B01D	Chemistry	Chemical engineering
B01D	Chemistry	Chemical engineering
B01D	Chemistry	Chemical engineering
B01F	Chemistry	Chemical engineering
B01J	Chemistry	Chemical engineering
B01L	Chemistry	Chemical engineering
B02C	Chemistry	Chemical engineering
B03B	Chemistry	Chemical engineering
B03C	Chemistry	Chemical engineering
B03D	Chemistry	Chemical engineering
B04B	Chemistry	Chemical engineering
B04C	Chemistry	Chemical engineering
B05B	Chemistry	Chemical engineering
B06B	Chemistry	Chemical engineering
B07B	Chemistry	Chemical engineering
B07C	Chemistry	Chemical engineering
B08B	Chemistry	Chemical engineering
C14C	Chemistry	Chemical engineering
D06B	Chemistry	Chemical engineering
D06C	Chemistry	Chemical engineering
D06L	Chemistry	Chemical engineering
F25J	Chemistry	Chemical engineering
F26B	Chemistry	Chemical engineering
H05H	Chemistry	Chemical engineering
A62C	Chemistry	Environmental technology
B01D	Chemistry	Environmental technology
B01D	Chemistry	Environmental technology
B01D	Chemistry	Environmental technology
B01D	Chemistry	Environmental technology

B01D	Chemistry	Environmental technology
B01D	Chemistry	Environmental technology
B01D	Chemistry	Environmental technology
B01D	Chemistry	Environmental technology
B09B	Chemistry	Environmental technology
B09C	Chemistry	Environmental technology
B65F	Chemistry	Environmental technology
C02F	Chemistry	Environmental technology
E01F	Chemistry	Environmental technology
F01N	Chemistry	Environmental technology
F23G	Chemistry	Environmental technology
F23J	Chemistry	Environmental technology
G01T	Chemistry	Environmental technology
B25J	Mechanical engineering	Handling
B65B	Mechanical engineering	Handling
B65C	Mechanical engineering	Handling
B65D	Mechanical engineering	Handling
B65G	Mechanical engineering	Handling
B65H	Mechanical engineering	Handling
B66B	Mechanical engineering	Handling
B66C	Mechanical engineering	Handling
B66D	Mechanical engineering	Handling
B66F	Mechanical engineering	Handling
B67B	Mechanical engineering	Handling
B67C	Mechanical engineering	Handling
B67D	Mechanical engineering	Handling
A62D	Mechanical engineering	Machine tools
B21B	Mechanical engineering	Machine tools
B21C	Mechanical engineering	Machine tools
B21D	Mechanical engineering	Machine tools
B21F	Mechanical engineering	Machine tools
B21G	Mechanical engineering	Machine tools
B21H	Mechanical engineering	Machine tools
B21J	Mechanical engineering	Machine tools
B21K	Mechanical engineering	Machine tools
B21L	Mechanical engineering	Machine tools
B23B	Mechanical engineering	Machine tools
B23C	Mechanical engineering	Machine tools
B23D	Mechanical engineering	Machine tools
B23F	Mechanical engineering	Machine tools
B23G	Mechanical engineering	Machine tools
B23H	Mechanical engineering	Machine tools
B23K	Mechanical engineering	Machine tools
B23P	Mechanical engineering	Machine tools
B23Q	Mechanical engineering	Machine tools
B24B	Mechanical engineering	Machine tools
B24C	Mechanical engineering	Machine tools
B24D	Mechanical engineering	Machine tools
B25B	Mechanical engineering	Machine tools
B25C	Mechanical engineering	Machine tools
B25D	Mechanical engineering	Machine tools
B25F	Mechanical engineering	Machine tools

B25G	Mechanical engineering	Machine tools
B25H	Mechanical engineering	Machine tools
B26B	Mechanical engineering	Machine tools
B26D	Mechanical engineering	Machine tools
B26F	Mechanical engineering	Machine tools
B27B	Mechanical engineering	Machine tools
B27C	Mechanical engineering	Machine tools
B27D	Mechanical engineering	Machine tools
B27F	Mechanical engineering	Machine tools
B27G	Mechanical engineering	Machine tools
B27H	Mechanical engineering	Machine tools
B27J	Mechanical engineering	Machine tools
B27K	Mechanical engineering	Machine tools
B27L	Mechanical engineering	Machine tools
B27M	Mechanical engineering	Machine tools
B27N	Mechanical engineering	Machine tools
B30B	Mechanical engineering	Machine tools
F01B	Mechanical engineering	Engines, pumps, turbines
F01C	Mechanical engineering	Engines, pumps, turbines
F01D	Mechanical engineering	Engines, pumps, turbines
F01K	Mechanical engineering	Engines, pumps, turbines
F01L	Mechanical engineering	Engines, pumps, turbines
F01M	Mechanical engineering	Engines, pumps, turbines
F01P	Mechanical engineering	Engines, pumps, turbines
F02B	Mechanical engineering	Engines, pumps, turbines
F02C	Mechanical engineering	Engines, pumps, turbines
F02D	Mechanical engineering	Engines, pumps, turbines
F02F	Mechanical engineering	Engines, pumps, turbines
F02G	Mechanical engineering	Engines, pumps, turbines
F02K	Mechanical engineering	Engines, pumps, turbines
F02M	Mechanical engineering	Engines, pumps, turbines
F02N	Mechanical engineering	Engines, pumps, turbines
F02P	Mechanical engineering	Engines, pumps, turbines
F03B	Mechanical engineering	Engines, pumps, turbines
F03C	Mechanical engineering	Engines, pumps, turbines
F03D	Mechanical engineering	Engines, pumps, turbines
F03G	Mechanical engineering	Engines, pumps, turbines
F03H	Mechanical engineering	Engines, pumps, turbines
F04B	Mechanical engineering	Engines, pumps, turbines
F04C	Mechanical engineering	Engines, pumps, turbines
F04D	Mechanical engineering	Engines, pumps, turbines
F04F	Mechanical engineering	Engines, pumps, turbines
F23R	Mechanical engineering	Engines, pumps, turbines
F99Z	Mechanical engineering	Engines, pumps, turbines
G21B	Mechanical engineering	Engines, pumps, turbines
G21C	Mechanical engineering	Engines, pumps, turbines
G21D	Mechanical engineering	Engines, pumps, turbines
G21F	Mechanical engineering	Engines, pumps, turbines
G21G	Mechanical engineering	Engines, pumps, turbines
G21H	Mechanical engineering	Engines, pumps, turbines
G21J	Mechanical engineering	Engines, pumps, turbines
G21K	Mechanical engineering	Engines, pumps, turbines

A41H	Mechanical engineering	Textile and paper machines
A43D	Mechanical engineering	Textile and paper machines
A46D	Mechanical engineering	Textile and paper machines
B31B	Mechanical engineering	Textile and paper machines
B31C	Mechanical engineering	Textile and paper machines
B31D	Mechanical engineering	Textile and paper machines
B31F	Mechanical engineering	Textile and paper machines
B41B	Mechanical engineering	Textile and paper machines
B41C	Mechanical engineering	Textile and paper machines
B41D	Mechanical engineering	Textile and paper machines
B41F	Mechanical engineering	Textile and paper machines
B41G	Mechanical engineering	Textile and paper machines
B41J	Mechanical engineering	Textile and paper machines
B41K	Mechanical engineering	Textile and paper machines
B41L	Mechanical engineering	Textile and paper machines
B41M	Mechanical engineering	Textile and paper machines
B41N	Mechanical engineering	Textile and paper machines
C14B	Mechanical engineering	Textile and paper machines
D01B	Mechanical engineering	Textile and paper machines
D01C	Mechanical engineering	Textile and paper machines
D01D	Mechanical engineering	Textile and paper machines
D01F	Mechanical engineering	Textile and paper machines
D01G	Mechanical engineering	Textile and paper machines
D01H	Mechanical engineering	Textile and paper machines
D02G	Mechanical engineering	Textile and paper machines
D02H	Mechanical engineering	Textile and paper machines
D02J	Mechanical engineering	Textile and paper machines
D03C	Mechanical engineering	Textile and paper machines
D03D	Mechanical engineering	Textile and paper machines
D03J	Mechanical engineering	Textile and paper machines
D04B	Mechanical engineering	Textile and paper machines
D04C	Mechanical engineering	Textile and paper machines
D04G	Mechanical engineering	Textile and paper machines
D04H	Mechanical engineering	Textile and paper machines
D05B	Mechanical engineering	Textile and paper machines
D05C	Mechanical engineering	Textile and paper machines
D06G	Mechanical engineering	Textile and paper machines
D06H	Mechanical engineering	Textile and paper machines
D06J	Mechanical engineering	Textile and paper machines
D06M	Mechanical engineering	Textile and paper machines
D06P	Mechanical engineering	Textile and paper machines
D06Q	Mechanical engineering	Textile and paper machines
D21B	Mechanical engineering	Textile and paper machines
D21C	Mechanical engineering	Textile and paper machines
D21D	Mechanical engineering	Textile and paper machines
D21F	Mechanical engineering	Textile and paper machines
D21G	Mechanical engineering	Textile and paper machines
D21H	Mechanical engineering	Textile and paper machines
D21J	Mechanical engineering	Textile and paper machines
D99Z	Mechanical engineering	Textile and paper machines
A01B	Mechanical engineering	Other special machines
A01C	Mechanical engineering	Other special machines

A01D	Mechanical engineering	Other special machines
A01F	Mechanical engineering	Other special machines
A01G	Mechanical engineering	Other special machines
A01J	Mechanical engineering	Other special machines
A01K	Mechanical engineering	Other special machines
A01L	Mechanical engineering	Other special machines
A01M	Mechanical engineering	Other special machines
A21B	Mechanical engineering	Other special machines
A21C	Mechanical engineering	Other special machines
A22B	Mechanical engineering	Other special machines
A22C	Mechanical engineering	Other special machines
A23N	Mechanical engineering	Other special machines
A23P	Mechanical engineering	Other special machines
B02B	Mechanical engineering	Other special machines
B28B	Mechanical engineering	Other special machines
B28C	Mechanical engineering	Other special machines
B28D	Mechanical engineering	Other special machines
B29B	Mechanical engineering	Other special machines
B29C	Mechanical engineering	Other special machines
B29D	Mechanical engineering	Other special machines
B29K	Mechanical engineering	Other special machines
B29L	Mechanical engineering	Other special machines
B33Y	Mechanical engineering	Other special machines
B99Z	Mechanical engineering	Other special machines
C03B	Mechanical engineering	Other special machines
C08J	Mechanical engineering	Other special machines
C12L	Mechanical engineering	Other special machines
C13B	Mechanical engineering	Other special machines
C13B	Mechanical engineering	Other special machines
C13B	Mechanical engineering	Other special machines
C13B	Mechanical engineering	Other special machines
C13C	Mechanical engineering	Other special machines
C13G	Mechanical engineering	Other special machines
C13H	Mechanical engineering	Other special machines
F41A	Mechanical engineering	Other special machines
F41B	Mechanical engineering	Other special machines
F41C	Mechanical engineering	Other special machines
F41F	Mechanical engineering	Other special machines
F41G	Mechanical engineering	Other special machines
F41H	Mechanical engineering	Other special machines
F41J	Mechanical engineering	Other special machines
F42B	Mechanical engineering	Other special machines
F42C	Mechanical engineering	Other special machines
F42D	Mechanical engineering	Other special machines
F22B	Mechanical engineering	Thermal processes and apparatus
F22D	Mechanical engineering	Thermal processes and apparatus
F22G	Mechanical engineering	Thermal processes and apparatus
F23B	Mechanical engineering	Thermal processes and apparatus
F23C	Mechanical engineering	Thermal processes and apparatus
F23D	Mechanical engineering	Thermal processes and apparatus
F23H	Mechanical engineering	Thermal processes and apparatus
F23K	Mechanical engineering	Thermal processes and apparatus

F23L	Mechanical engineering	Thermal processes and apparatus
F23M	Mechanical engineering	Thermal processes and apparatus
F23N	Mechanical engineering	Thermal processes and apparatus
F23Q	Mechanical engineering	Thermal processes and apparatus
F24B	Mechanical engineering	Thermal processes and apparatus
F24C	Mechanical engineering	Thermal processes and apparatus
F24D	Mechanical engineering	Thermal processes and apparatus
F24F	Mechanical engineering	Thermal processes and apparatus
F24H	Mechanical engineering	Thermal processes and apparatus
F24J	Mechanical engineering	Thermal processes and apparatus
F24S	Mechanical engineering	Thermal processes and apparatus
F24T	Mechanical engineering	Thermal processes and apparatus
F24V	Mechanical engineering	Thermal processes and apparatus
F25B	Mechanical engineering	Thermal processes and apparatus
F25C	Mechanical engineering	Thermal processes and apparatus
F27B	Mechanical engineering	Thermal processes and apparatus
F27D	Mechanical engineering	Thermal processes and apparatus
F28B	Mechanical engineering	Thermal processes and apparatus
F28C	Mechanical engineering	Thermal processes and apparatus
F28D	Mechanical engineering	Thermal processes and apparatus
F28F	Mechanical engineering	Thermal processes and apparatus
F28G	Mechanical engineering	Thermal processes and apparatus
F15B	Mechanical engineering	Mechanical elements
F15C	Mechanical engineering	Mechanical elements
F15D	Mechanical engineering	Mechanical elements
F16B	Mechanical engineering	Mechanical elements
F16C	Mechanical engineering	Mechanical elements
F16D	Mechanical engineering	Mechanical elements
F16F	Mechanical engineering	Mechanical elements
F16G	Mechanical engineering	Mechanical elements
F16H	Mechanical engineering	Mechanical elements
F16J	Mechanical engineering	Mechanical elements
F16K	Mechanical engineering	Mechanical elements
F16L	Mechanical engineering	Mechanical elements
F16M	Mechanical engineering	Mechanical elements
F16N	Mechanical engineering	Mechanical elements
F16P	Mechanical engineering	Mechanical elements
F16S	Mechanical engineering	Mechanical elements
F16T	Mechanical engineering	Mechanical elements
F17B	Mechanical engineering	Mechanical elements
F17C	Mechanical engineering	Mechanical elements
F17D	Mechanical engineering	Mechanical elements
G05G	Mechanical engineering	Mechanical elements
B60B	Mechanical engineering	Transport
B60C	Mechanical engineering	Transport
B60D	Mechanical engineering	Transport
B60F	Mechanical engineering	Transport
B60G	Mechanical engineering	Transport
B60H	Mechanical engineering	Transport
B60J	Mechanical engineering	Transport
B60K	Mechanical engineering	Transport
B60L	Mechanical engineering	Transport

B60M	Mechanical engineering	Transport
B60N	Mechanical engineering	Transport
B60P	Mechanical engineering	Transport
B60Q	Mechanical engineering	Transport
B60R	Mechanical engineering	Transport
B60S	Mechanical engineering	Transport
B60T	Mechanical engineering	Transport
B60V	Mechanical engineering	Transport
B60W	Mechanical engineering	Transport
B61B	Mechanical engineering	Transport
B61C	Mechanical engineering	Transport
B61D	Mechanical engineering	Transport
B61F	Mechanical engineering	Transport
B61G	Mechanical engineering	Transport
B61H	Mechanical engineering	Transport
B61J	Mechanical engineering	Transport
B61K	Mechanical engineering	Transport
B61L	Mechanical engineering	Transport
B62B	Mechanical engineering	Transport
B62C	Mechanical engineering	Transport
B62D	Mechanical engineering	Transport
B62H	Mechanical engineering	Transport
B62J	Mechanical engineering	Transport
B62K	Mechanical engineering	Transport
B62L	Mechanical engineering	Transport
B62M	Mechanical engineering	Transport
B63B	Mechanical engineering	Transport
B63C	Mechanical engineering	Transport
B63G	Mechanical engineering	Transport
B63H	Mechanical engineering	Transport
B63J	Mechanical engineering	Transport
B64B	Mechanical engineering	Transport
B64C	Mechanical engineering	Transport
B64D	Mechanical engineering	Transport
B64F	Mechanical engineering	Transport
B64G	Mechanical engineering	Transport
A47B	Other fields	Furniture, games
A47C	Other fields	Furniture, games
A47D	Other fields	Furniture, games
A47F	Other fields	Furniture, games
A47G	Other fields	Furniture, games
A47H	Other fields	Furniture, games
A47J	Other fields	Furniture, games
A47K	Other fields	Furniture, games
A47L	Other fields	Furniture, games
A63B	Other fields	Furniture, games
A63C	Other fields	Furniture, games
A63D	Other fields	Furniture, games
A63F	Other fields	Furniture, games
A63G	Other fields	Furniture, games
A63H	Other fields	Furniture, games
A63J	Other fields	Furniture, games

A63K	Other fields	Furniture, games
A24B	Other fields	Other consumer goods
A24C	Other fields	Other consumer goods
A24D	Other fields	Other consumer goods
A24F	Other fields	Other consumer goods
A41B	Other fields	Other consumer goods
A41C	Other fields	Other consumer goods
A41D	Other fields	Other consumer goods
A41F	Other fields	Other consumer goods
A41G	Other fields	Other consumer goods
A42B	Other fields	Other consumer goods
A42C	Other fields	Other consumer goods
A43B	Other fields	Other consumer goods
A43C	Other fields	Other consumer goods
A44B	Other fields	Other consumer goods
A44C	Other fields	Other consumer goods
A45B	Other fields	Other consumer goods
A45C	Other fields	Other consumer goods
A45D	Other fields	Other consumer goods
A45F	Other fields	Other consumer goods
A46B	Other fields	Other consumer goods
A62B	Other fields	Other consumer goods
A99Z	Other fields	Other consumer goods
B42B	Other fields	Other consumer goods
B42C	Other fields	Other consumer goods
B42D	Other fields	Other consumer goods
B42F	Other fields	Other consumer goods
B43K	Other fields	Other consumer goods
B43L	Other fields	Other consumer goods
B43M	Other fields	Other consumer goods
B44B	Other fields	Other consumer goods
B44C	Other fields	Other consumer goods
B44D	Other fields	Other consumer goods
B44F	Other fields	Other consumer goods
B68B	Other fields	Other consumer goods
B68C	Other fields	Other consumer goods
B68F	Other fields	Other consumer goods
B68G	Other fields	Other consumer goods
D04D	Other fields	Other consumer goods
D06F	Other fields	Other consumer goods
D06N	Other fields	Other consumer goods
D07B	Other fields	Other consumer goods
F25D	Other fields	Other consumer goods
G10B	Other fields	Other consumer goods
G10C	Other fields	Other consumer goods
G10D	Other fields	Other consumer goods
G10F	Other fields	Other consumer goods
G10G	Other fields	Other consumer goods
G10H	Other fields	Other consumer goods
G10K	Other fields	Other consumer goods
E01B	Other fields	Civil engineering
E01C	Other fields	Civil engineering

E01D	Other fields	Civil engineering
E01F	Other fields	Civil engineering
E01F	Other fields	Civil engineering
E01F	Other fields	Civil engineering
E01F	Other fields	Civil engineering
E01F	Other fields	Civil engineering
E01F	Other fields	Civil engineering
E01F	Other fields	Civil engineering
E01F	Other fields	Civil engineering
E01H	Other fields	Civil engineering
E02B	Other fields	Civil engineering
E02C	Other fields	Civil engineering
E02D	Other fields	Civil engineering
E02F	Other fields	Civil engineering
E03B	Other fields	Civil engineering
E03C	Other fields	Civil engineering
E03D	Other fields	Civil engineering
E03F	Other fields	Civil engineering
E04B	Other fields	Civil engineering
E04C	Other fields	Civil engineering
E04D	Other fields	Civil engineering
E04F	Other fields	Civil engineering
E04G	Other fields	Civil engineering
E04H	Other fields	Civil engineering
E05B	Other fields	Civil engineering
E05C	Other fields	Civil engineering
E05D	Other fields	Civil engineering
E05F	Other fields	Civil engineering
E05G	Other fields	Civil engineering
E06B	Other fields	Civil engineering
E06C	Other fields	Civil engineering
E21B	Other fields	Civil engineering
E21C	Other fields	Civil engineering
E21D	Other fields	Civil engineering
E21F	Other fields	Civil engineering
E99Z	Other fields	Civil engineering