Master Thesis

How does knowledge development and diffusion influence the innovation system of biorefinery technologies?

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Preface

"We cannot solve our problems with the same thinking we used when we created them." – Albert Eistein

This quote reminds me of the core of the problem for sustainable innovations. We are trying to solve problems related to climate change by making current production systems smarter, more efficient and more renewable. Small steps in the good direction, but something seems to be blocking a large scale transformation to sustainable production systems, even when the technology itself is already present.

One of the concepts that may hold the key to such a transformation is called the bio-based economy. This is why I present to you my master thesis on the innovation system of a set of technologies aimed at utilising all the potentials biomass possesses.

During my studies in the field of the bio-based economy, I became more and more fascinated by the subject and the potential it holds for the future. *AgencyNL* offered me a place to work on my thesis and to do something meaningful with my work. Kees Kwant invited me to work on a database containing European funded bio-based economy projects for the SAHYOG project. The aim was to identify collaboration possibilities in this field between Europe and India. He provided me with the freedom to develop and use my own methods and encouraged me to create a product with societal relevance as well. He is dedicated to accelerating the developments within these fields and provided me with his feedback during my thesis.

I want to thank my supervisor, Simona Nergo, for her effort in providing me with feedback, in particular during the research proposal phase. Our discussions helped to sharpen the theoretical embedding and the research scope. Furthermore, I want to thank my second reader, Gaston Heimeriks for his feedback on my research proposal and thereby his contribution to this final piece.

I hope you will enjoy reading this thesis and I hope my efforts will help the bioeconomy to move a small step forward.

Michiel Evers, BSc

Utrecht, 11 February 2014

Abstract

Biorefineries have the potential of becoming an important in the future European energy and production system. They can contributes to policy objectives on climate change, energy security and green growth as it is the only C-rich material besides of fossil resources. However, the large potential of biorefineries does not automatically lead to a large share of biorefineries in future energy and production systems. Recent insights in innovation studies suggest that the success chances of technological innovations are to a large extent determined by the innovation system, the systems that develops, commercializes and diffuses technology.

The influence of network formation on the innovation system of biochemical biomass conversion technologies for biorefineries are analysed in this research. A TIS approach combined with methods from social network analysis is used to analyse knowledge development and diffusion in the period between 2002 and 2013 in joint European research projects in the sixth and seventh framework projects. The focus is on how these two key innovation processes influence the innovation system with the objective to gain insight in the dynamics of these two innovation processes and to analyse the relationship between the structure of the system in terms of its components and the functioning of the system in terms of its key innovation processes.

Based on this analysis, a number of interaction patterns for the development and diffusion of knowledge with other important innovation processes were found. These two functions fulfil important roles in young innovation systems, but in order for the system to move to the next phase, the presence of favourable markets seems to be a key requirement. This research emphasized the importance of network formation. The structure of these networks is an important determinant for the flow of knowledge through the networks. Next to facilitating knowledge flows, networks fulfil other important function in emerging innovation systems: they enable organisations to attract human capital and granted certain key actors power to influence the direction of future developments.

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1 Introduction

The strong dependence of industrialised economies on fossil fuels from the intensive use and the consumption of petroleum derivates, combined with the increasing scarcity of these fossil resources, causes environmental and political concerns. European policy is aimed at reducing its dependency on these fossil resources by the substitution of petroleum derivates with renewable resources (European Commission, 2011). Biomass has the highest potential to substitute petrol-resources, since it is the only C-rich material available on Earth besides fossil resources (Cherubini, 2010). During the last decades, biomass and its products have been investigated as alternative feedstock for (i) electrical/heat energy, (ii) transport fuels and (iii) chemicals. A biorefinery is a facility that integrates biomass conversion processes.

The development of biorefineries can be considered as a radical innovation as it holds the potential to transform the fossil-based system into a more renewable system. The European Commission (EC) supported development and implementation of biomass conversion technologies through various R&D programs since the eighties (Faaij, 2006). Attention on the development of biomass conversion technologies increased over the last decade in the sixth and seventh framework programs[1]. The EC has high expectations on the development of biorefineries: *"green energy and bio-products are solid alternatives to fossil fuels and products made from oil, in the short to medium term. The large-scale transformation of biomass into a wide range of end-products will take place in biorefineries"* (European Commission, 2013). However, despite significant historical attention, biomass conversion technologies thus far fail to realize a large scale break through (Suurs & Hekkert, 2009). A large potential does not automatically lead to a large scale substitution of fossil resources by biomass resources. Innovation and technological change involve by its very nature a fundamental element of uncertainty: outcomes of these processes cannot be known ex ante (Dosi, 1988). Nevertheless, innovation scholars have shown that the success chances of a technology can be increased by conscious and intelligent management (Negro, et al., 2012; Hekkert, et al., 2007).

An important insight that has dominated the field of innovation studies is the fact that innovation is a collective activity and takes place within the context of an innovation system (Freeman, 1997; Lundvall, 1992; Nelson & Winter, 1977; Hekkert, et al., 2007). Innovations are generated by networks of interacting organisations and individuals (Freeman, 1997). As a result, organisations increasingly organise their access to complementary knowledge networks and policy makers emphasize the importance of collaboration networks for innovation. The OECD[2] indicated recently that *"the potential for innovation depends on how well knowledge circulates and how well the system is connected: policies to foster and enable the development of world class clusters and networks are thus of growing importance"* (OECD, 2008). Knowledge is regarded as a key input for innovation which places the processes of knowledge development and learning at the heart of a process of technological change (Lundvall & Nielsen, 2007).

In recent years, the 'technological innovation systems' (TIS) framework has been developed to assess the performance of an innovation system. Key processes within innovation systems have been identified that are decisive for the shaping and development of technology (Hekkert, et al., 2007). These processes are called system functions, and have been successfully applied by innovation scholars to deliver explanations for the success or failure of (sustainable) technologies (Hekkert, et al., 2007; Wieczorek, et al., 2013; Negro & Hekkert, 2008; Negro & Hekkert, 2012; Negro, et al., 2008). The purpose of analysing a TIS is to evaluate the

[1] Framework programs are funding schemes created by the European Union in order to support and encourage research.

[2] The *Organisation for Economic Co-operation and Development* (OECD) is an international economic organisation of 34 countries founded in 1961 to stimulate economic progress and world trade (OECD, 2013).

development of a particular technological field in terms of the structures and processes that support or hamper it. Knowledge development and knowledge diffusion are included as functions of the innovation system. Knowledge is a pre-requisite for the development of an emerging technology. Lundvall (1991) even states that knowledge is the most fundamental resource in modern economies and learning the most important process. Suurs (2009) pointed out that the functions knowledge development and knowledge diffusion are of particular importance for immature innovation systems. However, little research has been done on the specific role of knowledge development and diffusion as a driving for the build-up of innovation systems (Suurs, 2009). This research focuses therefore on knowledge development and –diffusion in the context of an emerging TIS. The analytical focus on system functions only, however, runs the risk of losing sight of the important role of actors. Innovations are generated and implemented by networks of interacting actors. It is the actors of a TIS that through their choices and actions, generate, diffuse and utilise technologies (Binz, et al., 2014; Markard & Truffer, 2008). The specific approach presented in this research therefore aims at how actor-networks influence the dynamics of knowledge development and diffusion. The following research question is central to this study:

RQ: How did network formation affect the development of a biorefinery-TIS over time and how can this development be accelerated?

The main contribution to recent TIS literature is that it provides insight into the process of technological change in relatively young innovation systems. The answer of this question is relevant to the society as well as it provides new insights in how innovation can be supported within the bioeconomy and will as such help Europe realize the potential of biobased products and energy, thereby lowering GHG emissions. However, to be able to answer the main question, the following sub-questions need to be answered at first:

SQ(1): How do development- and diffusion of knowledge affect the formation of an innovation system for biorefineries over time?

SQ(2): What are the current drivers and barriers for the development of biomass conversion technologies?

SQ(3): How could the diffusion of biomass conversion technologies be accelerated?

This research is organised as follows: section two presents the theoretical framework that has been used in order to analyse the functional and structural development of the innovation system. Section three presents the methodology used for the analyses. Section four presents the historical context of the research. The results are presented in section five and analysed in section six. Section seven presents the discussion of the research and the conclusions concerning the theoretical implications are presented in section eight.

2 Theoretical framework

The theoretical concepts that serve as a guideline for the research are presented in this section. First Technological Innovation System (TIS) theory is explained. IS theory is used as a heuristic framework to analyse the knowledge development and diffusion within the biorefinery industry. Thereafter, the relevance of complementing a TIS analysis with Social Network Analysis (SNA) is elaborated. SNA is used to analyse the structure innovation system in terms of its knowledge development and diffusion processes.

2.1 Technological innovation systems

The concept of technological innovation systems has gained importance in recent years as analytical construct to study innovation processes and early industry emergence (Markard, et al., 2012; Hekkert, et al., 2007; van der Valk, et al., 2011; Wieczorek, et al., 2013). Innovation is conceptualized as an interactive, recursive process, embedded in a set of co-evolving actors, networks and institutions (Markard & Truffer, 2008). Carlsson and Stankiewicz (1991) defined a TIS as a *"network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure and involved in the generation, diffusion and utilisation of technology"* (Carlsson & Stankiewicz, 1991, p. 111). The TIS concept highlights the systemic interplay of complementary actors in networks and the broader institutional structures in technological fields (Nelson, 1993; Lundvall, 1992; Edquist, 2005). The purpose of analysing a TIS is to evaluate the development of a particular technological field in terms of its processes and structures that support or hamper it. The identified barriers may then be easier addressed by policy (Wieczorek, et al., 2013). The structure of a TIS is defined as the actors, networks and institutions that support the development, diffusion and commercialisation of new technology (Hekkert, et al., 2007). The functions are key processes that are important for the build-up and functionality of a TIS (see Table 1). By focussing on key innovation processes, Bergek et al. (2008) and Hekkert et al. (2007) identified a set of seven key processes for innovation**.** The performance of a TIS depends on how well its actors can sustain these seven systemic building processes.

Function	Description
F1: Entrepreneurial activities	Entrepreneurs are essential for a well functioning innovation system. Their role is to generate new business opportunities by turning the potential of new knowledge, networks and markets into concrete actions.
F2: Knowledge development	Knowledge is a fundamental resource in innovation processes. Therefore, the development of (new) knowledge is crucial for the performance of the system.
F3: Knowledge diffusion	Knowledge needs to be exchanged with relevant actors to facilitate a process of learning.
F4: Guidance of the search	A clear development goal for a technology, based on technological expectations, articulated user demands and societal discourse enables selection, which guides the distribution of resources.
F5: Market formation	The creation of markets for the new technology is important for IS development. In the early phases of development, these can be small niche markets, but as the development progresses, larger markets are needed to facilitate cost reduction and to create incentives for entrepreneurs to move in.
F6: Resource mobilisation	The financial, human, and physical resources necessary are necessary inputs for all activities in the innovation system.
F7: Creation of legitimacy	Innovation is by definition characterised by high levels of uncertainty. A certain level of legitimacy is required for all actors to commit to the new technology.

Table 1 – Functions of a technological innovation system (Adapted from *Wieczorek et al. 2013)*

The structure and key processes complement each other: the key processes, if badly fulfilled, signal problems in the structure. For example, weaknesses of the functions knowledge development and knowledge diffusion may relate to the network structure: weak networks can lead to inefficient use of complementary resources among actors and thus hamper the development of knowledge, while too strong networks may result in blindness towards external developments, making the system vulnerable for lock-in (Narula, 2002). Analysing the key processes is very helpful in tracing system failures for the emergence of new technologies, but a strong focus on the functions, however, runs the risk of losing sight of the important role of actors (Musiolik & Markard, 2011). The focus of this study is on the dynamic aspect of a TIS, it is therefore important to assess how certain structural elements came into existence and which functions act as a driving force for the build-up of the TIS (Suurs, et al., 2010).

2.1.1 The dynamics of TIS emergence

Structures involve elements that are relatively stable over time. Nevertheless, especially for emerging technologies, these structures are not yet fully developed. For an emerging technology, a TIS has yet to be built up (Suurs, et al., 2010). A new TIS does not come into existence overnight, but is gradually shaped over time (Suurs, et al., 2010). Literature on technological innovation systems stressed that emerging technologies will pass through a so-called formative stage before they can be expected to pass into a stage of market diffusion (Jacobsson & Bergek, 2004). A TIS in a formative stage is characterized by the fluidity of the emerging technology and by weak, or even absent, technological and institutional support structures (Utterback & Afuah, 1997). During the formative stage, new actors need to be involved in the development, networks need to be formed and institutional structures to support the technology need to be designed (Jacobsson & Bergek, 2004). The phase of development of a TIS can be described by its position on the *S-curve*. The curve describes the process of development, application and further diffusion of the technology. The S-curve can be divided into different phases: the first phase is the *pre-development phase*, where a working prototype is produced. The first commercial applications are developed in the *development phase*. The technology will be diffused on a larger scale in the *take-off phase* , the market size will grow further in the *acceleration phase* until saturation occurs in the *stabilisation phase* where the degree of diffusion stabilizes (Hekkert, et al., 2011).

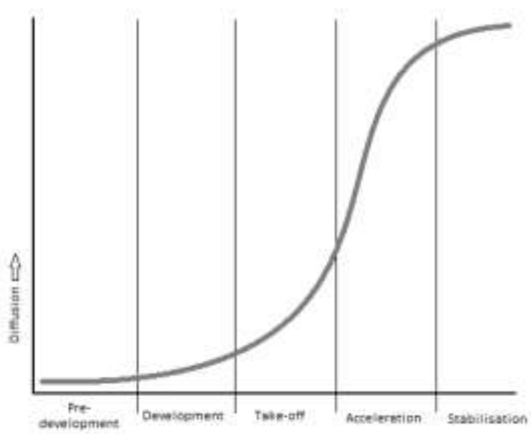

Figure 1 – Phase of development (Adapted from Hekkert et al. 2011)

This process van can be accelerated by interacting- and reinforcing systems functions over time. This phenomenon is described in TIS literature as a process of cumulative causation, also called motors of innovation (Hekkert, et al., 2007; Suurs, et al., 2010).

Research on cumulative causation processes suggest that such self-reinforcing dynamics are necessary in order to establish a broad diffusion of sustainable technologies into the current incumbent energy- and production system (Suurs & Hekkert, 2009; Suurs, et al., 2010; Suurs, et al., 2010). These motors are not independent of the TIS structures: motors emerge from a configuration of structural factors and in turn rearrange that configuration. The active motors depend on the phase of development of the TIS: if the technology is still in an early phase of development, certain functions will be more relevant than those for a mature technology (Bergek, et al., 2008; van Alphen, et al., 2010; Hekkert, et al., 2011; Suurs & Hekkert, 2009).

Suurs (2009) identified four successive motors of innovation, related to the different phases of TIS maturity. Knowledge creation and diffusion is the driving force of TIS development during its early phases (Suurs, 2009). Immature TISs are typically driven at first by a *science and technology push motor* and dominated by *knowledge development* (F2), *knowledge diffusion* (F3), *guidance of the search* (F4) and *resource mobilisation* (F6). The dynamic of the *STP Motor* involves a sequence of positive expectations and/or research outcomes, leading to government supported R&D programmes and the allocation of financial resources to the emerging technology. This in turn will boost scientific activities. During the formative phase of a TIS, high levels of uncertainty exist in terms of technologies, markets and regulations (Utterback & Afuah, 1997). As more knowledge becomes available on the potential of the technology, the degree of uncertainty surrounding the technology decreases and more organisations will enter the arena. Higher levels of accumulated knowledge reduce the uncertainty concerning the technology as it enables organisations to predict more accurately the nature and commercial potential of changes in the environment (Boekema, 2000). The science and technology industry typically take the position of enactors; these are the actors committed in the very early stages of a TIS to the further development of an emerging technology. If the *STP Motor* is sustained, it has a lasting impact on the knowledge structure and the supply side of the TIS. The number of scientists and firms involved in developing the technology increases, and their relations become stronger.

In order for a TIS to progress to the next phase, the *entrepreneurial motor* needs to be activated. The *Entrepreneurial motor* is partly similar to the *STP Motor,* but a strong presence of *Support from Advocacy Coalitions* and *Entrepreneurial Activities* sets it apart from the *STP Motor*. An important difference with the dynamics of the *STP Motor* is that in this motor *Entrepreneurial Activities* strongly interact with *Knowledge development* and *Knowledge Diffusion.* Firms and utilities take the position of enactors and there this motor is characterised by an increasing presence of demand-side actors.

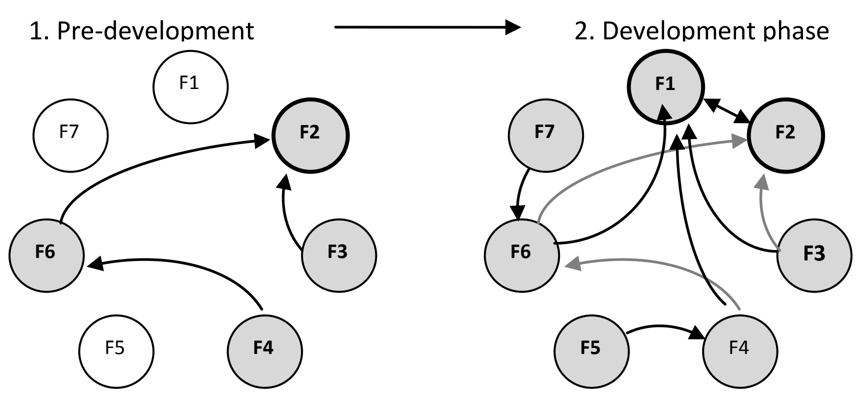

Figure 2 – Dominant functions and functional patterns in the pre-development and development phase. The numbers correspond to the functions in table 1 (Adapted from Hekkert et al. 2011)

Limited performance of relevant functions indicates potential barriers to innovation system development (van Alphen, et al., 2010). The link between the knowledge industry and commercial organisations can thereby be considered as important hinges for an innovation system to move from a pre-development phase to a development phase. Entrepreneurial experimentation depends on new companies entering the field, and most importantly, the ties formed between them and the knowledge network. The performance of the knowledge network and the ties of new companies with this network are therefore important determinants for the innovation system to progress from the pre-development phase into the development phase (Binz, et al., 2014).

Knowledge development and knowledge diffusion are therefore of vital importance for innovation system development in its early stages, but these concepts have been poorly conceptualised in traditional TIS studies. The conceptualisation of knowledge development and knowledge diffusion in traditional TIS studies is rather simplistic and ignores to some extent the dynamics of knowledge development processes (Coenen & López, 2010). So far, TIS scholars mostly conceptualise knowledge development in terms of the number of R&D projects, patents and investments in R&D over time. Knowledge development as such is defined without reference to the actors or networks involved in the process, but with a strong focus on the way in which it is generated (Binz, et al., 2014). This conceptualisation ignores some of the key processes of knowledge development: actors differ in their ability to tap into external knowledge sources. Knowledge flows for innovation activities are therefore unevenly distributed through the innovation network. In order to understand the dynamics of knowledge production and knowledge flows through networks, it is useful to make a distinction between tacit and codified forms of knowledge: codified knowledge can be articulated and stored in certain media and thereby easily transferred (Boekema, 2000). Tacit knowledge is in contrast difficult to transfer by means of writing or verbalizing it and it cannot be removed from its humans and its social context. It therefore evolves in much more complex settings and its diffusion is restricted to close interactions in dense networks (Binz, et al., 2014). The transfer of more tacit forms of knowledge therefore required more intensive and personal ties than the transfer of codified forms of knowledge (Gertler, 2003). The position of actors and their relational ties to others in the network therefore influences the extent to which actors can shape the technological field in which they are operating. The structure of the knowledge network is therefore an important determinant of knowledge flows through the innovation network and has its implications for TIS development, as knowledge transfer from the knowledge industry to commercial organisations is regarded as a requirement for the build-up of a TIS. This implicates that commercial organisations actively need to participate in the knowledge network in order to gain access to all dimensions of knowledge. The analysis of knowledge creation from a network perspective therefore allows a more sophisticated examination of knowledge development and diffusion.

2.1.2 The need for a closer look at knowledge development in networks for emerging TISs

The concept of networks plays a major role from an innovation systems perspective (Musiolik & Markard, 2011; Bergek, et al., 2008; Jacobsson & Johnson, 2000). Interaction takes place between the actors in networks (Jacobsson & Johnson, 2000). Networks can influence actors in two ways: first, through the flow and sharing of information within the network. Secondly, through differences in the position of actors in the network, which cause power and control imbalances (Tidd & Bessant, 2009). Networks of actors facilitate interactive learning and the exchange of knowledge (Markard & Truffer, 2008). According to the resource-based view of firms, innovation and long-term survival require access to external knowledge. Networks as such can be described as bundles of resources which are made available by network members or which emerge in the network. Actors therefore engage in social ties through which they seek access to complementary resources to achieve their individual goals (Fritsch & Kauffeld-Monz, 2010).

Networks are traditionally used in TIS literature at a mostly qualitative and metaphorical level and ignore the influence of specific actors on system building processes, especially in the case of emergent technologies (Coenen & López, 2010). Networks are described as informal structures which facilitate the exchange of information, knowledge and other resources between innovating actors (Musiolik, et al., 2012). More recent approaches therefore use the notion of *formal networks* to describe organisational structures with clearly identifiable members with clearly identifiable members where firms and other organisations come together to achieve common aims or to solve specific tasks (Musiolik, et al., 2012; van der Valk, et al., 2011; Wieczorek, et al., 2013)**.** Formal network have been shown to strategically create system resources that are crucial for the build-up of the TIS (Musiolik & Markard, 2011).

In order to analyse the innovative performance of networks, literature in the area of social network analysis (SNA) provides insight into concepts of network structure that may influence the direction and extent of diffusion of knowledge through a network (Mueller-Prothmann, 2012). In the case of TIS, the structure of the knowledge network can function as an important indicator for the performance of the network. Structural weaknesses will have a negative impact on the creation and diffusion of knowledge.

The diffusion of knowledge through a network is reflected by its structure. Diffusion occurs through interaction: the structure of the network in which actors interact influences the extent of diffusion and thus the innovative potential of the system (Cowan, et al., 2004). A network analysis can also reveal the profile of specific actors and the role they play in the innovation system. Some actors, the so-called prime movers who control critical resources or pursue very dedicated innovation activities, may be able to exert significant influence on direction of technological development of the innovation system in an early phase of development (Markard & Truffer, 2008). It is therefore important to analyse both the structure and the position of important actors in the network over time.

Important concepts to analyse the structure are *cohesion* (density and connectivity) and *centralisation* (the balance of the network) (van der Valk, et al., 2011; Wasserman & Faust, 1994). Cohesion measures the extent to which actors that are part of the network are related to each other. A limited number of relationships are expected to limit the performance of the network. Fritsch and Kauffeld-Monz (2010) found a positive relation between embeddedness in the network and inter-organisational exchange of knowledge. Cohesion can be viewed as the capacity for social ties to carry information that reduces uncertainty and increases trust between actors (Guilati, 1998). Cohesion enables the accumulation of social capital, but overembeddedness may hamper the performance (Coleman, 1988). Although research has shown that dense networks seem to perform better than fragmented ones (Graf & Henning, 2009), high cohesion could reduce the variety of knowledge and as such reduces the number of opportunities for novel combinations and experimentation. High cohesion increases the chances of an early lock-in of a specific technology (Fritsch & Kauffeld-Monz, 2010).

Centralisation refers to the emergence of so called 'hubs', e.g. above average connected central nodes. An actor's more central position within a network will be beneficial due to his superior access to many sources of external knowledge (Brenner, et al., 2013). The increased centralisation in networks is able to influence the network performance in two ways: highly centralised structures are more robust because their structure is not likely to change due to the removal of a few nodes or edges. Secondly, a clear sense of leadership exist in more centralised networks and participants operate often more efficiently in the case of problems (van der Valk, et al., 2011; Mueller-Prothmann, 2012). The drawback of networks that are highly centralised is that these networks are heavily dependent on their hubs. These hubs can be considered important centres of knowledge development and diffusion (Mueller-Prothmann, 2012).

3 Methodology

This section of the report deals with the research methodology in order to test the hypotheses as mentioned in the theoretical framework. The analysis will focus on data retrieved from CORDIS[3], complemented by data from qualitative interviews.

3.1 Research design

The research aims at uncovering how knowledge development and diffusion affects the structure of the TIS of biorefinery technologies. In order to develop statements about the influence of knowledge development and knowledge diffusion, the unit of analysis comprises the organisations participating in research projects cofounded by the EC. The focus of this research is on knowledge development and diffusion related to biochemical biomass conversion technologies, which are regarded as promising biomass conversion routes in biorefineries (Faaij, 2006; Brethauer & Wyman, 2010). The level of analysis of this research comprises the European biorefinery industry. A cross-sectional design with case study elements was executed in order to collect data. As this study focuses on the biorefinery industry, it is not possible to generalise findings concerning knowledge development and diffusion without reference to the special characteristics of the biorefinery industry. By using a cross-sectional research design, the researcher is in a better position to establish relationships between the variables on an industry level.

Methods from social network analysis were used to analyse the collaborative R&D projects in CORDIS. The participants in these projects can be regarded as actors involved the knowledge development and diffusion network. Interviews with experts were used to complement findings from the structural analysis and to uncover the impacts of knowledge development and diffusion on the other functions of the innovation system. Combining these methods enables the researcher to develop statements about the relationships as stated in the sub-questions.

3.2 Data collection

Multiple sources of data were used in the study in order to apply triangulation. That is, by using multiple sources of evidence, the probability that data are based on coincidence diminishes, because the data are more likely to be valid if multiple sources of data support the same findings (Bryman, 2012). For the analysis of how knowledge development and diffusion are influencing the innovation system, data both qualitative and quantitative in nature, from several sources were used: (i) scientific, governmental and industrial literature, (ii) CORDIS and several (iii) stakeholder interviews. These different sources are elucidated in the next paragraphs.

Reports from scientific research projects and industrial publications tend to be original and recent and they have the advantage of providing contextual data. Data of actor's subjective views can be compared with data from other sources in order to be able to establish relationships between the variables in the conceptual model. This type of data was found on the actor's publicly accessible websites. Data originating from these sources was used to supplement data from the other sources.

CORDIS is an online database of all co-funded research projects by the European Commission. CORDIS contains information on budgets for research, technical information on the research itself and details on the involved actors. Data from this source was accessed online through the website of CORDIS. Additional, non-public available information in CORDIS was retrieved through Agency NL. Projects in the 6th and 7th

[3] '*Community Research and Development Information Service'* (CORDIS) is an information space committed to European R&D activities and technology transfer (European Commission, sd)

framework programs (2002-2013) were included in the analysis. Projects were filtered using different combinations of keywords like: biomass, bioenergy, fermentation, anaerobic digestion, bio-ethanol, hydrolysis, bio-methanol, bio-methane, lignocellulosic, and so on. Results were filtered by hand and projects with no connection to biochemical biomass conversion were removed from the dataset.

3.2.1 Interviews with experts

To gather data concerning the actors perceptions on the functioning of the IS, experts were identified through the SNA and interviewed. The network analysis was used to identify organisations of interest and these were contacted for interviews. Organisations were selected, based on their degree centrality. The higher the degree centrality, the better connected and the more central the organisation is. Interviewees of these organisations were expected to possess more and better information. The sample size depended on applying triangulation and data saturation. As it was impossible to ex ante know the sample size needed to achieve theoretical saturation, the aim was interview between six and ten interviewees. Contact information was retrieved through *AgencyNL.* In order to limit the influence of socially desirable answers, the anonymity of the interviewees was guaranteed, table 1 provides the anonymous oversight of all interviewees.

Interviews are particularly helpful in the generation of an intensive, detailed examination of a case (Bryman, 2012). Given the character of this research, semi-structured interviews (i.e. qualitative interviews) were used for several reasons. First, to be able to infer casual relationships between the functions TIS, it was necessary to understand the subjective opinion of different actors in the IS. Secondly, qualitative interviews tended to be flexible due to the ability of responding directly and asking for explanations. Thirdly, it enabled the researcher to obtain rich and detailed answers (Bryman, 2012).

By using open ended questions, the assumed relationships between the concepts in the research questions were tested. Answers indicated whether a relationship exists and open ended questions were useful to explore the mechanisms of these relationships.

Experts	Function
Interviewee 1	Manager at Research Organisation
Interviewee 2	Intermediary between industry and academia
Interviewee 3	Researcher
Interviewee 4	Manager International projects at an university
Interviewee 5	Consultant at a public body
Interviewee 6	Researcher at a commercial organisation
Interviewee 7	Manager at a commercial organisation

Table 2 – Overview interviewees

3.2.2 Network analysis

Data on joint R&D projects that are part of the FP6 and FP7 were collected from CORDIS. Using these data, the networks were compiled and the different aspects of the structure were examined. If organisations were in the same joint R&D project, knowledge exchange was expected to take place, which is represented by an edge between the two actors (the nodes) in the network. Wassermann and Faust (1994) provide an overview of possible measurements, both concerning the position of the individual nodes in the network and the network as a whole (Wasserman & Faust, 1994). For the analysis of the structure of the network, only the measures of the network as a whole were used (Scott & Carrington, 2011). Measures addressing the cohesion of the network are the density of the network, its average path length and diameter (longest possible path in the network). These measures provide information on both the relative number of linkages in the network and the extent to which these linkages connect different nodes in the network (Wasserman & Faust, 1994). The network centralisation can be examined by calculating the average degree, skewness and kurtosis of the distribution of the degrees (van der Valk, et al., 2011; Scott & Carrington, 2011). The centralisation index provides an overall insight into the inequality of centrality of individual actors, while the skewness and the kurtosis provide insight in the inequality by comparing the degree distribution to the normal distribution (Mueller-Prothmann, 2012). The skewness of the degree distribution provides insight on whether there are many nodes with a relatively high degree or many nodes with a low degree. The kurtosis reflects the 'peakedness' of the distribution: A positive kurtosis indicates the presence of some nodes with an extremely high degree (van der Valk, et al., 2011).

To assess the different measures, the program Gephi was used (The Gephi Consortium, 2012). Within Gephi, the different measures can be calculated and the network data can be visualised (The Gephi Consortium, 2012). The measures were calculated for each year from 2004 until 2012, taking only active projects in that period into account. The original data is a 'two-mode' network, a matrix containing projects and project participants. This two-mode network was converted into a one-mode, containing only participants, using Pajek (V. Batagelj, 2003).

3.3 Operationalization

The main concepts, derived from theory, that guide the analysis, have been operationalized according to their theoretical meaning as discussed in the theoretical framework, with 'structure of the network', 'knowledge development' and 'knowledge diffusion' being the independent variables.

Structure of the network refers to actors and the networks connecting these actors. The different actors interact with each other in networks that develop and diffuse technology. Changes in structure were indicated by comparing network statistics and visualisations over time.

Knowledge development refers to the mechanisms of learning in the innovation system. Knowledge is a fundamental resource for innovation. Therefore, the development of knowledge is fundamental for innovation systems. Knowledge development was indicated by the number of R&D projects and the knowledge field on which it is building.

Knowledge diffusion through networks refers to the mechanisms of knowledge exchange in order to facilitate learning. Both formal and informal networks were examined. Actors participating together in a project indicate a goal-oriented, formal network. The total number of ties connecting an actor to the rest of the network indicates the informal network. The process of knowledge diffusion was indicated by the cohesion and centrality of the network over time and by the strength of the relationships between actors in the eyes of the interviewees.

3.4 Data analysis

The data from the social network analysis will be analysed and compared with the data from the interviews. Concepts of the theoretical framework will serve as so called 'sensitising concepts' to help distinguish what is relevant.

3.4.1 Quantitative data

The network analysis is used to analyse the emerging knowledge network. As different organisational types are expected to perform different functions in Innovation Systems, a different colour is assigned to each type of actor in order to be able to analyse the network composition. The division is made, based on the existing categorization of actors in CORDIS (CORDIS, 2013):

- Commercial organisations: these organisations are important for the commercialisation of the knowledge. Their presence indicates industry participation. Their embeddedness and position can indicate how efficient the knowledge is being commercialised.
- Higher or secondary education: these actors are needed to enrich the innovation system with skilled labour and they are involved in the development of (fundamental) knowledge. Their presence indicates academia participation. Their embeddedness and position indicate how much knowledge is being developed and how much power these types of organisations possess to influence developments.
- Research organisations: the primary objective of research organisations is to develop new knowledge. Their presence indicates research organisation participation. Their embeddedness and position indicates how much knowledge is being developed and how much power these actors possess to influence developments.
- Public bodies: these actors are not likely to be engaged in the knowledge development itself, but their presence is needed to be influence legislation on national level in order to support the system's development.
- Other: these are mostly interest groups of different types. They perform lobby activities to support certain technologies. Their presence indicates the existence of lobby groups. They are needed in the innovation system to create legitimacy and to create favourable legislative circumstances.

The edges between the actors represent flows of knowledge exchange. If actors participate in the same project, they were expected to exchange knowledge. The better an actor was connected to the network by its edges, the better the actor was able to access different knowledge flows. The network was visualised in timeframes of 3 years in order to allow a dynamic analysis of the evolving knowledge network. The networks were visualised using a force-directed layout. A force directed layout allows an intuitive visualisation of the network and enables the researcher to identify actors that hold important positions in the knowledge network.

While a structural actor-based bibliometric analysis leads to interesting results, it does not provide any information on the actual content of the research topics dealt with in the projects. Co-word analysis, that counts and analyses the co-occurrences of keywords in the projects (based on cosine distances among words), on the other hand, has the potential to address precisely this kind of analytic problem (Callon, et al., 1991). A content-based analysis on the project titles and project objectives is performed in order to differentiate different knowledge topics in the network. A co-word analysis was used to discover linkages among subjects in the research field, based on the co-occurrence in the project titles and the projects objectives (Heimeriks, 2013). The structural analysis together with the content-based analysis provides insight in the developments of the knowledge network.

3.4.2 Qualitative data

The qualitative data is analysed by means of coding, i.e. the process whereby data are broken down into parts which are given names (Bryman, 2012). All interviews have been transcribed into text files and sorted per interviewee, resulting in seven company-specific text files. These text files have been imported into ATLAS.ti where a process of open coding was conducted, i.e. labels were assigned to specific text fragments. Memos were made when ideas arose while coding. After the coding process was finished, concepts were organised around certain topics to create an overview, thereby providing an overview of the relevant functions knowledge development provides in the innovation system.

3.4.3 Testing the research questions

The sub-questions represent different dimensions of the main question. By providing answers to the sub-questions, statements on the main question can be formulated. The composition and the statistics provides in-depth understanding of structural developments of the knowledge network, and interview quotations from different interviewees provides in-depth understanding on how knowledge development and diffusion influence the IS.

3.4.4 Quality of research

Validity and reliability are core elements that need to be taken into account when doing research, since they are important criteria concerning the quality of research (Bryman, 2012).

Validity

The use of multiple sources increases the construct validity if all these sources point to the same outcome. By using interviews, public data and network data the construct validity was increased, however by interviewing only experts, an elite bias could be formed. The internal validity of a cross-sectional study design is typically weak as it is difficult to establish causal relationships from the data. Cross-sectional research produces associations rather than findings from which causal inferences can be made.

Reliability

As this study contains qualitative elements, it does not lend itself to be precisely replicated regarding the content, since the contextual setting of the organisation during this research could be different in the future. However, by providing as much transparency as possible by describing the research process in great detail and justify certain decisions, the reliability was increased.

4 Background of biochemical conversion technologies

Before providing the results of the different analyses, it is important to provide context on the development of biorefineries. A short historical description of the events that resulted in the emerging innovation system of biochemical biomass conversion technologies will be described in the section below, followed by an overview of the biochemical biomass conversion technologies.

4.1 History and current status of industrialisation of biorefineries

The use of biomass for energy and fuels has a very long history. Bioethanol has been in the first Otto engine in 1860 and later by Henry Ford as an automotive fuel. The use of biofuels declined dramatically as the large exploitation of crude oil began in the 1930s. The interest in biofuels arose two times in the last century where external circumstances forced a partial replacement of fossil fuels: during WOII and the oil crisis in the late 1970s (World Economic Forum, 2010). During the last decade of the 20th century, concerns about global warming and climate change were emerging on public agendas worldwide. These concerns began to translate into national and regional legislation during the beginning of the 21th century, pushing the development of biorefineries forward. The EU adopted its biofuels directive in 2003 which set a goal of 5.75% share of biofuels in 2010. In 2007, the EC set out new goals for 2020 through binding targets for each member states of a minimal 10% share of biofuels in transportation. The EC adopted more recently the strategy for 'Innovation for Sustainable Growth: A Bioeconomy for Europe' (2012) which included most of the preceding directives (European Commission, 2009; European Commission, 2011; European Commission, 2013). The technological development of second generation biomass processing technologies is one of the focus points of this strategy (European Commission, 2012). Currently, mostly first generation technologies (food-based feedstock) are used for biomass processing which causes some major societal debates like the food/fuel discussion, decreasing the legitimacy of bio-products (Balat & Balat, 2009; BIOPOL, 2009). The EC has high expectations on second generation technologies to counter these objections, thereby making the technological development of these technologies a priority. The EU's ambitious goals for the establishment of a more renewable economy have been met to a moderate extent and have not jet positioned the EU in a leading role globally. The *World Economic Forum* blames this in their report on the future of biorefineries on fewer commercialisation activities in Europe compared with the US and due to the fragmented nature of EU's R&D efforts and insufficient funding for demonstration plants (World Economic Forum, 2010).

Actors involved in biomass processing technologies can be found in a wide range of industries due to the complex value chains. The main biomass processing industries in Europe are the chemical industry, the biofuels industry and agro-industries (mainly the sugar and starch sectors) followed by the forestry sector (BIOPOL, 2009). The dominating approach is to integrate bio-based products and processing techniques in existing value chains by replacing traditional petroleum based products with 'green' alternatives of the same functionality and performance (World Economic Forum, 2010). The actors in Europe involved in biorefineries or demonstration projects are mainly located in Western Europe (BIOPOL, 2009). Biomass conversion technologies using food crops as feedstock are already commercially deployed while advanced biomass processing technologies, using lignocellulosic materials, biowaste and algae as feedstock are still under development but are expected to become commercial within the next 15-20 years (Clark, et al., 2012).

4.2 Biochemical biomass conversion technologies

Analysing the development of biorefineries from an innovation system perspective can be a challenge due to the complexity of the subject. The value chain of biorefineries do not contain clearly defined inputs, processes and outputs, but a wide range of feedstocks, a large number of processes and technologies and even a larger number of possible intermediary- and end products (Aresta, et al., 2012). According to the National Renewable Energy Laboratory (NREL), *"a biorefinery is a facility that integrates biomass conversion processes and equipment to produce fuels, power, and chemicals from biomass"* (NREL, 2009). . Biomass contains varying amounts of cellulose, hemicellulose, lignin and a small amount of extractive. The biorefinery concept has been developed in the last decade in order to use all these fractions in biomass as efficiently as possible (Faaij, 2006; Saxena, et al., 2009). In contrast, most of today's biofuels and biochemicals are produced in single production chains and not within a biorefinery concept. Although a number of different biorefinery concepts exist in the literature, all of these concepts are making use of biochemical-, thermo chemical-, or mechanical conversion technologies (see appendix 10.2) (Kamm & Kamm, 2004; Fernando, et al., 2006; Cherubini, 2010). To reduce complexity and enable in-depth analysis of the actor network, the focus of this research is on biochemical biomass conversion technologies, as these are considered as having a large potential for the future (Faaij, 2006).

Biochemical conversion makes use of enzymes, of bacteria and of other micro-organisms to break down biomass. The main biochemical conversion routes for biorefineries are anaerobic digestion (biogas and landfill gas utilization) and fermentation (ethanol from sugar and starch and ethanol from (ligno-) cellulosic biomass) (Faaij, 2006). The biomass can be converted to a range of products using these conversion processes like methane, H2, organic acids, ethanol, chemicals, etc. (IEA, 2012).

Conventional fermentation processes for the production of ethanol make use of sugar and starch components of biomass. Ethanol production from these crops is, however, far from competitive compared to fossil-based production (Faaij, 2006; Aresta, et al., 2012). Second generation bio-ethanol precedes the fermentation process with acid and/ or enzymatic hydrolysis of hemicelluloses and cellulose to break down these molecules into fermentable saccharides. The development of various hydrolysis techniques has gained major attention over the past decade in Europe. However, cheap and efficient hydrolysis processes are still under development. Acid hydrolysis is relatively expensive and inefficient but enzymatic hydrolysis is still unproven (Faaij, 2006). For the agro-food industry, this second generation technology is of interest to boost the competitiveness of existing production sites as it allows valorisation of process residues (Aresta, et al., 2012).

Anaerobic digestion of biomass is a low-temperature biochemical process through which a combustible gas (a mixture of carbon dioxide and methane) can be produced. Anaerobic digestion has already been applied commercially with success for a variety of feedstocks, such as manure, organic domestic waste, organic industrial waste, etc. Anaerobic digestion is particularly suited for wet biomass materials. Advanced, large scale systems are being developed for wet, industrial waste streams (Faaij, 2006).

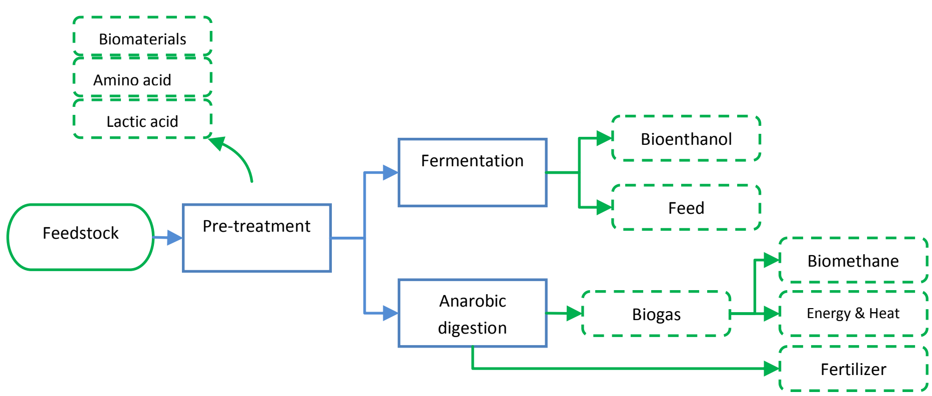

Figure 3 – Schematic representation of biochemical biomass conversion (IEA, 2012)

5 Overview of the results obtained

The results of the research are presented in this section. The results provide an overview of the relevant data concerning the research questions. These results provide insight in the structural development of the knowledge network, the performance of the network and how the build-up of the TIS can be accelerated. The structural development is graphically and visually presented in this section and interview outcomes are exemplified by quotes.

5.1 The effect of knowledge development on the formation of the TIS

To evaluate the knowledge developed in the CORDIS projects, the number and type of actors (research organisations, commercial organisations, etc.) involved in the knowledge development were studies, as well as the relationships between the actors. These results are mostly based on outcomes of the qualitative SNA. Three main themes were identified related to the effect of knowledge development on the formation of the TIS. Results on the formation of the knowledge network (i) provide the insight in the growth in terms of actors and resources flowing into the development of the relevant technologies. Results concerning the composition of the network (ii) focus on the actor groups in the network, and the participation of different actors groups in the knowledge network. Results concerning the performance of the network (iii) provide insight in how well knowledge can circulate in the network and if certain actors or actor groups dominate the knowledge network.

5.1.1 Formation of the knowledge network

In figures 4, 5 and 6 the networks of research projects related to biochemical biomass conversion technologies over time are visualised. From these figures, it becomes clear that the knowledge network related to these technologies has dramatically grown over the past decade. Nevertheless, the development of biorefineries is still in an early stage according to several interviewees. This is exemplified by interviewee 1 and 6 comments' on the development of the field:

> *"I honestly feel that we are still in a rather early phase because things are starting to move." (Interviewee 1)*
>
> *"There is still a room for gigantic potential because it is such an early industry." (Interviewee 6)*

These feelings correspond with the data from the research projects. The first project related to biochemical biomass conversion technologies was identified in 2004 in FP6, NOE-BIOENERGY. In the FP6, the number of projects started slowly to increase, resulting in 10 projects at the end of the Sixth Framework program in 2007 (CORDIS, 2013). In FP7, the biobased economy was identified as priority area under the research theme '*Knowledge-based Bio-Economy' (KBBE)*, resulting in a steeper growth of the number of projects (Euroean Commission, 2009). Research related to biochemical biomass conversion processes was not only restricted to this research theme, but distributed over 11 different research themes: *Energy, Environment, Food, Ideas, International Cooperation, KBBE, People, Nanomaterials, SME, Sustainable Development, and Transport (see* Appendix 10.1).

An increased growth in research activities took place under FP7. In total 122 projects were identified as being related to biochemical biomass conversion in the period from 2004 - 2012 (CORDIS, 2013). The average project size in terms of participating actors was between 10 and 14 except for the themes *People* and *Ideas*. Projects in these two themes were smaller and usually consisted out of 1 or 2 participants (see appendix 1 for more details) (CORDIS, 2013).

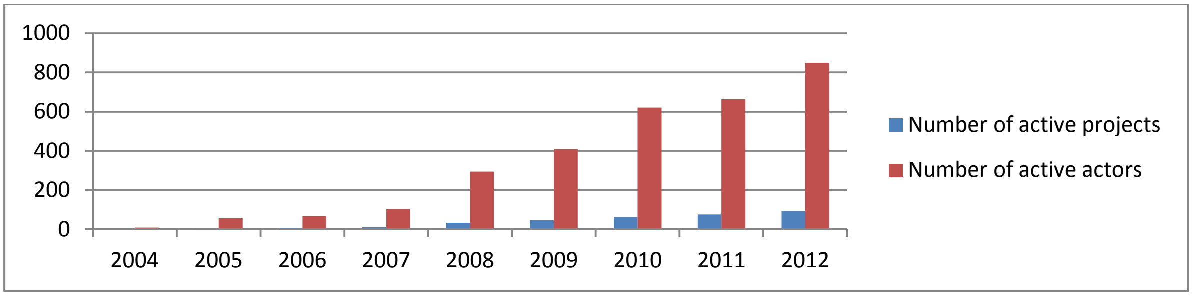

Table 3 – Number of active projects and participants per year (CORDIS, 2013)

Table 3 and table 4 illustrate the increasing number of projects and a similar growth in financial capital, with most investments from public sources (Table 4). At the end of 2012, little more than €530 million was invested in projects related to the development of biochemical biomass processing technologies, of which €360 million originates from public sources (CORDIS, 2013).

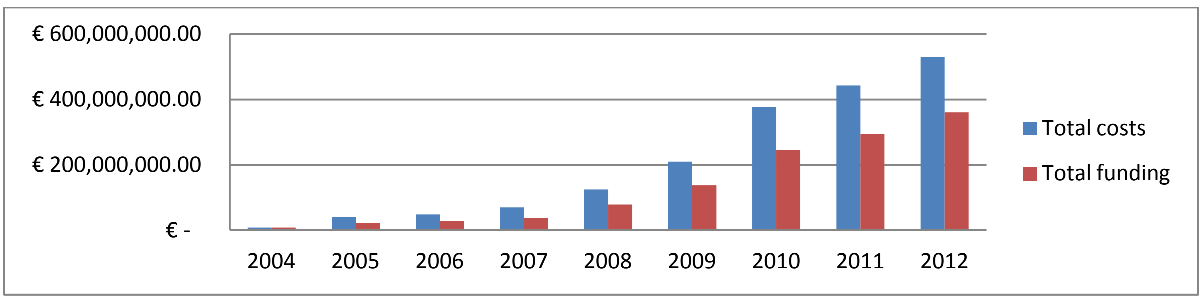

Table 4 – Total financial resources (in Euro's) (CORDIS, 2013)

5.1.2 Composition of knowledge network

During the first three years, 2004 - 2007, knowledge development occurred in isolated project consortia: this first period is represented in figure 4. The first cross-linkages between different project consortia were formed in 2008 by actors that participated in multiple projects, allowing knowledge exchange to take place between projects.

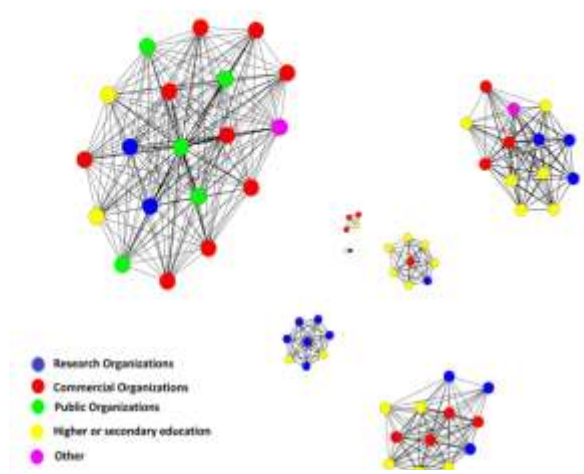

Figure 4 – Knowledge network (2004 – 2006)

An increase of actors and relationships can be observed in the period from 2007-2009 (CORDIS, 2013). In the period 2007-2009, more actors joined the knowledge network. New ties were formed and existing ties were reinforced.

The network is highly clustered, which can be expected as the network is build up out of project consortia. The knowledge network contains various actor types: commercial organisations, universities, research organisations, public organisations and interest groups, but the different actor types differ in their presence in- and participation to the network (CORDIS, 2013). The participation of commercial organisations, indicated by the presence in two or more research projects, is relatively low. Table 5 lists the participation in the knowledge network by type of actor.

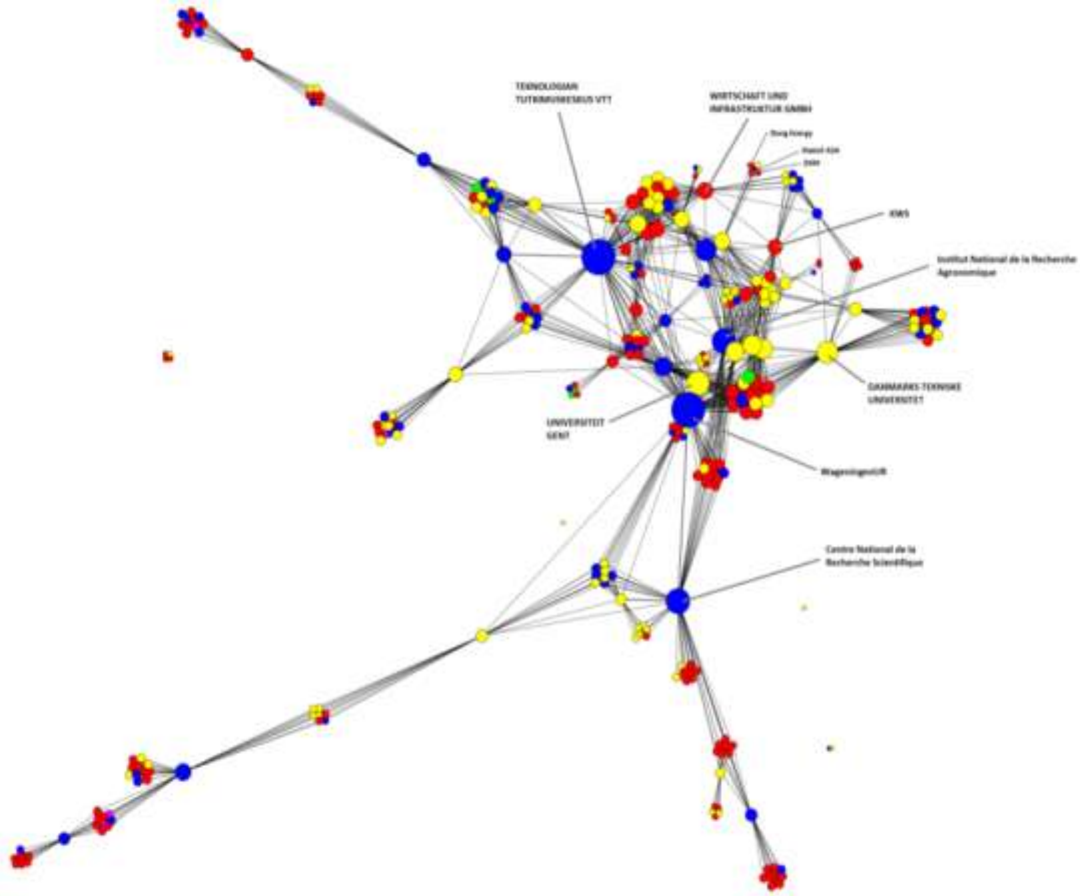

Figure 5 - Knowledge network (2007 - 2009)

In the period 2007 – 2009, most organisations contributing to the network were commercial organisations (table 5). However, looking at participation in two projects or more, commercial organisations score relatively low compared with research organisations and universities (respectively 8%, against 17% by universities and 18% by research organisations). The larger nodes in the network are blue or yellow, indicating respectively research organisations or organisations involved in higher- and secondary education. The SNA and interviews reveal that it is the scientific knowledge that drives the biomass conversion technologies innovation system.

The dominant players (indicated by the centrality of the actor in the network) in this period are *WageningenUR (research organisation & university)* and *VTT (research organisation), INRA (agricultural research organisation)* and *Centre National de la Recherche Scientifique* (*scientific research organisation)* (appendix 10.4). Most dominant players are located in the centre of the knowledge network, but the *Centre National de la Recherche Scientifique* is located more in the periphery of the network, and fulfils the important role of linking a number of small clusters to the knowledge network. The most important universities, next to *WageningenUR* are *Danmarks Tekniske Universitet* and *Universiteit Gent*. The commercial organisations, represented by red dots in figure 5, are mostly SME type of organisations (CORDIS, 2013). Only a few large multinationals are participating in this period: *Dong (fossil incumbent[4])*, *Statoil (fossil incumbent)* and *DSM (chemical incumbent)* are present, but these are mainly collaborating with each other, forming a small cluster at the periphery of the network (CORDIS, 2013).

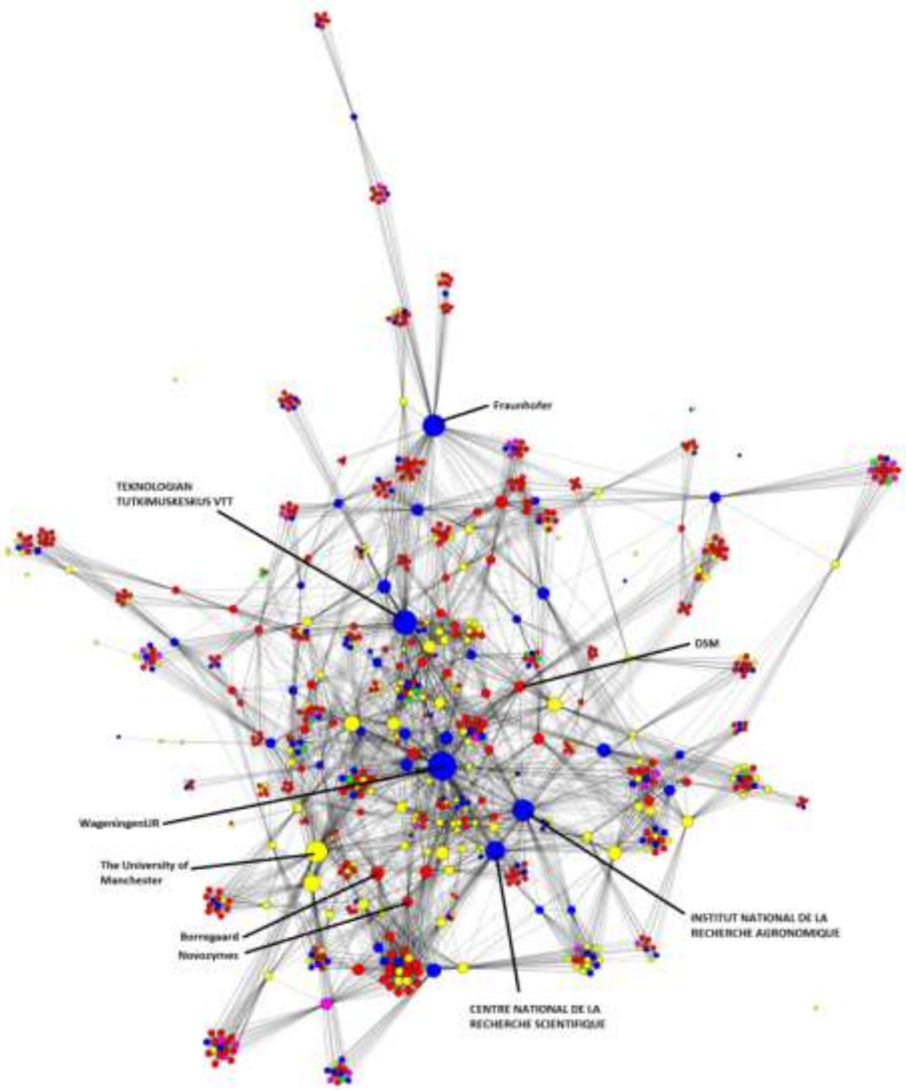

Figure 6 - Knowledge network (2010 - 2012)

The growth continued in the period 2010 - 2012 (figure 6). Compared with the previous period, a rapid increase of actors and an increase of ties between the actors can be observed. The dominant actors are still actors from research organisations and universities and compared with 2007 – 2009, with large similarities to the previous period. Next to *WageningenUR, INRA, VTT* and *Centre National de la Recherche Scientifique, Fraunhofer (applied-oriented research organisation)* and the *University of Manchester* stand out in terms of ties to the rest of the network (indicated by the actors' degree centrality). *Fraunhofer* has an important position at the periphery of the network, by linking multiple small clusters to the network.

[4] The term incumbent in innovation studies refers to an existing, usually large company that has a stable position in the market (Wieczorek, et al., 2013)

The share of commercial organisations has grown slightly over the years, but their participation in the knowledge network is still low (see table 5). For example, *WageningenUR* is the best connected organisation in the network with 149 links, whereas *Borregaard (developing biorefineries)* as the best connected commercial organisation has 59 ties to the rest of the network (CORDIS, 2013). Compared with the period 2007 – 2009, commercial organisations are getting better embedded in the network, mainly caused a small number of commercial organisations which are rapidly developing links to other actors. These better connected commercial organisations are incumbents from the chemical industry and firms developing biorefineries. Incumbents from the fossil-based industry were relatively absent in the knowledge network. *Borregaard, Arkema France (chemical incumbent), BIOTREND (life science research), OWS (developing biorefineries), Merck (chemical incumbent and DSM* were the most integrated commercial actors in the knowledge network.

Descriptive	Universities	Research organisations	Commercial organisations	Public organisations	Other
2007-2009					
% in projects	28%	20%	45%	4%	3%
% in two or more projects	17%	18%	8%	8%	0%
2010-2012					
% in projects	23%	18%	53%	2%	5%
% in two or more projects	33%	25%	12%	0%	3%

Table 5 – Participation per type of organisation (CORDIS, 2013)

5.1.3 Performance of the knowledge network

Table 6 lists the structural characteristics of the knowledge development network during the period under investigation. The density of the network increased during this period as a larger share of actors was active in two or more projects. The indicators reflecting the cohesion of the network suggest a mild growth in network cohesion over the years (table 6): the diameter and average path length are decreasing over the years.

Graph Statistics	2004	2005	2006	2007	2008	2009	2010	2011	2012
Centralisation									
Average degree	6	12.741	11.455	10.608	12.225	12.828	16.115	15.691	17.006
Skewness	-	-0.421	-0.098	0.1423	1.9092	2.7861	3.4648	3.0305	3.2879
Kurtosis	-	-0.214	-0.884	-0.5	7.0497	13.473	19.18	14.244	16.757
Cohesion									
Network Diameter	-	-	-	-	5	8	7	7	6
Average Path Length	-	-	-	-	2.441	3.407	3.048	3.196	3.025

Table 6 – Graph statistics per year (CORDIS, 2013)

Indicators reflecting the centralization of the network suggest a relative skewed growth in the network centralization over the years (table 6). These values indicate that a large part of the overall degree growth can be can be allocated to a few nodes with an extremely high degree as the skewness and kurtosis of the degree distribution rapidly increased in the same period. This finding points to the presence of knowledge hubs, a small number of extremely high connected actors in the knowledge network. These extremely high connected actors are represented by the larger dots in figures 5 and 6.

To summarize, the size the knowledge network was growing fast, while the density was decreasing. A reason for this is that the share or actors participating in two or more projects was low, but slowly increasing (table 6). The values for the skewness and kurtosis indicate a growth in inequality in the network, meaning that most of the growth of the average degree could be attributed to a few actors that were getting extremely connected to the rest of the network.

5.1.4 Topics in the network

Looking at the co-occurrence network of project-titles, it can be stated that the overall focus of the knowledge network is on the development of biofuels as the words 'biofuel' and 'biofuels' are in the very centre of the co-occurrence network of project titles (see figure 7 and appendix 10.5). Striking word-clusters are encircled. Most projects seem to have a technical focus. The word clusters related to fermentation and anaerobic digestion stand out, indicating that a lot of effort is put into the development of these technologies. Other focusses are on the use of micro-algae to develop biofuels and on microbial fuel cells.

The large focus on biofuels is striking, because interviewees regarded a higher added value in the use of biomass conversion technologies for the production of biochemicals and biomaterials, not in biofuels (interviewee 1, Interviewee 6).

> *"The future and the money is in the molecules with functional properties which can easily be converted into polymers or other products, in the chemicals." (Interviewee 2)*

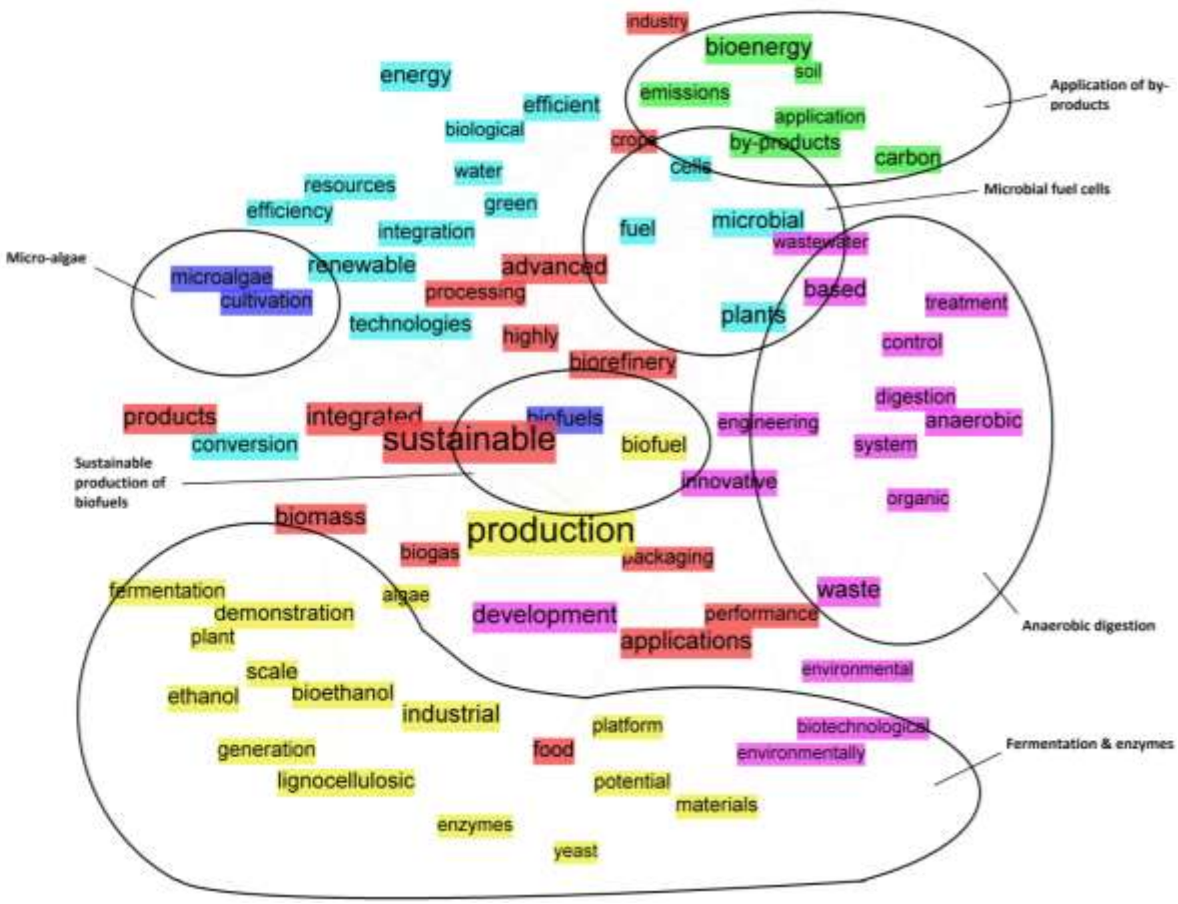

Figure 7 – Co-occurrence network of project titles (based on cosine distances among words)

5.2 The drivers and barriers of the Innovation system

These results concern the drivers and barriers of the TIS. The interviews with experts focussed firstly on the incentives to join the joint R&D projects and how they benefit from these projects. Secondly, interviewees were asked if these projects helped to improve the level of entrepreneurial activities and if knowledge is efficiently developed in these joint R&D projects.

5.2.1 Drivers for the development of biochemical biomass conversion technologies

Drivers	How
Funding	1. Attract new actors 2. Enables the exploration of risky areas
Networks	1. Provides access complementary knowledge fields 2. Provides access to new markets 3. Enables to recruit talent 4. Enables to influence agenda setting at European level 5. Scientific intelligence: enables commercial organisations to monitor developments in research fields of their interest

Table 7 – Drivers identified by the interviewees

The identified drivers are listed in table 7. The interviewees pointed out that the majority of the research projects are driven by the knowledge industry (Interviewee 3, Interviewee 5). These findings are in line with the observations in the previous section that universities and research organisations are the more active participators in the knowledge network.

> *"What we see very regularly is companies are talking back to the knowledge producers and are relying very much on knowledge producers to continue their success for business." (Interviewee 1)*

According to the interviewees from universities and research organisations, industry interest is growing, but developments are still mostly driven by the knowledge industry (research organisations and universities) (Interviewee 1, Interviewee 3, and Interviewee 4). Interviewees agreed that the availability of external funding is the main incentive to joint these joint R&D (Interviewee 1, Interviewee 3, and Interviewee 6). A secondary incentive for commercial organisations was described by one interviewee as a form of *scientific intelligence (Informant 1)*:

> *"I think the reason they participate is not actually to acquire specific knowledge of a specific topic that is in the project but they are more to do with a sort of scientific intelligence. They participate in a number of projects which allows them to keep their finger on the pulse of the field and see what's happening and where it is going." (Interviewee 1)*

Industrial interviewees mentioned that funding was their primary incentive to participate. These projects allowed them to receive funding for technologies in their pre-commercial track in areas for which the future commercial value was uncertain (Interviewee 6, Interviewee 7). This is exemplified by the following quotes:

> *"What we can do in these frameworks [...] is to investigate new areas that do not have a 100% commercial angle, jet to understand the market and technology potential." (Interviewee 6)*

> *"Priority business areas are too confidential to be in the project but the work they do in the project is somehow feeding their priority areas anyway." (Interviewee 1)*

The availability of R&D subsidies enabled commercial organisations to investigate technologies with high levels of uncertainty (Interviewee 6). One challenge for knowledge development of biochemical biomass conversion processes was to establish new value chains and to combine different industries and disciplines. Interviewee 3 pointed out that experts from one particular area tended to seek out other experts in the same area for collaboration instead of experts along the different tops in the value chain; the challenge is to find partners along the value chain that complement each other (Interviewee 4).

> *"They are a mixture of different types of actors and different types of knowledge. Participants are chosen in such a way that they will contribute to the knowledge base within the project." (Interviewee 1)*

All the interviewees stressed the importance of the build up networks. These networks were according to different interviewees the most valuable result from the project, more important than the report of the projects results (Interviewee 2, Interviewee 3, Interviewee 5, and Interviewee 6).

> *"I think that the networks are much more important than the reports."(Interviewee 3)*

The networks were formed during the start of the project. Close relationships were formed with certain project members, which were maintained after the projects ended (Interviewee 5). Interviewee 4 and Interviewee 5 pointed out that these relationships helped them to become a more globally oriented organisation. The networks were a mechanism of diffusing and accessing knowledge:

> *"As a certain actor, you are generally involved in a number of projects, allowing cross-fertilization between projects to happen." (Interviewee 4)*

Other benefits of networks and maintaining networks which the interviewees pointed out were: they allowed organisations to (i) recruit talent, (ii) provided access to new partners, markets and industries, (iii) networks brought together different disciplines and (iv) helped to fill in knowledge gaps of individual actors. These networks also provided actors with visibility and contacts in the EC, allowing them to influence agenda setting (Interviewee 3, Interviewee 4 and Interviewee 6).

> *"If you are regarded as leading in a particular area and have done a lot of coordination, you are becoming interesting for students. Scouting talents is becoming increasingly important and these project allow you to scout on a European level." (Interviewee 4)*
>
> *"...the exchange with companies and academia's is important and thereby allows identifying talent and identifying possible collaboration partners in Universities." (Interviewee 6)*

For successful research projects, the networks were even maintained and regarded as valuable after the projects ended.

> *"My experience is that once you have a project that has been successful you have a very strong demand from the project parents to continue the work in some form or another in future projects." (Interviewee 1)*

Interviewees differentiated between formal channels of knowledge exchange (e.g. patens, reports workshops, newsletters and publications) and informal channels of knowledge exchange (labour mobility and contact through the networks). Interviewees question the efficiency of the formal channels of knowledge exchange and assign more value to the informal channels of knowledge exchange (Interviewee 3, Interviewee 4). Interviewee 6 pointed out that:

> *"The knowledge is documented in reports, that is shared, but I also think it is fair to say that a lot of really valuable knowledge is not really documented." (Informant 6)*
>
> *"The knowledge outcomes of projects are stored in reports.... But the network you build is much more important than the reports. I'm more inclined to look for the persons than the report. For the large organisations, you know the people and their activities which allows to access specific information." (Interviewee 3)*

Labour mobility is regarded by several interviewees as an important mechanism, facilitating tacit dimensions of knowledge flows. The network actors develop through participation in research projects can be used to attract human resources to access this knowledge.

> *"But I'm also thinking about know-how in a different understanding... The knowledge that is formed in the heads of researchers, which are often young people that perform research activities, will often look for jobs afterwards... Employers can use the projects as a recruitment channel through which they can access these skills and knowledge." (Informant 2)*

5.2.2 Hampering factors for the development of biochemical biomass conversion technologies

Obstacles	How
System level	
Price of biobased products & lack of a market	Biobased products are perceived as too expensive in comparison with the fossil substitutes
Ineffective diffusion of knowledge	1. Missing step to the market 2. Commercial actors use secrecy to protect valuable knowledge 3. Limited face to face contact
Missing fundamental knowledge	Biotechnology and synthetic biology can be further exploited to facilitate the development of biochemical biomass conversion technologies
Project level	
Project size	Projects were regarded as being too large
Different interests	1. Actor types differ in their perceived timeframes 2. Actor types differ in their research strategy

Table 8 – Obstacles identified by the interviewees

Hampering factors were identified by the interviewees on two different levels: on the systems' level and on the individual project level. Table 8 lists all the interviewees hampering factors. The lack of a market for biobased products was considered as main obstacle for further growth on the systems level. This is exemplified by the comments of Interviewee 2 and Interviewee 5:

> *"The problem is not that it can't be done technological, but there's no commercial perspective for it. (Interviewee 2)*

> *"A lot of these different technologies are out there, the technology works, but it is simply too expensive to produce products that way." (Interviewee 1)*

> *"The biobased technologies are more expensive and someone needs to pay for it. No one dares to designate the bill to someone." (Interviewee 5)*

Interviewee 2 and Interviewee 3 mentioned uneven competition another obstacle for the biobased industry. Biobased products are often submitted to stricter admission procedures to enter the market than their fossil counterparts, already for years on the market:

> *"Barriers are raised of institutional nature like much heavier admission procedures." (Interviewee 2)*

Although interviewees agreed that most obstacles are of non-technological nature, interviewee 1 pointed out that there is still a lot of fundamental knowledge missing:

> *"Obviously there is a lot of work going on, but I think we are still lacking a lot of fundamental knowledge in many areas that will in some future period lead to the explosion of this technology on the industrial field." (Interviewee 1)*

According to the interviewees, there are high expectations on biotechnology and synthetic biology for biochemical biomass conversion technologies:

> *"We still have a long way to go to realize the full potential of the different areas of biotechnology from enzyme technologies through to construction of new robust industrial strains." (Interviewee 1)*

The use of biotechnology is currently very limited according to Interviewee 1, while it could make a large contribution to the future potential of biorefineries.

> *"When you look at the way biotechnology has been used at the moment it is still in a way a very minor technology if you look at the whole of let's say, the chemical industry. Whereas I anticipate within the next few decades' biotechnology will be a major technology but for that there is still a lot of knowledge lacks." (Interviewee 1)*

Another obstacle identified by the interviewees is related to knowledge flows between different types of actors. Interviewees agreed that commercialisation activities within these projects are very low. They believed that projects didn't go far enough to produce new products or processes and that the structure of the projects in itself was not suited to support entrepreneurial activities (Interviewee 1, Interviewee 4 and Interviewee 6).

> *"We have fundamental knowledge, we can demonstrate proof of concept, but we are missing the step to the market." (Interviewee 4)*
>
> *"I would say when it comes to a general entrepreneurship, it is very low. You don't create the momentum, you don't have the speed, you don't meet often enough to create entrepreneurship." (Interviewee 6)*

Interviewees questioned the efficiency of knowledge diffusion and cross-fertilization (Interviewee 6). Communication usually takes place by mail, and physical contact is limited to a few times per year (Interviewee 3). These projects functioned as a relatively closed system. Knowledge stayed confidential during the project and sometimes even after the project has finished, depending to a certain extend on how well the knowledge can be protected through patents (Interviewee 1, Interviewee 5, and Interviewee 6). Interviewees pointed out that companies are often hesitant to share technical knowledge even with their project partners. Once a piece of knowledge was regarded by the commercial companies as valuable; they only shared the global findings with the project partners, while they were keeping the details for themselves (Interviewee 1, Interviewee 2, and Interviewee 6).

> *"You need to report what you have done, but there is no obligation to report specific details of that knowledge." (Interviewee 5)*
>
> *"… so you can't read it from the reports because people keep it as proprietary knowledge, I think more companies do that." (Interviewee 6)*
>
> *"It's actually more like having funding from one source, but don't sharing knowledge with many of the participating companies." (Interviewee 6)*

On the level of individual projects, the project size was perceived as the main obstacle. It was regarded by all interviewees as inefficient and too large. This is reflected by the comments of Interviewee 3 and 6:

> *"The different kinds of collaborations have been too big to be manageable, controllable, and productive." (Interviewee 6)*
>
> *"More will be achieved with specific, detailed, small projects, than with the large projects, especially if you compare it with each euro spent... Novelty often results from one to one project with the industry." (Interviewee 3)*

Other obstacles on the level of projects related to the difference in dynamics between different actor-types. The difference in time-frame per actor type was perceived as problematic by a number of interviewees (Interviewee 1, Interviewee 2, Interviewee 3, and Interviewee 4).

> *"...even for larger companies, what they regard as a long-term timeframe, is for us a short-term project. An SME wants to see results tomorrow." (Interviewee 4)*

Large companies are able commit to longer research tracks than SMEs that lack organisational resources and interest in fundamental issues (Interviewee 6). Interviewees from universities mentioned that it is easier to collaborate with larger multinationals, because these are more interested in fundamental issues (Interviewee 3). However, interviewee 3 and interviewee 5 pointed to a difference in focus between the knowledge industry and commercial organisations. Interviewee 6 pointed out that most companies use biobased resources as substitute for fossil resources, while interviewee 1 stressed that it would be more cost-efficient to make use of the functional properties of the biomass itself to produce products for which no fossil substitutes exist.

> *"The future for this industry is in the chemical sector ... where there are no fossil substitutes." (Interviewee 3)*

6 Data Analysis

This section includes the interpretation of the results by linking the outcomes of the research back to the theoretical background. It provides an overview which relationships exist between the concepts of the research questions.

6.1 Knowledge development and the formation of the biorefinery-TIS over time

The analysis of the results concerning the structure of the network suggests that the TIS of biochemical biomass conversion technologies is still at an early stage of development. This is confirmed by the perceptions of the interviewees regarding the maturity of the technologies. The analysis revealed that knowledge development and knowledge diffusion is a highly interrelated process in which knowledge is developed in networks of interacting actors. The presence of actors in two or more projects enabled knowledge to flow between projects. Interviewees stressed the importance of sharing knowledge to develop new knowledge.

The networks provided them with means to access complementary knowledge. The build-up of the knowledge network was triggered by the availability of funding for joint research projects on a wide range of topics. Certain general topics are identified by the European Commission , but actors have the freedom to pursue the areas of their interest. The development of the network over time revealed a steady, fast growth of the knowledge network. Striking was the emergence of a small number of actors that became extremely connected to the network. They often entered the knowledge network in an early phase and quickly developed new ties. Interviews with interviewees from such actors revealed that their position granted them a position of visibility for policy makers, which enables them to influence agenda setting. They could thereby act as advocacy groups for the technologies, positively affecting *guidance of the search* (F4). The knowledge network could act as such both as learning- and political network. The presence of knowledge hubs can therefore be seen as strength for IS in an early stage of development.

Analysing the presence of different types of actors and their participation revealed that the knowledge network was largely driven by the knowledge industry, although commercial actors represent in terms of their numbers roughly half of the knowledge network. The dominant actors are mainly from research organisations and universities. Next to the development of knowledge, universities perform an important additional role of training skilled experts which in turn contribute to the further development of the TIS which makes their participation in a young TIS very important.

In the different network visualisations can be observed that the commercial organisations (in red) are mainly represented by small dots. The difference in participation to the network will influence the extent to which actors are able to access external knowledge sources, influencing their innovative performance. In line with this analysis, interviews revealed a similar issue. Interviewees felt that entrepreneurial experimentation was not encouraged in the joint R&D projects and stressed the need to diffuse the knowledge to the entrepreneurial community.

A small improvement can be observed in the period 2010 – 2012 compared with the period 2007 – 2009 in participation of commercial actors to the network, which is confirmed by the interviewees. The performance of knowledge flows to- and between actors in the knowledge industry is currently better than to- and between technology developers. Due to the limited ties of commercial organisations to the network potential synergies are likely to be insufficiently utilised. The better connected commercial organisations in the network are mainly from the chemical and biorefinery industry. Interviewees from commercial organisations pointed out that framework projects are not always suited for the development of certain technologies. Joint development projects are according to them best suited for technologies in a pre-commercial track with high levels of uncertainty. Striking is the relative absence of large incumbents of the energy industry in the knowledge network over time. The absence of such actors may have a negative effect as these actors bring important capabilities in the market.

6.2 Drivers and hampering factors of the Innovation system

The findings on identified drivers and hampering factors are summarised in figure 8. Driving the development of the TIS was the availability of public funding for the research projects. Actors considered this as the primary incentive to joint. Interviewees regarded the formed relationships with project partners, often even maintained after the projects ended the most valuable outcome of the joint research projects. Interviewees stressed the importance of knowledge diffusion for the innovative performance, however, the efficiency of knowledge development and diffusion within projects was questioned. In general, there is a sense of a sufficient level of knowledge diffusion. Interviewees regarded the formal channels of knowledge diffusion as inefficient, but parties know each other and are able, if necessary, to gain access to each other’s knowledge. However, the diffusion of technical knowledge is limited because companies are very cautious of losing their competitive advantage. Commercial actors actively use secrecy and patenting as means to protect the valuable knowledge. Project size was mentioned as another obstacle for knowledge diffusion, interviewees regarded shorter, one to one projects, as being more efficient in terms of knowledge development.

The network in itself is regarded as a driver for knowledge development. Interviewees valued networks because it provided them with access to skilled labour, complementary knowledge, access to markets, and as mentioned before allowed them to influence agenda setting. By entering the system, actors contributed to the pool of resources, both tangible as human. The networks added to the human capital through the involvement of new experts and by functioning as a recruiting channel for skilled labour. These findings strongly suggest a positive relationship between *network accumulation* and *resource mobilisation* (both human resources as financial resources). As the benefits are accessed through the network, highly connected organisations are more able to use these network benefits than lesser connected organisations which can reinforce their position even more.

Networks have on a systems level a positive influence on knowledge -development and –diffusion, resource mobilisation (each actor brings new financial- and human capital into the system), guidance of the search and to a lesser extent market formation.

The analysis confirms the importance of market formation for the innovation system to develop itself further. In the interviews turned out that without the presence of a market, knowledge development will not stimulate the entrepreneurial activities. Knowledge development can produce plenty of new business opportunities, but interviewees explained the relative absence of entrepreneurial activities with the poor commercial performance of biobased products. A mismatch between the focus of the knowledge network and the opportunities for the biochemical biomass conversion technologies might ask for more specific *guidance* (F4) of the knowledge network.

The present motor of innovation is similar to the pre-development motor identified by Suurs (2009). In order to meet policy targets (*F4: Guidance of the search)*, R&D funding mechanisms were implemented by the EC (*F6: Resource mobilisation)* which attracted- and enabled actors to investigate promising technologies (European Commission, 2012). These actors are organised in networks through which provides them with several network benefits. Highly connected actors are often regarded as experts and are involved by policy makers in agenda setting (*F4: Guidance of the search)*. Market formation seems to be a key requirement to move from a *pre-development phase* to the *development phase*.

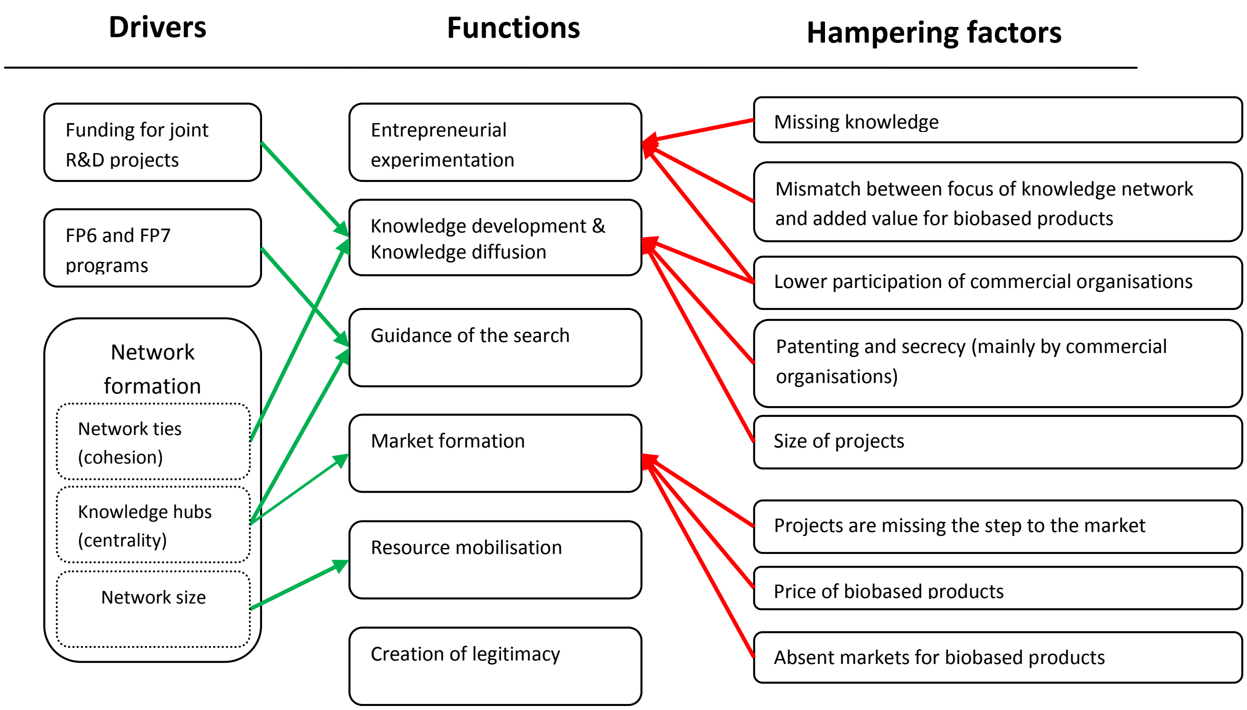

Figure 8 – Identified drivers and hampering factors

To summarize, *knowledge development* (F2) and *diffusion* (F3) are interrelated. The funding programs help to stimulate knowledge development by providing financial resources to perform research into certain areas. These fit between these areas and actual needs of the industry may be questionable.

Interviewees pointed out that most barriers negatively affecting the functioning of the innovation system were of non-technological nature. Although they felt that some (fundamental) knowledge was still missing, other factors formed important obstacles preventing the technology from reaching its full potential.

Knowledge development (F2) and *diffusion* (F3) are clearly interrelated in this case study. Knowledge is developed within projects. The presence of actors in two or more projects enabled knowledge to flow between projects. As actors participated in more projects, their visibility increased, granting them a position of power and the ability to exert influence over the direction of knowledge development. The knowledge network could act as learning- and political network as such. Interviewees stressed the importance of sharing knowledge to develop new knowledge. The networks provided them with means to access complementary knowledge. Knowledge hubs exert political power as well: the knowledge hubs are able to influence agenda setting, thereby acting as powerful advocacy groups, positively affecting *guidance of the search* (F4). The presence of knowledge hubs can therefore be seen as strength for IS in an early stage of development.

With growth of the knowledge network, more resources enter the system. A distinction should be made between tangible resources (fees of members and subsidies) and human resources (skilled experts). The primary incentive to join the knowledge network was the availability of financial resources. By entering the system, actors contributed to the pool of resources, both tangible as human. These findings strongly suggest a positive relationship between *network accumulation* and *resource mobilisation* [F6]. The networks added to the human capital by training new experts and by functioning as a recruiting channel for skilled labour.

Without the presence of a market, knowledge does not stimulate the entrepreneurial activities. Knowledge development can produce plenty of new business opportunities, but interviewees explained the relative absence of entrepreneurial activities with the poor commercial performance of biobased products. Market formation as such seems to be a key requirement to move from a *science and technology push motor* to the entrepreneurial motor.

6.3 Accelerating the development

In order to accelerate the development, the most important factor is to create markets for biobased products. The difficulty for biobased product, preventing market success, are their high costs compared with their fossil substitutes. The interviews revealed that biobased product have better chances of success on markets by (i) making use of the functional properties of biomass itself, instead of transforming biomass resources into intermediate products compatible existing production lines. By (ii) creating (institutional) level playing fields and though (iii) subsidising schemes.

In order to resolve the mismatch between a strong focus on biofuels in the knowledge network, while the highest potential lies in the chemical sector, more guidance is needed. Interviewees pointed out that biofuels are not expected to compete on costs in the near future with their fossil counterparts and that direct competition with fossil substitutes can be prevented. The framework programs are currently supporting the development of a wide range of technologies related to biorefineries, while more focus on specific promising technologies may help directing effort into the knowledge development to the areas where the largest potential for biobased products lies.

The focus of the knowledge network needs to be adjusted to match the needs of the biochemical- and biomaterial sectors. The rising presence of chemical incumbents in the knowledge network indicates a current interest of the chemical sector, but markets for the (unique) biobased products are needed to reinforce this current development.

A second issue which needs to be addressed is related to the processes of knowledge development and diffusion itself. Current knowledge is insufficiently communicated to the entrepreneurial community. As knowledge is only shared to a certain degree with project partners and tacit forms of knowledge require close and intensive connections in order to be shared with other actors, enhanced participation in the knowledge network is a necessity for commercial organisations to profit from the developed knowledge.

Knowledge development itself contributes to the development of the field, however, this could be improved through (i) smaller and more focussed projects and through (ii) improved knowledge diffusion within projects.

7 Conclusion

Biochemical biomass conversion technologies hold the potential to tackle major energy issues and climate change problems, to create jobs and to contribute to (sustainable) economic growth. The knowledge network seems to be driving the development of biorefineries. Dominant actors, able to influence the future direction of research, are mainly from the knowledge industry. In order for the Innovation system to proceed to a next phase, it seems to be very important that demand-side actors will take on a more leading role. The participation of commercial actors in the knowledge network is growing, but the absence of markets for biobased products is slowing this development.

Policy attention is currently focussed on stimulation demonstration activities of a wide range of technologies related to biorefineries. These findings suggest that it may be more efficient to direct policy effort into creating markets and lowering admission requirements to allow for more entrepreneurial experimentation. Favourable markets are likely to trigger more commercial actors to enter the knowledge network, thereby improving the hinge between the knowledge industry and commercial organisations. This would be essential for the European competitiveness in the bio-based economy, the diffusion of bio-based products and in the long run to the achievement of the European 2050 vision of moving to a competitive low carbon economy (European Commission, 2011).

A theoretical implication of this research for TIS theory is that function, *knowledge diffusion (F3)*, needs to be adjusted. A TIS is analysed though its key processes, important for its functioning. *Network formation* is of key importance for innovation systems and networks fulfil a broader role than just the diffusion of knowledge. Through the analysis of networks and the formation of networks, a more complete assessment of the systems performance may be achieved. With proposed modification, structural developments will be reflected better in the functional approach.

8 Discussion

The implications of the findings are discussed in this section.

The aim of this study was to analyse how the formation of knowledge networks affected the development of biochemical biomass conversion technologies. This study identified several mechanisms networks perform to support the development. A limitation of this study is that only the part of the Innovation System related to knowledge development and diffusion is analysed. This entails the risk of missing structural and functional developments relevant for this research. Further research is needed to clarify this issue.

The theoretical background and the research questions were based on a TIS approach, whereby the development of the IS was focussed around a technology, in this case biochemical biomass conversion technologies. The research focussed on knowledge development and diffusion and its effects on other system functions and on the system's structure. This dynamic approach has been useful because it provided insight in the structural developments of an emerging innovation needed for further growth. Because a TIS approach exceeds national borders as well, the TIS approach was useful in investigating the development of biochemical biomass within a European context.

Several remarks concerning the reliability and the validity of this research need to be made. First, the construct validity of this research is weakened because it was not always able to use multiple indicators per concept. As a result, there was room for the individual interpretation of information provided by the interviewees during the interview and by the SNA. The results from the SNA must be interpreted with caution, especially since the interviewees regard project size as a limitation for knowledge flows. If actors were in the same project, exchange of knowledge was assumed to take place. The interviews revealed that there are large differences in the extent of knowledge exchange within projects. Knowledge exchange was only assumed to take place during the projects. However, interviewees still addressed value to some of relationships with project partners after the project ended. Another problem in interpreting the results from the SNA is that knowledge exchange took place on a personal level, not on an organisational level. Taking these considerations into account, it could be that the actual knowledge network of the framework projects related to biochemical biomass conversion technologies differs from the current visualisation. However, the implication for the construct validity is limited because the focus of this study was on general developments of the system, not the detailed examination of single cases.

The intention was to apply triangulation by using multiple sources and thereby increasing the validity for the results. This appeared not to be feasible as a difference was made in types of participants to the knowledge network. Not all the expert types are represented by two or more experts. In case of divergent results, further questions were asked to the experts to clarify the topic.

The internal validity was ensured within this research by using proper explanations through the use of an adequate theoretical framework.

The results regarding the development of the innovation system and the relationships between the systems functions only hold for this particular case. Some of the relationships may be generalized, taking into account the unique context of this research. As the research by Suurs (2009) pointed out, functional differences in the so-called 'motors of change' exist, depending on the phase of development of the innovation system. As this case-study concerns a IS in its pre-development phase, generalized results are only valid to a certain extent for IS in similar phases of development. The external validity is typically weak for case studies with qualitative elements due to the small sample size and care should be taken in generalizing the results.

Concerning the external reliability, this study does not lend itself to be replicated precisely regarding the context as the contextual setting of the experts could be different in the future. However, by describing the research process and by justifying certain decisions, as much transparency about the research process as possible was provided.

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10 Appendices

10.1 Division of projects over CORDIS research themes

Theme	Number of projects	Average project size	Objective
ENERGY	26	11.1	Research focussed at energy sustainability and energy security
PEOPLE	26	2.2	Improving European Human Capital
KBBE	23	14.3	Developing a European Knowledge based Bio-economy (including themes such as food, agriculture and fisheries, and biotechnology)
SME	16	10.8	Strengthen SMEs and helping them with the development of new technology-based products
IDEAS	9	1.2	Reinforce excellence, dynamism and creativity in European Research
SUSTDEV (FP6)	7	9.7	Research focussed at sustainable development
NMP	7	13.1	Research focussed at nanotechnology and nanomaterials
TRANSPORT	3	6.3	Develop greener and smarter transportation system
FOOD (FP6)	2	13.0	Food related research
ENVIRONMENT	2	14.0	Environment related research
INCO	1	6.0	Research related to international cooperation (with non-EU countries)

Table 9 – Number and size of project per theme in CORDIS

10.2 Biomass conversion technologies

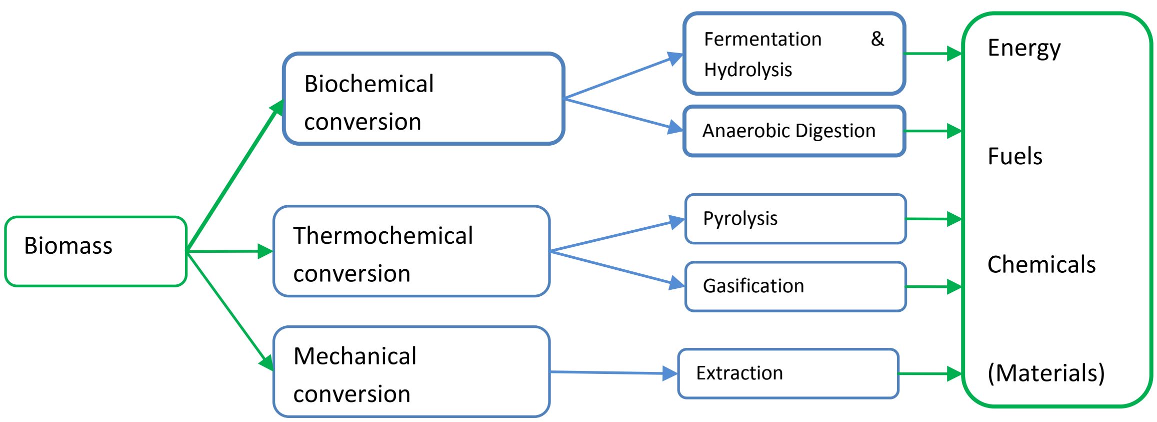

Figure 9: Main conversion routes in biorefineries (IEA Task 42, 2009; IEA, 2013)

10.3 Interview Guide

Quality of CORDIS

1) How are your experiences with projects funded under the different framework programs?
2) Do the framework programs help to fill knowledge gaps?

Knowledge development

1) What generally happens with the knowledge developed in the joint R&D projects?
2) Do others use the knowledge developed within the R&D projects?
    a) How do they use the knowledge?
3) Do project generally produce (or is expected to produce) any patents and publications?
    a) If not: why not?
    b) If so: why do you publish?
4) Do projects often result in follow-up projects?
    a) If so, how?
5) Do projects generally result in new products or services?
    a) If so, how?
6) Are there any spin offs and who are they?
7) How does the knowledge from the CORDIS projects contribute to the innovation system?
8) How do you decide what kind of knowledge to develop?
9) What are the leading organisations in knowledge development?
10) What knowledge fields are still under-developed?
11) What expertise is most needed?
12) How would you rate the influence of knowledge development on entrepreneurial activities on a scale from 1 to 5?
13) How would to rate the influence of knowledge development on the creation of legitimacy for the technology on a scale from 1 to 5?

Knowledge diffusion

1) How intensive are your contacts with other firms?
2) What is the value of the contribution of other participants in the projects?
3) Are there sufficient types of actors contributing to the knowledge development?
4) Is there any communication with organisations outside the learning network with the aim to align knowledge development to the needs of actors in the innovation system?
5) Does contact with other firms lead to new business activities (and spin-offs) or research projects?
6) How would you rate the influence of knowledge diffusion on entrepreneurial activities on a scale from 1 to 5?
7) How would you rate the influence of knowledge diffusion on knowledge development on a scale from 1 to 5?

Entrepreneurial activities

1) Are there spin-offs or other business activities aimed at commercialising knowledge developed in the joint research projects?
2) How are these spin-offs performing?
3) Where does the commercialisation of knowledge take place? More in spin-offs or more in existing firms?
4) What are the products?

Creation of legitimacy

1) Is investment in the technology seen as a legitimate decision?
2) Is there much resistance to the development of new technologies?
3) Are there lobby organisations and if so, who are they? Are the for- or against the technology?
4) Does new knowledge helps reduce the resistance?
5) Do the R&D projects help to reduce uncertainty concerning the projects?

10.4 Centrality per actor-type

	Research organisations		Higher education		Commercial organisations		Public organisations		Other (mostly interest groups)	
	Actor	Degree centrality	Actor	Degree centrality	Actor	Degree centrality	Actor	Degree centrality	Actor	Degree centrality
2007 - 2009	Wageningen UR	72	UNIVERSITEIT GENT	46	Wirtschaft & Infrastruktur GmbH & Co Planungs KG	28	THE SECRETARY OF STATE FOR ENVIRONMENT, FOOD AND RURAL AFFAIRS	21	SUSTAINABLE ENERGY ACTION	18
	TEKNOLOGIAN TUTKIMUSKESKUS VTT	72	DANMARKS TEKNISKE UNIVERSITET	41	DYADIC NEDERLAND BV	26	AGIRE - AGENZIA VENEZIANA PER L'ENERGIA	18	DI ANDREAS MOSER	12
	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE	48	THE UNIVERSITY OF MANCHESTER	36	SEKAB E-TECHNOLOGY AB	26	COMUNE DI VENEZIA	18	C.R.F. SOCIETA CONSORTILE PER AZIONI	11
	INSTITUT NATIONAL DE LA RECHERCHE AGRONOMIQUE	48	UNIVERSITY OF YORK	36	KWS	25	GEMEENTE AMSTERDAM	18	ASOCIACION NACIONAL DE EXTRACTORESDE ACEITE DE ORUJO DE ACEITUNA	10
	VIB	41	SVERIGES LANTBRUKSUNIVERSITET	35	ROAL OY	25	OBCINA DESTRNIK (MUNICIPALITY OF DESTRNIK)	18	ASSOCIAZIONE PRODUTTORI D OLIO DI OLIVA ACLITERRA	10
2010 - 2012	Wageningen UR	149	THE UNIVERSITY OF MANCHESTER	105	BORREGAARD INDUSTRIES LIMITED	59	THE SECRETARY OF STATE FOR ENVIRONMENT, FOOD AND RURAL AFFAIRS	21	EUROPEAN BIOMASS INDUSTRY ASSOCIATION	49
	TEKNOLOGIAN TUTKIMUSKESKUS VTT	124	DANMARKS TEKNISKE UNIVERSITET	78	ARKEMA FRANCE SA	52	Agriculture and Agri-Food Canada	17	SOLAGRO ASSOCIATION	23
	FRAUNHOFER-GESELLSCHAFT ZUR FOERDERUNG DER ANGEWANDTEN FORSCHUNG E.V	111	UNIVERSITEIT GENT	73	BIOTREND - INOVACAO E ENGENHARIA EM BIOTECNOLOGIA SA	51	UNITED UTILITIES WATER PLC	17	CONSORZIO DI BONIFICA DI SECONDO GRADO PER IL CANALE EMILIANO ROMAGNOLO	22
	INSTITUT NATIONAL DE LA RECHERCHE AGRONOMIQUE	108	CHALMERS TEKNISKA HOEGSKOLA AB	65	ORGANIC WASTE SYSTEMS NV	46	AGENCIA DE RESIDUS DE CATALUNYA	16	DEUTSCHE GESELLSCHAFT FUR INTERNATIONALE ZUSAMMENARBEIT (GIZ) GMBH	22
	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE	94	ALMA MATER STUDIORUM-UNIVERSITA DI BOLOGNA	62	MERCK KGAA	45	CONSELLERIA DE MEDI AMBIENT I HABITATGE - GENERALITAT DE CATALUNYA	16	ASSOCIATION NATIONALE DES INDUSTRIES ALIMENTAIRES	19

10.5 Word co-occurrence network

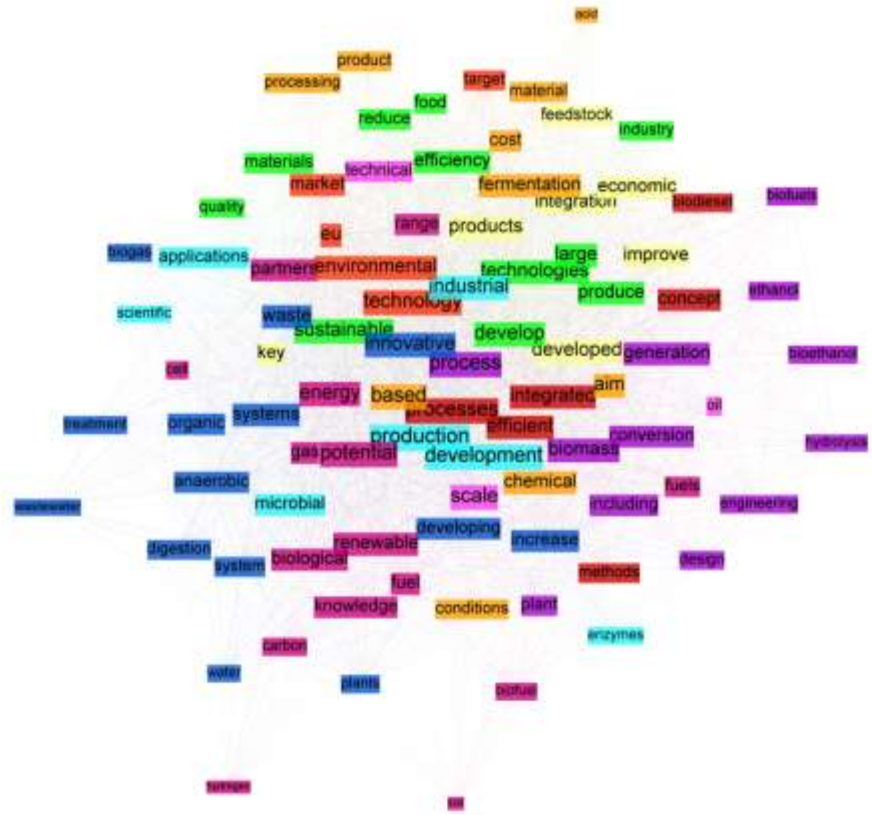

Figure 10 – Co-occurrence words project objectives