Promoting Industrial Symbiosis: 
Analysing Context and Network Evolution during Biowaste-to-Resource Innovations

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“Knowledge is of no value unless you put it into practice”

- Anton Chekhov -
Summary

Government and industry increasingly face challenges resulting from resource scarcity and climate change. By reducing carbon emissions whilst promoting resource efficiency and business development, industrial symbiosis has been recognised as a strategy to manage these challenges. Industrial symbiosis can be interpreted as the innovative use of waste from one company as a resource for another company, i.e. waste-to-resource innovation. These resource innovations involve the development of relations between waste producers and users, and often governmental organisations and other actors. A review of industrial symbiosis and relevant network and innovation literature concluded that empirical understanding of the implementation of industrial symbiosis, and consequently how it can be promoted by public and private organisations, needed considerable improvement. Hence, a qualitative empirical exploration was conducted to answer the question: *How and why did industrial symbiosis develop over time?* The exploration was carried out in the Humber region (UK) and, with several bio-based developments emerging in the area, focused on bio-waste-to-resource innovation. Case studies with companies revealed: the social process through which resource partnerships developed; important contextual conditions (resource security, economic benefits, and governance); and varying network diversification and strengthening strategies. Analysing these innovations in their longer-term dynamic contexts revealed different business-responses to context-changes through their varying innovation and government-engagement strategies. Some companies were constrained by poor harmonisation of economic and various governmental drivers. In particular, since 2012, regional governance capacity for biowaste-to-resource innovation decreased while such innovations gained momentum at national government level. These findings have added to understanding of variation in factors and processes associated with implementing industrial symbiosis through company activities, strategies, and collaborations; and the relations between context dynamics, evolution of industrial symbiosis networks, and on-going business development. The level of detail revealed in this inductive empirical research contributed to identifying numerous further research directions. Moreover, practical recommendations were provided to companies and governmental organisations supporting the promotion of industrial symbiosis and contributing to the on-going transition to a more resource efficient and circular economy.
Statement of Originality

“This thesis and the work to which it refers are the results of my own efforts. Any ideas, data, images or text resulting from the work of others (whether published or unpublished) are fully identified as such within the work and attributed to their originator in the text, bibliography or in footnotes. This thesis has not been submitted in whole or in part for any other academic degree or professional qualification. I agree that the University has the right to submit my work to the plagiarism detection service TurnitinUK for originality checks. Whether or not drafts have been so-assessed, the University reserves the right to require an electronic version of the final document (as submitted) for assessment as above.”

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Foreword on the thesis format

This following thesis integrates the elements of a traditional thesis employed in UK universities (introduction, methodology, results and discussion) with the Scandinavian PhD thesis model of a synthesis of undertaken research and published and publishable manuscripts emanating from the research. Except for Chapter 1, 4 and 8, all chapters are already published or in publishable format. I chose this format because an important element of my motivation for this doctoral research was to make real contributions to academia and practice. I believed this purpose would be better served by peer-reviewed publications and stakeholder engagement activities than by a traditional thesis. Given that standalone publications form a large part of the presented thesis there is, however, some unavoidable repetition, particularly in the introductions and methods of the results chapters. Furthermore, to ensure a coherent storyline throughout this thesis, every chapter starts with a paragraph on ‘Thesis context’ explaining how the chapter fits into the overarching storyline.
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PART A

INTRODUCTION

Chapter 1: Introducing the research focus and thesis outline

Chapter 2: Promoting industrial symbiosis: Using the concept of proximity to explore social network development

Chapter 3: A system evolution perspective on promoting industrial symbiosis
Introducing the research focus and thesis outline

This chapter briefly outlines the subject and contents of this thesis. It summarises the research gaps that will be introduced in detail in Chapter 2 and 3, which were studied during this research project. Research aims and questions will be introduced and the chapter concludes with an outline of the thesis structure.
Chapter 1: Introducing the research focus and thesis outline

1.1 Transition to a resource efficient circular economy using renewable resources

The availability of natural resources is predicted to be increasingly impaired, whilst resource prices and price volatility are expected to continue to increase in the foreseeable future (ME Assessment 2005; Dobbs et al. 2011; Lee et al. 2012; Morgan 2014). At the same time carbon emissions need to be limited to constrain further climate change (IPPC 2014). Driven by growing resource scarcity and climate change, society urgently needs to move towards a more circular and resource efficient economy that is less dependent on fossil resources (OECD 2009; Laybourn and Morrissey 2009; UNEP 2011; EC 2011a, 2011b; Lin et al. 2013; Hoffman et al. 2014; Finster and Hernke 2014; Rowney 2014).

Industries can become more resource efficient by reducing their usage of natural resources (ME Assessment 2005; UNEP 2011). Resource efficiency can be increased through the development of circular production systems such as those created through industrial symbiosis. Industrial symbiosis can be described as the development of working agreements between industrial and other organisations that, through the innovative reuse, recycling or sharing of resources, lead to resource efficiency (Jensen et al. 2011a). Indeed, industrial symbiosis has been recognised in the public and private sector as a strategy to promote resource efficiency and business development whilst limiting carbon emissions (Laybourn and Morrissey 2009; EC 2011b).

With the necessity and benefits of industrial symbiosis broadly accepted, this research evolved in 2012 from the question “Can we formulate a strategy to actively promote and implement industrial symbiosis, based on the published knowledge in industrial ecology?”. Literature reviews revealed a limited understanding of the development of industrial symbiosis. It emphasised the importance of further research into the social processes leading towards these resource synergies in order to inform pro-active strategies promoting such innovations (Frosch and Gallopoulos 1989; White 1994; Korhonen et al. 2004).
1.2 Gaps in understanding of the evolution of industrial symbiosis

Industrial symbiosis tends to involve collaborations due to the nature of the process in which ‘waste’ from one company is turned into a resource for another company (Renner 1947; Frosch and Gallopoulos 1989). As a minimum this involves the development of relations between waste producers and their clients, and additionally it can involve governmental organisations at national, regional and local level as well as universities and other research institutes (Park et al. 2008; Laybourn and Morrissey 2009). In other words, it involves the development of social networks. Hence the development of industrial symbiosis has been studied with social network approaches (Ashton 2008; Doménech and Davies 2009; Paquin and Howard-Grenville 2012; Zhang et al. 2013). Furthermore, the development of industrial symbiosis often involves innovation (Boardman and Gardner 2006). Industrial symbiosis has been linked to a) various types of innovation such as product, process and organisational changes, b) different innovation activities including knowledge exchange and research & development, and c) varying degrees of change ranging from business-level up to systemic changes (Huber 2000; Mirata and Emtairah 2005; Boardman and Gardner 2006; Jensen et al. 2011a; Lombardi and Laybourn 2012). Despite these different applications of the term ‘innovation’, invariably industrial symbiosis has been associated with environmental improvements and was as such described as environmental or eco-innovation. Given the apparent importance of social networks and innovation for industrial symbiosis, this study focuses on these two themes.

In recent years, industrial ecologists have developed a general idea about the development of industrial symbiosis networks. Admittedly leaving out some of the nuances presented within the industrial ecology community; Industrial symbiosis is thought to start developing in response to changes in contextual factors such as policies and markets (Desrochers 2004; Boons 2008). First, individual symbiotic relations emerge randomly between companies that often are geographically proximate (Baas and Boons 2004; Doménech and Davies 2011a; Chertow and Ehrenfeld 2012). Then awareness and competencies regarding industrial symbiosis start to develop whilst also shared norms of trust and reciprocity, i.e. norms governing collaborations, emerge between companies (Doménech and Davies 2011a; Chertow and Ehrenfeld 2012). This enables the development of more and more complex
resource partnerships (Baas and Boons 2004; Doménech and Davies 2011a; Chertow and Ehrenfeld 2012; Paquin and Howard-Grenville 2012). The industrial symbiosis network grows denser over time (Chertow and Ehrenfeld 2012; Paquin and Howard-Grenville 2012) and this increasingly stable and closed network promotes more innovative resource synergies (Mirata and Emtairah 2005; Doménech and Davies 2011b). There are, however, some fundamental issues and considerable knowledge gaps in these general ideas about the evolution of industrial symbiosis networks, which constrain the formulation of effective and efficient approaches for their promotion.

First, understanding how and why social networks develop between resource partners (i.e. waste producers and users) and other organisations needs further research. Although a few industrial ecologists have researched how social networks develop in the case of industrial symbiosis (e.g., Ashton 2008; Doménech and Davies 2009), these studies focused on a limited range of social factors and consequently other social factors may have remained under-explored. In particular, geographic proximity and trust are generally considered crucial for the development of industrial symbiosis (e.g., Ashton and Bain 2012; Taddeo et al. 2012; Chertow and Ehrenfeld 2012). However, empirical findings on the role of these factors published within industrial ecology (e.g., Lyons 2007; Jensen et al. 2011a) and in economic geography (e.g., Boschma 2005; Ter Wal 2009; Broekel and Boschma 2012) provide grounds to pose further questions. In particular, there is a need to learn more about the meaning, need for, and role of both geographic proximity and trust and to explore other potentially important factors in the development of industrial symbiosis, such as hierarchies in networks and institutional ‘space’ for innovation (also see, Deutz and Lyons 2008; Deutz 2014). Chapter 2 (Velenturf and Jensen 2016) will provide a more detailed discussion on this subject and suggest that empirical qualitative studies that observe, rather than surmise, how and why industrial symbiosis develops in different scenarios and contexts is the most appropriate way forward.

Second, the general ideas above indicate that norms associated with industrial symbiosis emerge whilst innovation capacity increases. For example, it has been argued that the emergence of an industrial symbiosis network could promote ‘cultural embeddedness’ i.e. shared norms and trust, such as about waste and resources, or a ‘culture of cooperation’
(Ashton 2008; Doménech and Davies 2011a; Paquin and Howard-Grenville 2012). In other words, the network developments are thought to be leading to changes in the context within which industrial symbiosis develops. However, such change in the institutional context could not be observed in all studies on this subject (e.g., Pakarinen et al. 2010), suggesting that this is an area that needs further research. Furthermore, it has been argued that the cultural changes then go on to benefit more innovative resource synergies (Mirata and Emtairah 2005; Doménech and Davies 2011b). Both the changes in context and the increased innovation are thought to be driven by the increasing network density over time. However, well-established network theories suggest that the emergence and persistence of norms and the increased innovation capacity would not be supported by the same network conditions (Coleman 1988; Burt 1992). While the high network density would theoretically support the emergence of new norms (Coleman 1988), such networks could lead to lock-in and reduced innovation capacity as well (Day 1994; Granovetter 2005). This idea will be elaborated in Chapter 3 which proposes a more dynamic view of the evolution of industrial symbiosis networks.

Third, while a multitude of studies have researched how contextual conditions such as policy, regulation and markets can promote or constrain industrial symbiosis (e.g., Desrochers 2004; Boons 2008; Jacobsen and Anderberg 2009; Costa and Ferrão 2010; Jensen et al. 2011b), the exact mechanisms through which such macro-factors influence the inter-organisational network dynamics merit further research (Jiao and Boons 2014). More precisely, the qualitative understanding of the ways in which the factors ‘arrive’ in the networks of the companies that adopt resource synergies need to be studied further. One way in which policy and regulation could arrive in the networks of companies, that eventually may adopt industrial symbiosis practices, is through the implementation of interventions through governance networks (Barrett 2004; Flanagan et al. 2010, 2011), such as through supportive activities in the case of self-organised industrial symbiosis or more actively through facilitated or planned approaches (Shi et al. 2012; Ehrenfeld and Gertler 1997; Gibbs and Deutz 2005, 2007; Laybourn and Morrissey 2009; Shi et al. 2010; Mathews and Tan 2011; Paquin and Howard-Grenville 2012; Christensen 2012). Observation of these governmental strategies and their relative successes also suggest that the governance measures need to fit to the regional industrial characteristics (Hoffman 2003; Gibbs and
Deutz 2007; Deutz and Lyons 2008; Jacobsen and Anderberg 2009; Costa and Ferrão 2010), similar suggestions have also been made in the systems of innovation literature (Tödtling and Trippl 2005; Asheim et al. 2011a). The mechanisms through which immergent processes such as policy and regulatory changes might influence the development of industrial symbiosis, and vice versa, will be further explored in Chapter 3.

1.3 Research aims and questions

The previous section revealed that the simple but obvious question How and why did industrial symbiosis develop? is yet to be fully answered. Furthermore, it is evident from the literature that the market and governmental contexts are influencing industrial symbiosis. However, exactly how, i.e. through which steps, these contexts influence industrial symbiosis (the top-down processes) and, conversely, how industrial symbiosis might drive changes in the institutional context (the bottom-up processes) needs considerable further research. The research gaps can be summarised as follows:

1. Understanding how and why social networks developed between resource partners and other organisations, further discussed in Chapter 2 (Velenturf and Jensen 2016).
2. Understanding how top-down and bottom-up processes interacted and might contribute to the evolution of industrial symbiosis, further explored in Chapter 3.

Both research gaps are qualitative in nature and are caused by limited empirical and open exploration of industrial symbiosis innovations with a detailed analysis of the context within which the innovations are realised.

The precise research focus was narrowed down through a process of identifying mutually interesting and legitimate research aims for both the stakeholders in the Humber region, where this study was carried out, and for the Evolution and Resilience of Industrial Ecosystems (ERIE) project, of which this doctoral study was part. This process will be further explained in Chapter 4. Through these interactions it was decided to focus on one particular type of industrial symbiosis: biowaste-to-resource innovation. These innovations, particularly in the bioenergy sector, were gaining momentum in the Humber region and over the course of this study various innovations did indeed come to fruition (UKTI 2009; Humber Local Enterprise Partnership 2014; Bondholders 2014). Moreover, the development
of a bio-waste bio-economy was increasingly recognised as a strategy to reduce dependency on fossil and other finite resources and constrain carbon emissions whilst generating economic benefits including increased sustainability and energy security (DEFRA and BIS 2012; Science and Technology Select Committee 2014; Government 2014, 2015a). While the sustainability benefits of bio-based developments have not been undisputed such critique fell outside of the scope of this study (Ragauskas et al. 2006; Searchinger et al. 2008; Cherubini and Stromman 2011).

Having reviewed the relevant literature and taken on board the interests of all actors involved in this study, it was decided to carry out a qualitative exploration to contribute to academic understanding of industrial symbiosis and practical knowledge on the promotion of biowaste-to-resource innovation, by answering the following research questions:

*How and why did industrial symbiosis, interpreted as biowaste-to-resource innovation, develop over time?*

a) How and why did collaborations between resource partners develop during biowaste-to-resource innovations?

b) How did the governance of, and policy and regulation implemented by, regional governmental and associated organisations influence biowaste-to-resource innovation?

c) How did top-down processes, such as developments in markets and governance, and bottom-up processes, such as network development during biowaste-to-resource innovation, mutually influence each other over time?

### 1.4 Thesis outline

This thesis consists of four parts. Part A introduces the research focus, aims, gaps and questions, Chapter 1 opened the introduction and Chapter 2 and 3 will provide the necessary detail. Part B will explain the methodology adopted for this study (Chapter 4). Part C will present the results in three published or publishable chapters (Chapter 5-7). Part D will provide a brief discussion to answer the overarching research question and discuss the academic and practical contributions made in this thesis (Chapter 8).
Promoting industrial symbiosis: Using the concept of proximity to explore social network development

This chapter discusses the first research gap, understanding how and why social networks developed between resource partners and other organisations. The chapter has been accepted for publication and the full reference is: Velenturf, Anne P.M., Jensen, Paul D. (2016) Promoting industrial symbiosis: Using the concept of proximity to explore social network development. *Journal of Industrial Ecology* Vol. 20 (4): 700-709, which has been published in its final form at doi: 10.1111/jiec.12315. Paul Jensen contributed to the contents of the sections on geographic proximity (2.2.1) and trust (2.2.2) whilst also providing general feedback on the complete article. All other contributions, including the development of the article concept and first full version up to completion and publication, were the result of my work.
Chapter 2: Promoting industrial symbiosis: Using the concept of proximity to explore social network development

Anne P.M. Velenturf and Paul D. Jensen

Summary

Industrial symbiosis (IS) has been identified as a strategy for promoting industrial sustainability. IS has been defined as the development of close working agreements between industrial and other organisations that, through the innovative reuse, recycling or sharing of resources, leads to resource efficiency. Key to IS are innovation and social network development. This article critically reviews IS literature and concludes that, to inform pro-active strategies for promoting IS, the understanding of the social processes leading to resource innovation needs to be improved. Industrial ecologists generally believe that close geographic proximity and trust are essential to the development of IS. This article argues, however, that there is a need to learn more about the meaning of, need for, and specific role of geographic proximity and trust in IS and, additionally, that other potentially important social factors have remained under-explored. To move IS research forward, this article suggests to engage with research in economic geography on the concept of ‘proximity’, which draws attention to the ways in which geographic, cognitive, institutional, social and organisational distances between actors might affect innovation. Arguably the analytically distinct but flexible dimensions of proximity can be useful to explore how and why IS develops. The resulting qualitative knowledge would form a basis for researching whether general patterns for IS development exist and, more importantly, could inform public and private strategies that indicate which actions could be taken, when and in what way to promote resource synergies and sustainable industrial development.

Keywords: Resource synergies, Innovation, Social factors, Geographic proximity, Trust

2.1 Introduction

There is a pressing need to understand the social processes that underlie sustainable industrial development (Frosch and Gallopoulos 1989; White 1994; Korhonen et al. 2004).
Such understanding is necessary to inform pro-active strategies for the development of sustainable industrial systems (Korhonen et al. 2004). Pro-active strategies are needed because it is likely that the availability of many natural resources, which are crucial to the on-going functioning of a multitude of industries, will be increasingly impaired while simultaneously resource prices will continue to increase (ME Assessment 2005; Dobbs et al. 2011). One suggested route to improve the sustainability of industries is decreasing the input of natural resources into industrial systems by increasing resource efficiency (ME Assessment 2005; UNEP 2011). A strategy for increasing resource efficiency is the development of circular production systems such as those created through industrial symbiosis (IS). IS has been defined as the development of close working agreements between industrial and other organisations that, through the innovative reuse, recycling or sharing of resources, lead to resource efficiency (Jensen et al. 2011a). Allowing IS systems to develop organically would arguably take too long. For example, the IS system in Kalundborg initially developed over a period of at least 25 years (Ehrenfeld and Gertler 1997; Christensen 2012). This time period clearly does not reflect ‘urgent’ development of sustainable industrial systems. Hence, pro-active strategies for IS, that are informed by an understanding of the social processes leading to the adoption of IS practices, are required.

It has been recognized that the realization of resource symbioses often involves innovation (Huber 2000; Mirata and Emtairah 2005; Boardman and Gardner 2006; Jensen et al. 2011a; Lombardi and Laybourn 2012). Because IS naturally involves two or more collaborators, social networks are considered important for its development (Ashton 2008; Doménech and Davies 2009). Thus social networks and innovation are identified as key themes to complement existing IS research. To date, it seems to be generally accepted in industrial ecology that geographic proximity and trust between companies are essential for the realization of IS (e.g., Chertow and Ehrenfeld 2012; Ashton and Bain 2012; Taddeo et al. 2012). This belief was partly based on agglomeration and cluster development studies in economic geography, which has been an important source of inspiration for industrial ecologists (e.g., Lowe 1997; Ashton 2009). This article suggests that economic geography could yet provide more insights into the pro-active development of IS by engaging with the continuously developing body of literature on the concept of ‘proximity’.
There is an on-going discussion among economic geographers about the role of social networks in innovation (e.g., Howells 2002; Nooteboom and Gilsing 2004; Ter Wal 2009; Boschma and Martin 2010; D’Este et al. 2013). Pivotal in this discussion is the concept of proximity, which is about the ‘distances’ between actors and how these distances affect innovation (Boschma 2005). These distances can be absolute and relative, e.g. physical distance and what industrial ecologists have called ‘mental distances’ respectively (Ashton and Bain 2012). Mental distance has been associated with similarities at a cognitive level, such as shared norms about waste handling, which could enable collaboration between companies (Sterr and Ott 2004; Chertow and Ashton 2009; Ashton and Bain 2012). The on-going discussion on proximity in economic geography is particularly interesting for industrial ecologists because the roles of geographic proximity and trust in promoting innovation are regularly debated and, as will be argued in this article, these social factors also merit further research and debate in IS literature.

This forum article argues for using the concept of proximity as a new pathway to research how and why innovative IS develops. First industrial ecology literature will be critically reviewed, particularly focusing on geographic proximity and trust, leading to the identification of directions for further research on IS. The concept of proximity and its potential benefits to IS research will then be discussed, arguing that the analytically distinct though flexible dimensions of proximity offer valuable new starting points to explore the role of various social factors in the realization of innovative IS. The article concludes with an example of applying the concept of proximity to an IS study that resulted in practical outcomes that are likely to inform pro-active strategies for the development of resource efficient industrial systems.

2.2 Current understanding of social processes leading to industrial symbiosis

Geographic proximity and trust are generally considered important for the development of resource synergies (e.g., Chertow and Ehrenfeld 2012; Ashton and Bain 2012; Taddeo et al. 2012). In the early days of industrial ecology, this belief was largely based on conclusions
derived from industrial agglomeration studies (Lowe 1997) and on studies of the self-organised IS in such places as Kalundborg (Ehrenfeld and Gertler 1997). To explain this statement further, industrial agglomerations, or the locating of companies in geographic proximity of each other, may lead to the increased likelihood of resource synergies. Similar to biological systems, the more businesses in type and number that are present in a given area, the more potential resource reuse pathways exist, and the greater the likelihood that these businesses may fill continually evolving IS niches, which, in turn, is believed to improve the effectiveness of exchanges in the region as a whole (Ring 1997; Korhonen 2001a; Korhonen 2001b; Sterr and Ott 2004; Ashton 2009; Jensen et al. 2011b; Jensen et al. 2011c). In this theory, which derives from basic ecosystem development thinking (e.g., Odum 1969), geographic proximity can be seen to drive increased resource efficiency at a local and regional geographic scale. Additionally, industrial ecologists have studied how IS has evolved (Ehrenfeld and Gertler 1997; Korhonen and Snakin 2003; Ashton 2009; Paquin and Howard-Grenville 2012; Chertow and Ehrenfeld 2012). Ideas about the evolution of industrial ecosystems were derived from empirical examples such as Kalundborg. In the example of Kalundborg, IS primarily developed through bottom-up processes between companies that were located in geographic proximity, where the employees were part of a small community and knew and trusted each other prior to the development of IS (Ehrenfeld and Gertler 1997; Jacobsen and Anderberg 2009). This model, i.e. companies in geographic proximity in which employees get to know and trust each other prior to or simultaneously with the development of synergies, dominates current perspectives on promoting IS (Sterr and Ott 2004; Hewes and Lyons 2008; Jacobsen and Anderberg 2009; Chertow 2009; Chertow and Ehrenfeld 2012; Ashton and Bain 2012; Taddeo et al. 2012). However, there are elements of this perspective that merit further investigation.

2.2.1 Geographic proximity

Local and regional geographic scales are generally accepted as the most suitable for IS development (e.g., Chertow 2009; Simboli et al. 2012). However, from the point of view of metabolic flows, industrial ecologists have studied at what geographic scales resources flow and found that resources and resource networks can develop over a variety of distances (Sterr and Ott 2004; Tong and Lifset 2007; Lyons 2007; Jensen et al. 2011a). Nevertheless,
the need for geographic proximity between companies in social networks, for the promotion of IS, has remained largely unchallenged. There are empirical studies that suggest that geographic proximity between actors may be neither as ubiquitous nor as essential in promoting IS as is regularly presented. Indeed, the importance of geographic proximity can be challenged based on existing empirical research from within the field of industrial ecology. The assumption that geographic distances for the exchange of wastes and by-products should be short is largely based on the balance between transaction costs and the value of the material (Sterr and Ott 2004). However, within documented IS case studies there is no evidence to categorically back up this assumption. In fact, to the contrary, an empirical study into the movement of thousands of recyclates between members of the United Kingdom’s National Industrial Symbiosis Programme (NISP) found that there was no correlation between transport distance and the quantities or value of a broad range of materials (Jensen et al. 2011a). In terms of potential environmental considerations limiting the distances that materials move, the aforementioned study also notably found that the carbon savings resulting from symbiotic resource reuse, significantly outweighed the carbon emissions produced during transportation of the materials to their point of reuse. This (and a later related study) instead concluded that the distance materials move, to realize IS, is primarily driven by relative geospatial industrial diversity and the consequent likelihood of finding a potential unrelated symbiosis partner able to reuse a given waste or by-product (Jensen et al. 2011a; Jensen et al. 2011c). It is important to note, however, that these conclusions referred primarily to facilitated IS, where a third-party neutral practitioner employed their knowledge of a given geographic area to identify and engage with potential industrial and other IS collaborators. These findings, nevertheless, have proven not to be unique to facilitated IS. In more general terms, it has been suggested that there is no specific scale at which recycling is best managed since a variety of resources have been observed to be recycled at multiple geographic scales (Lyons 2007; Velenturf 2016a; Chapter 5). Since resources are recycled at multiple scales, the movement of these resources must have been organised and thus social networks must also exist at multiple scales. The existence of social networks at multiple scales implicitly challenges the importance of geographic proximity in these social networks.
In addition to transaction costs of the physical movements of materials, transaction costs have also been related to the social interactions that are required to organise material exchanges. Sterr and Ott (2004) argued that, as the geographic distances in recycling networks became longer, costs to overcome so-called ‘mental distances’ increased. The increase in costs would be caused by the necessity and increased difficulty to develop trust between companies that did not have any formal or informal relationship prior to the material exchange. Also communication and coordination costs would rise. Various scholars in industrial ecology have argued that geographic proximity is a necessity in building intercompany trust (Gibbs 2003; Sterr and Ott 2004; Hewes and Lyons 2008), but this necessity can be questioned, as was also recognized by Lombardi and Laybourn (2012). The assumption that geographic proximity may support the generation of inter-organisational trust has been taken from human geography (MacKinnon et al. 2002), however, this assumption has been questioned in other fields in the on-going discussion about mechanisms for interaction and coordination of learning and innovation (Boschma 2005; Ter Wal 2009; Broekel and Boschma 2012). The need to overcome mental distances and in particular to create trust merits further research altogether and this will be discussed in the next section.

2.2.2 Trust

Trust is considered of key importance to the development of IS, whether it is a self-organised, facilitated or fully planned process (Ehrenfeld and Gertler 1997; Gibbs 2003; Sterr and Ott 2004; Hewes and Lyons 2008; Ashton 2008; Jacobsen and Anderberg 2009; Doménech and Davies 2011a; Chertow and Ehrenfeld 2012). This conviction is based on several publications that emphasize how trust is important for business and innovation (Granovetter 1985; Porter and Linde 1995; Putnam 1995; Uzzi 1996).

The importance of trust in business and innovation has been widely and methodically discussed in various disciplines. Particularly in innovation and proximity studies, trust is considered an important subject (Gulati 1995; Cooke et al. 1997; Lundvall et al. 2002; Boschma 2005; Ter Wal 2009). However, perhaps industrial ecologists have been selective in their interpretations. Despite literature emphasizing the importance of trust (for extensive
overviews of ‘trust’ literature see e.g. Rousseau et al. (1998) and Nooteboom (2002)), its importance has also been questioned and it has been suggested that trust could be substituted by other social factors, such as hierarchies and coercion as well as confidence in institutional frameworks (Nooteboom and Gilsing 2004; Boschma 2005) (discussed further in following sections). Furthermore, although various authors argue that it would indeed benefit companies to be embedded in dense social networks that foster trust (Walker et al. 1997; Tsai and Ghoshal 1998), it has also been suggested that dense networks can be detrimental to business and innovation, for example because it can lead to cognitive lock-in and reduced creativity (Granovetter 1985; Grabher 1993; Day 1994; Uzzi 1996; Boschma 2005; Granovetter 2005). Consequently, the presence of trust may also be associated with barriers to innovation. This apparent contradictory thinking suggests that industrial ecologists should research the role of trust in innovative resource synergies in an open and holistic manner.

Many important questions about the role of trust in the development of IS have not been rigorously answered. Trust is a vague term and is regularly applied in an equally vague manner. Trust can have many meanings and without explaining what one means by ‘trust’, the academic and practical use of the research outcomes will be impaired. In order to maximize contributions to on-going IS research and practical IS strategies, it is important to clearly ascertain why there is a need for trust, what it is that needs to be trusted, who needs to be trusted, how ‘much’ trust is needed and how it can be developed over varying geographic distances. It is important to answer these questions, because generating trust is not an easy task. It requires substantial investment of leadership skills, time and money (Hewes and Lyons 2008) which are often limited in availability. Hence knowledge is necessary to formulate effective strategies to generate the right kinds of ‘trust’, between the right people, in the right subjects, at the right time and through the right activities – all of which require further research.

Nevertheless, several researchers have explored the role of trust in IS (e.g. (Gibbs 2003; Ashton 2008; Hewes and Lyons 2008)). However, industrial ecologists have tended to assume trust is important without fully exploring if, how and why it may be important, and instead they have focused on understanding how trust can be generated (e.g. (Hewes and
Lyons 2008; Doménech and Davies 2011a)). Trust may have remained underexplored to this extent, because it has been considered inherent to the concept of eco-industrial developments such as IS. This is expressed in the following quote:

“The concept of eco-industrial parks has as its basis inter-firm collaborating and networking, based upon trust and reciprocal relations. Without these an eco-industrial park does not exist (...).” (Gibbs 2003: 230)

In general, it is not clear what industrial ecologists mean by trust. Trust can have many dimensions (Nooteboom 2002), covering for example different levels of social systems including inter-personal trust, inter-organisational trust, and trust in institutions governing IS. Additionally, different subjects can be trusted, such as trust in the long-term supply of a given resource, trust in competencies and intentions and/or trust in the mutual benefits derived from a synergy. Furthermore, the purpose of trust has been clarified to varying degrees. Inter-company trust has been presented as a broad general concept underlying the development of IS (Baas 1998; Baas and Boons 2004; Doménech and Davies 2011a). More specifically, trust has been associated with overcoming motivational or behavioral barriers, consisting of the willingness to participate in IS projects (Heeres et al. 2004; Gibbs and Deutz 2007; Sakr et al. 2011), the lowering of transaction costs for the development of IS (Chertow and Ehrenfeld 2012), and openness to share information with potential IS partners (Gibbs 2003; Sterr and Ott 2004; Jacobsen and Anderberg 2009).

Despite the abovementioned publications, even IS literature itself provides grounds to challenge the role of trust. For example, in the specific case of facilitated IS the nature and development of trust between companies has been questioned (Jensen et al. 2011a). Despite the absence of any prior professional acquaintance or obvious ‘short’ mental distances, companies engaged with each other and the third-party facilitator’s program (NISP) because they were confident (i.e. trusting) that there might be a business development opportunity. Another suggestion within industrial ecology that the role of trust needs further research, was identified in Ashton (2008). The suggestion that trust could be substituted by other social factors (Nooteboom and Gilsing 2004; Boschma 2005) might be supported by Ashton’s (2008) work. Contrasting existing conclusions, Ashton’s results showed that, in a social network of formal and informal relations between managers, the most central network actors were also the most trusted. However, based on network
theory, a central network position can also be interpreted as a powerful position, because a central network actor may have faster and multiple ways of access to resources whilst more peripheral network actors may depend on central actors (Scott 2000). Hence, it can be said that the network represents a hierarchy, in which the central actors are more powerful than the more peripheral actors. In Ashton’s (2008) study, trust was found to correlate with the presence of IS. However, keeping in mind the possible correlation between trust and hierarchy of actors, it could be that both trust and hierarchy correlated with the presence of IS and that both factors may have played a role in the development of IS. This theory might be supported by other industrial ecology research, which will be discussed in the next section.

2.2.3 Hierarchy and coercion

Network hierarchies such as presented by Ashton (2008) can, as discussed above, represent dependencies between actors. These dependencies can come into play when an actor wants to do something that requires resources from another actor. Resources should be interpreted broadly, for example these can be contacts but also money, materials, knowledge and skills. Hierarchies are formed based on the resources available to actors. Each actor is constrained by the resources that are available to it. ‘Constrain’ is a synonym for ‘pressure’ and ‘coercion’ (Oxford 2007), and as such hierarchy can be the medium through which coercion operates. Coercion generally has a negative connotation; however, it can also be used to achieve positive environmental outcomes which are arguably for the greater good. Furthermore, as suggested earlier, it should be noted that coercion does not exclude the operation of other factors such as trust (in whatever variety of forms it might exist). Despite the potential role coercion could play in the development of IS, coercion has remained largely underexplored in the literature on eco-industrial developments in Europe and the US. Conversely, publications about eco-industrial development in China and the Republic of Korea suggest that coercion has played an important role. Eco-industrial development in these countries is generally the outcome of both top-down and bottom-up processes, processes in which both coercion and trust play a role (Park et al. 2008; Mathews and Tan 2011; Behera et al. 2012).
Exemplifying the role of coercion, the development of eco-industrial parks (EIP) in China will be briefly discussed. In China, the role of governments and public bodies is not always clear (Zhu et al. 2010), nevertheless environmental management of industrial systems has been described as centralized and top-down regulated (Liu and Ma 2010) and it has been argued that EIP initiatives are primarily government led (Shi et al. 2012b; Shi and Yu 2014). Governments can initiate change in industrial systems by contracting businesses to meet environmental targets (Geng et al. 2010) and regulating the quantity, price and destination of material flows through markets (Zhu et al. 2007). The Chinese government, rather than business, initiates eco-industrial initiatives because it is considered necessary in the fast transition towards a circular economy (Mathews and Tan 2011). Applications for EIP demonstration programs and EIP planning are government led (Shi et al. 2012a) and are usually initiated by an administrative committee or a general development corporation of an industrial park, which are representatives of the local government. Nevertheless, these organisations would like more business involvement (Tian 2013 pers. comms.). It is also interesting to note that, despite the clear top-down development of EIPs in China, the social relationships between stakeholders in an EIP do seem to help in the development of IS (Tian 2013 pers. comms.). This suggests the coexistence of top-down and bottom-up processes. Evidently coercion played a role in driving eco-industrial development in China. This example suggests that coercion can play a role in eco-industrial developments and IS, and shows that important social factors might have remained under-explored in sections of IS literature.

2.3 Engaging IS research with the concept of proximity

Although there is valuable published research on the subject of IS and its facilitation (e.g., Ashton 2008; Jensen et al. 2011c; Paquin and Howard-Grenville 2012), the critical review of industrial ecology literature in the first half of this article revealed that there is still a limited understanding of the various social factors that might play a role in IS development. As discussed earlier, it is not clear what role geographic proximity plays in social processes leading to IS. It is also not clear what ‘trust’ means in the context of IS, and there is no rigorous evidence about how and why it develops during the realization of resource synergies. Furthermore, social factors such as hierarchy may be important too, and more
open investigations might reveal other social factors relevant to IS. To conclude, there are still significant gaps in the understanding of social processes for the development of IS. It is proposed here, however, that these gaps can be filled by various elements of the continuously developing concept of proximity. The following section recommends and demonstrates how IS researchers could engage with the concept of proximity, using it as a new ‘lens’ through which the development of resource synergies can be explored.

2.3.1 The concept of proximity

Similar to industrial ecology, scholars in geography questioned how innovation could be promoted. In cluster literature particularly, geographic proximity was considered to be of key importance for learning and innovation and it assumed that knowledge networks were confined to regional borders (Castells 1996; Ter Wal and Boschma 2008). However, further exploration of knowledge networks has proven that connections for learning and innovation also includes contacts outside the regional borders and that a combination of intra- and inter-regional knowledge networks benefits innovation (Asheim and Isaksen 2002; Bathelt et al. 2004; Broekel and Meder 2008). Hence it could be argued that geographic proximity is “neither a necessary nor a sufficient condition” for inter-organisational learning and knowledge transfer (Boschma 2005). To explore this matter further, economic geographers engaged with a group of spatial and industrial economists who had formulated the concept of ‘proximity’ (Gilly and Torre 2000; Torre and Gilly 2000). Whilst acknowledging the variety of applications of the concept of proximity, generally it has been used to explore, or measure, the differences between actors and the effects of those differences on inter-organisational interaction for – and coordination of – innovation (Boschma 2005). The literature basis of the concept of proximity shows some overlap with the concept of embeddedness (such as, Granovetter 1985; Uzzi 1996), which is well-known to industrial ecologists. However, in contrast to embeddedness, the concept of proximity has developed an analytically distinct focus on inter-organisational processes while also ‘isolating’ various proximity dimensions (Zukin and DiMaggio 1990; Boschma 2005). With the concept of proximity, industrial ecologists could generate valuable contributions to further understanding on how, why and when innovative IS develops between companies. Importantly, the concept of proximity also enables the distinction of social factors such as
trust (in all its forms) and hierarchy and thus facilitates the exploration of their role in IS separately. Although the dimensions of proximity, which will be introduced shortly, are analytically separate, each dimension does show some variation in the meaning they have been given (Knoben and Oerlemans 2006). Rather than following one specific set of meanings, it is recommended to gain an understanding of the variation and explore which meaning fits best to the case of IS, i.e. to use the proximity concept as an aid or ‘lens’ to observe IS processes in an exploratory though not unnecessarily vague manner. Boschma (2005a) argued for five dimensions of proximity that can be analytically separated which enables empirical analysis of their discrete roles: these are geographic, cognitive, organisational, social and institutional proximity. These five dimensions and their variable meaning will be briefly discussed.

2.3.1.1 Geographic

Geographic proximity has been described as the absolute distance and also as the perceived or relative traveling distance between economic actors (Boschma 2005; Knoben and Oerlemans 2006). Furthermore, geographic proximity can be permanent or temporary (Knoben and Oerlemans 2006). Geographic proximity can have a positive influence on the exchange of tacit and codified knowledge (Howells 2002), however, empirical studies have also shown that a combination of local and non-local relations benefits learning and innovation (Asheim and Isaksen 2002; Broekel et al. 2010), i.e. both types of relations are important (Jaffe et al. 1993; Bathelt et al. 2004; Boschma and ter Wal 2007).

2.3.1.2 Cognitive

Cognitive proximity is about cognitive frameworks which can differ due to the context within which people have developed. For innovation and learning, some academics consider the whole social and physical context within which an individual developed and adopted, for example, norms and values that guide their behaviour (Boschma 2005). Others have a narrower and more practice-oriented interpretation of cognitive frameworks, linking them to market and technical competencies (Wuyts et al. 2005; Knoben and Oerlemans 2006). Arguably, the broader interpretation risks overlap with institutional proximity (see below).
and the narrower interpretation might be related to organisational proximity (see below) (Knoben and Oerlemans 2006). Many academics have argued that cognitive diversity is necessary for learning and innovation (see e.g., Nooteboom 2000; Nooteboom and Gilsing 2004). Diversity can be measured by the number of different actors involved as well as the differences between the actors (Wuyts et al. 2005). Arguably, cognitive differences between actors are necessary to trigger creativity and develop new ideas (Cohendet and Llerena 1997; Nooteboom and Gilsing 2004). Conversely, the cognitive differences need to be sufficiently reduced to enable learning and innovation, i.e. economic actors need to have enough ‘cognitive overlap’ to enable communication and knowledge transfer and absorption (Nooteboom 2000; Nooteboom and Gilsing 2004).

2.3.1.3 Institutional

To analyse institutional proximity, generally the definition of institutions as provided by North (1990) has been adopted, distinguishing formal and informal institutions. Institutional proximity is thought to impact on knowledge transfer and coordination (Kirat and Lung 1999). Institutional proximity can ease communication because increased institutional overlap between actors would prevent that all knowledge needs to be made explicit and, moreover, an institutional setting can provide institution-based trust which reduces uncertainty (Nooteboom and Gilsing 2004; Boschma 2005). Institutional proximity has been researched at two levels, the national/ regional and the inter-organisational level (Knoben and Oerlemans 2006; Boschma 2005). When researched at the inter-organisational level, institutional proximity risks overlap with social and organisational proximity (discussed next). Hence, to keep the proximity dimensions analytically separate, institutional proximity might better be interpreted and applied to research how institutions at the social macro-level promote and constrain innovation.

2.3.1.4 Social

Social proximity shows considerable overlap with social and structural embeddedness. Social proximity is about the influence of shared social space on innovation and learning and can be described as the degree to which economic relations are socially embedded at the
micro level, for example through friendship, kinship and professional acquaintance (Boschma 2005; Knoben and Oerlemans 2006). These social relations might facilitate knowledge transfer (Knoben and Oerlemans 2006). Moreover, socially embedded relations have been associated with trust, which is thought to function as a control mechanism against opportunistic behaviour (Nooteboom and Gilsing 2004; Boschma 2005). Particularly when innovations involve mostly tacit knowledge, trust may be an important coordination mechanism (Gertler 2003; Nooteboom and Gilsing 2004). However, when knowledge can be codified it could also be formulated in contracts and, theoretically, inter-personal trust would be of lesser importance (Nooteboom and Gilsing 2004).

2.3.1.5 Organisational

Organisational proximity has been described in a very wide sense covering all relative proximities (e.g., Gilly and Torre 2000). Others, however, have been more specific. Generally organisational proximity has been described as either the similarities in routines and incentives of organisations, for example profit and non-profit organisations would have different incentives for their economic activities, or the degree of autonomy and control that organisations have over each other (Broekel and Boschma 2012). The degree of autonomy and control can vary, for example, depending on the strength of economic and financial inter-dependencies between organisations (Kirat and Lung 1999). Dependencies do not have to be symmetrical (Nooteboom and Gilsing 2004), they can be hierarchical (Boschma 2005). As a result organisational proximity can be associated with hierarchy which can, as discussed before, facilitate coercion.

2.3.2 New pathways for IS research

The concept of proximity can be used in a variety of research approaches. Hence, depending on the level of knowledge in a given subject area, the most suitable research phase and accompanying methodology can be selected and make use of the concept of proximity. Economic geographers have applied the concept of proximity in mostly quantitative studies that ranged from empirical observation of phenomena to testing and theorizing about innovation (see for example, Oerlemans and Meeus 2005; Broekel and Meder 2008; Broekel
These predominantly quantitative studies have resulted in lists of factors that can benefit innovation. Arguably, however, such lists of factors are difficult to translate into public and private action to promote innovation because of the missing qualitative understanding of how and when these factors should be brought into practice (Sorenson 2014, pers. comms.). Hence it could be suggested that proximity research needs to increase its focus on qualitative empirical observation prior to measuring and testing, and eventually theorizing about, the role of social factors. This argumentation is also relevant to IS research, because various researchers have already started hypothesizing and theorizing about the role of various social factors in IS development, as demonstrated and critiqued earlier in this article, while qualitative gaps in understanding are evidently prevalent. Hence, at this moment, similar to the proximity literature, a qualitative exploratory methodology to observe and describe how IS has developed might be the most suitable approach to progress this body of research. IS literature does include qualitative studies already (such as, Ehrenfeld and Gertler 1997; Gibbs and Deutz 2005; Hewes and Lyons 2008; Behera et al. 2012; Paquin and Howard-Grenville 2012) and the further use of empirical qualitative methodologies would prevent the problem economic geographers are currently experiencing, as explained above, the problem of knowing which factors might be important but not being able to easily translate this knowledge into tangible strategic advice because specific understanding of exactly how and when the factors play a role in innovation processes is limited. Furthermore, empirical qualitative studies could, with care, directly inform public and private strategies to promote IS while also building a robust basis to formulate and test hypothesis which could eventually lead to a more generalized theory for promoting IS.

There are important questions in IS research that are yet to be fully answered, such as the simple but obvious: how and why did IS develop? Was there a particular order in which social factors played a role? What do the social factors, in the case of IS, look like empirically? To answer such questions, the concept of proximity, together with empirical and theoretical contributions from IS literature, can be used to produce and inform a research framework which includes a wide range of potentially relevant social factors in the development of IS. Such a framework can be used as a guide, which would still be open to interpretation of the selected social factors as well as other social factors not previously
included in the framework, to observe how and why IS developed. The research framework could be adopted as part of various methodologies such as case studies (see for example, Mason 2002; Yin 2009). Depending on resources available for the research project, a number of case studies could be carried out. If sufficient cases can be carried out some forms of qualitative comparative analyses (see for example, Lambert and Fairweather 2010) might even be feasible in order to identify general patterns.

The suggested research framework has already been applied (Velenturf 2016a; Chapter 5) to IS case studies within the Humber region of northern England and has provided tangible results which, as hoped, add to existing research and conclusions on the roles of various social factors such as geographic proximity and trust within the development of IS (full results to be published). In brief, a multiple case study design was applied to explore the development of organic and facilitated innovative resource synergies between companies in the emerging bio-energy sector. Each innovation process was ‘observed’ using documents, from the resource partners and third parties, and semi-structured interviews with the participating businesses. Data were analysed combining both conceptual and grounded coding methods (see for example, Bryman 2012). The initial coding tree was based on social factors that were considered important in innovation and IS, and these included intra- and inter-organisational as well as social macro-factors. During the case studies the coding tree was ‘pruned’ in some places while it was populated with new and further refined codes in other places. The role of each social factor was then analysed separately and also in relation to other factors. Then these analyses were combined in case study reports to generate a holistic understanding of how and why the resource synergy developed. In each case study the innovative material synergy was realized through similar steps and revealed remarkable similarities in the social processes that had led to IS. To be explicit, the innovation process was predominantly triggered by changes in the legislative and economic context. Potential resource partners were then identified as well as other actors that had to be involved in the innovation process. An initial business case was then made followed by a longer period of building shared knowledge and understanding, indeed this was the basis for trust in the resource synergy. At this point the collaboration was formally agreed with a contract before being realized. These results and more nuanced findings partly confirmed, complemented and sometimes, notably, countered current IS literature. For example, inter-organisational
trust in various subjects and characteristics of collaborators, such as confidence in mutual
benefits and capability to deliver the synergy, was indeed found to be important and was
generated through a number of activities, such as site visits and financial, health and safety
checks, which was part of a larger ‘social mechanism’ in which other social factors were
found to be highly relevant too. Such information, when carefully analysed, can be used for
targeted action to promote IS between companies. For example, the results surprisingly
suggested that some popular informal social events, such as business dinners, had very
limited value for generating trust. The presence of a tangible track-record of business
professionalism, however, sometimes simply in terms of the existence of operational
management systems, (i.e. for quality, environmental and/or health and safety), coupled
with a convincing business case, could be far more effective in promoting collaboration.
Indeed, being able to easily garner an evidence base of business professionalism, through
formal site audits or less ‘structured’, sometimes furtive, observations of a potential
symbiosis partner, played a large role in the realization of a synergy. The findings from these
case studies are being used to discuss strategies with public and private organisations
aiming to actively promote innovative context specific resource synergies in the Humber
region.

2.4 Conclusion

This article has discussed why industrial ecologists have generally asserted that geographic
proximity and trust are important in the development of IS. During this discussion, however,
it also became evident that these factors merit further research. In particular there is a need
to learn more about the meaning, need for, and role of geographic proximity and trust and
to explore other potentially important factors in the development of IS, such as hierarchies
in networks and institutional ‘space’ for innovation. In order to take IS research forward, it
has been recommended to engage with literature on the concept of proximity, arguing that
the analytically distinct but flexible dimensions of proximity are useful tools to progress IS
research. Arguably, to date, the most suitable line of research would be empirical qualitative
studies that, rather than surmising, observe how and why IS develops in different scenarios
and contexts. The resultant inductive and empirical understanding could be appropriately
followed by research phases such as the testing of hypotheses and theorizing how IS can be
promoted. More importantly, detailed qualitative knowledge could, while bearing in mind the specific context in which the knowledge would be generated, inform what actions public and private organisations can take, in what way and at what time, to assist the pro-active development of resource synergies and sustainable industrial systems.
A system evolution perspective on promoting industrial symbiosis

This chapter explores the second research gap that was identified in Chapter 1, understanding how top-down (immergent) and bottom-up (emergent) processes interact and might contribute to the evolution of industrial symbiosis. While Chapter 2 focused on the network processes that may happen within an industrial system, this chapter takes a wider system perspective and explores the relations between network processes and changes in the contextual conditions within which industrial symbiosis may develop. This chapter has not been published on its own although parts of it have been used in the results articles presented in Chapter 5-7.
Chapter 3: A system evolution perspective on promoting industrial symbiosis

Abstract

The evolution of industrial symbiosis is an emerging field within industrial ecology. Some generalised ideas about industrial symbiosis dynamics suggest a self-reinforcing cycle of increasingly innovative resource synergies that both creates and benefits from an emerging collaborative culture while industrial symbiosis practices become the social norm. However, contradicting empirical observations and alternative theories suggest that further research on the evolution of industrial symbiosis is necessary. After a bibliographical review of research published on this subject within the industrial symbiosis and closely associated eco-industrial park community, this article revisits relevant bodies of literature to explore the identified knowledge gaps further. Contributing to understanding emergent processes of network development, two basic network theories are discussed and integrated into an industrial life-cycle perspective suggested by exploration-exploitation literature. Then, by visiting systems of innovation literature, the article puts the evolution of industrial systems into their broader societal and environmental context and investigates ideas about successive changes in context and industries as they mutually affect each other. Finally, the article suggests the new concept of ‘complementary variety’ to understand how companies change the industrial context through successive resource synergies. The article concludes with a summary of the broadened perspective on industrial symbiosis evolution and suggests future research directions for this field of study.

Key words: Network evolution, Network theories, Exploration-Exploitation, Systems of Innovation, Related variety, Diversity, Complex Adaptive Systems

3.1 Introduction

Industrial ecology can be described as the study of material and energy flows (White 1994). It studies the effects of these metabolic flows on their context and, conversely, the influences of context on these flows. The aim is to understand how material and energy flows can be changed and, ultimately, to contribute to the development of sustainable
industrial systems. The implicit distinction between flows and context, internal and external factors, is broadly reflected within the industrial ecology community. Generally, industrial systems are perceived as embedded in society, which in turn depends on the physical or natural environment and the whole biosphere (Erkman 1997; den Hond 2000; Howard-Grenville and Paquin 2008). Some authors would even view the whole industrial system as context (e.g., Jensen et al. 2011c) and this enables integrating inter-organisational and intra-organisational networks into the overall system perspective (Figure 3.1).

Different factors/indicators can be observed at all of the identified system levels, for example from the largest to the smallest system levels (Figure 3.1): global temperature, resource reserves, GDP, industrial diversity, industrial symbiosis, company annual turnover. These factors can vary over time (i.e. evolve) and they could affect each other. For example, economic prosperity (social level) can impact on the amount of investment going into industrial systems, and investment positively correlates with innovation performance within industrial systems (Bilbao-Osorio and Rodriguez-Pose 2004). Hence, understanding how the factors at each system level might evolve and affect each other is important in order to understand how industrial systems can be steered towards more sustainable states over time.
Figure 3.1: Industrial systems can be seen as part of the socio-economic system, which depends on the physical environment and the biosphere. Within industrial systems, inter-organisational and intra-organisational networks can be distinguished through which energy, material and information can flow (White 1994; Erkman 1997; den Hond 2000; Chertow 2000; Howard-Grenville and Paquin 2008; Korhonen et al. 2004; Chertow et al. 2008; Jensen et al. 2011c).

Turning to the evolution of industrial symbiosis, individual resource synergies are thought to develop randomly in a region (Baas and Boons 2004; Domenech and Davies 2011a; Chertow and Ehrenfeld 2012) in response to changes in contextual conditions such as markets and policies (Desrochers 2004; Boons 2008). Over time, more resource synergies are expected to emerge and, ultimately, all the symbioses within the region are considered to lead to the creation of an industrial ecosystem (Chertow and Ehrenfeld 2012). Cultural changes are considered to support such ‘ecosystem approach’ (Frosch and Gallopoulos 1989) and, besides functioning as a driver of industrial symbiosis, researchers suggested later that industrial symbiosis could also lead to cultural changes (Lombardi and Laybourn 2012; Chertow and Ehrenfeld 2012). Taking these arguments together, researchers seem to suggest a self-reinforcing cycle through which industrial symbiosis contributes to cultural changes that then go on to benefit more and more innovative resource synergies (Mirata and Emtairah 2005; Doménech and Davies 2011b). However, the evolution of industrial
symbiosis is an emerging body of literature and there are various important knowledge gaps that merit further research.

After a critical review of literature on the evolution of industrial symbiosis and the identification of knowledge gaps regarding associated emergent and immergent processes (Section 3.2), the gaps in understanding will be further explored by discussing related bodies of literature on network theories and industrial life cycles (Section 3.3), systems of innovation (Section 3.4), and related variety and complex adaptive cycles (Section 3.5). The article concludes with suggestions for further theoretical and empirical research on the development of industrial symbiosis over time (Section 3.6).

3.2 Evolutionary perspectives in industrial symbiosis literature

3.2.1 Bibliographical analysis of evolution in industrial ecology literature

Evolution has gained increasing interest within the industrial symbiosis and associated eco-industrial park community (Figure 3.2a and b). Evolution is a relatively new subject within this community and although many authors discussed evolution along the side-lines of their research (Figure 3.2a) there is a growing body of literature that specifically focuses on evolution of industrial symbiosis and eco-industrial parks (Figure 3.2b).

Figure 3.2: Publications included in the Web of Science database per year (a) with evolution, industrial symbiosis and/or eco-industrial park as topic and industrial symbiosis and/or eco-industrial park in the title, and (b) with evolution, industrial symbiosis and/or eco-industrial park as topic and industrial symbiosis and evolution and/or eco-industrial park and evolution in the title. Figures copied from Web of Science Citation Report tool in August 2015.
Searching the Web of Science in August 2015 returned 51 articles, editorials and book chapters with evolution, industrial symbiosis and/or eco-industrial parks as topic as well as in the title (Figure 3.2b). The titles and abstracts were entered into NVivo for a word frequency count in order to identify key words and themes (Figure 3.3, Table 3.1). Besides (parts of) the search terms, other frequently written terms include network/ networks, environmental, economic, production, energy and system/ systems, which pertain to the environmental and economic benefits associated with industrial symbiosis and eco-industrial parks and the system perspective that is innate to the discipline industrial ecology. Further down the list terms like policy, waste and regional can be found, which highlights the importance of policy in supporting industrial symbiosis and the preference for the regional focus within this sub-discipline (also see, Velenturf and Jensen 2016; Chapter 2).

Even further down the list, outside the scope of Table 3.1, institutional (ranking 71), complex (86), context (87), government (127) and innovation (156) were included. Indeed, the systems perspective with factors within industrial networks and their context potentially affecting each other (as discussed in Section 3.1) could be seen as complexity dynamics. Furthermore, industrial symbiosis does indeed often involve innovation (e.g., Boardman and Gardner 2006; Jensen et al. 2011a) while the developing networks could play a broader role in learning and innovation in other areas of sustainable development (Mirata and Emtairah 2005; Patala et al. 2014).

This section will build on the systems perspective introduced in Section 3.1 and, based on the literature search, further introduce and critically review network evolution and important contextual factors including policy, institutions and government.
Figure 3.3: Word cloud of key words and themes abstracted from literature on evolution, industrial symbiosis and eco-industrial parks, using NVivo’s word frequency query tool.

Table 3.1: Key words and themes abstracted from literature on evolution, industrial symbiosis and eco-industrial parks, using NVivo’s word frequency query tool.

<table>
<thead>
<tr>
<th>Word</th>
<th>Count</th>
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<tr>
<td>Industrial</td>
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<tr>
<td>Eco</td>
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<td>economic</td>
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<td>production</td>
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3.2.2 Context and network development

In industrial ecology, few researchers have studied how changes in intra- and inter-organisational networks can lead to changes in contextual conditions (e.g., Wallner et al. 1996; Andrews 2000). Conversely, a multitude of studies researched how contextual conditions such as regulation and markets can constrain or promote sustainable development in industrial regions (e.g., Desrochers 2004; Boons 2008; Jacobsen and Anderberg 2009; Costa and Ferrão 2010; Jensen et al. 2011b). Nevertheless, most researchers believe there are mutual effects between processes within networks and contextual conditions.

3.2.2.1 Emergent processes: Industrial symbiosis network characteristics and dynamics

Industrial symbiosis tends to involve various actors such as companies, governments, NGOs, communities, and knowledge institutes (Korhonen et al. 2004; Boons et al. 2011), who may be exchanging flows of material, energy and/or information (Chertow 2000; Korhonen et al. 2004). In other words, industrial symbiosis tends to involve the development of social and metabolic networks. Hence, the development of industrial symbiosis has been studied with network approaches (such as, Howard-Grenville and Paquin 2006), for example with Ecological Network Analysis (Fiscus 2009; Zhang et al. 2009; Li et al. 2010) and Social Network Analysis (Ashton 2008; Doménech and Davies 2009; Paquin and Howard-Grenville 2012; Zhang et al. 2013). Social networks consist of actors and their relations. Social Network Analysis is an interdisciplinary research method to study social structures as a whole (Scott 1988, 2000) as well as the dynamics within the relations in a social structure (Borgatti et al. 2009).

Industrial symbiosis networks have been characterised by high levels of trust, long-term and strong relations, reciprocity, increasing network density and diversity, geographic proximity and a growing collaborative culture (Doménech and Davies 2009). More and more successful innovative resource synergies are thought to develop as industrial symbiosis
networks evolve, supported by the growing trust and reciprocal communication as well as the low ‘transaction costs’ for both the social and the metabolic exchanges which arguably would become too high over extended geographic distances (Sterr and Ott 2004; Chertow et al. 2008; Doménech and Davies 2009). This argumentation, however, does not align with observations of resource synergies elsewhere (Lyons 2007; Jensen et al. 2011a) and hence Chapter 2 (Velenturf and Jensen 2016) argued that further open exploration of network developments are necessary.

Network density and diversity are thought to increase while industrial symbiosis networks develop over time. Industrial ecologists have subscribed various benefits to those dynamics. Higher density has been associated with a collaborative culture that favours industrial symbiosis (Domenech and Davies 2011a). However, Walter and Scholz (2006) found neither a significant positive effect of network density on network performance, i.e. whether collaborative targets were achieved, nor a negative effect of high network density such as lock-in. The latter might be linked to the short persistence of the studied innovation networks. Short persistence could also be observed in the case of resource synergies, particularly when differences between actors were larger (Paquin et al. 2014), while others indeed observed more durable industrial symbioses (Doménech and Davies 2011b). The social and metabolic networks observed by Doménech and Davies (2011b) in Kalundborg were also found to have high density but lock-in did not occur. However, explanation for the absence of lock-in was not conclusive and would require further research, particularly since these observations contradict long-standing and broadly accepted network theories (Day 1994; Granovetter 2005). Turning to network diversity, higher diversity has been associated with increased opportunities for resource exchanges (Jensen et al. 2011c). However, diversity of actors is not necessarily beneficial: Increasing diversity is also associated with potentially opposing views, making leadership necessary (Korhonen et al. 2004) for example to integrate knowledge from heterogeneous actors (Walter and Scholz 2006; Steward et al. 2008). In both the cases, perhaps a network leader or facilitator can counter negative effects of high density and diversity on innovation and collaboration in industrial symbiosis networks (Korhonen et al. 2004; Walter and Scholz 2006; Paquin and Howard-Grenville 2009).
The dynamics of increasing network density and diversity have been associated with increased innovation. During this process, contextual conditions might change as a result of the evolution of industrial symbiosis networks (Paquin and Howard-Grenville 2012). Arguably the emergence of an industrial symbiosis network could promote ‘cultural embeddedness’ i.e. shared norms and trust, such as about waste and resources, or a ‘culture of cooperation’ (Ashton 2008; Doménech and Davies 2011a; Paquin and Howard-Grenville 2012). In other words, the network developments are thought to be leading to changes in the context within which industrial symbiosis develops. However, such change in the institutional context could not be observed in all studies on this subject (e.g., Pakarinen et al. 2010). This suggests that the effects of networks on context need further research. Furthermore, innovation and the emergence of new norms might not be supported by the same network dynamics, which will be further discussed in Section 3.3.

3.2.2.2 Immergent processes: Context-dependency of industrial symbiosis development

While some studies focused predominantly on network development and, in some cases, how these dynamics may have altered the context, others focused more on contextual conditions that supported and/or constrained the development of industrial symbiosis and eco-industrial parks. Industrial symbiosis is generally considered to start in response to changes in the context, such as market and government intervention (Desrochers 2004; Boons 2008). Additionally, a number of contextual conditions have been suggested to benefit the development of industrial symbiosis networks over time, including the presence of a collaborative culture, an industrial community in a geographically confined area, high industrial diversity, increasing resource scarcity, and increasing regulatory pressure (Chertow 2007; Boons et al. 2011; Doménech and Davies 2011a; Jensen et al. 2011c). Hence it is no surprise that industrial ecologists have recommended the analyses of the context within which industrial symbiosis is to be developed (e.g., Costa and Ferrão 2010). It has been suggested that context analyses should predominantly focus on the analyses of technological, institutional, organisational, economic and cognitive aspects (Jacobsen and
Anderberg 2009), showing high resemblance to industrial localisation factors (Renner 1947) and the concept of embeddedness which has been adopted by several researchers within the industrial symbiosis research community (e.g., Boons and Howard-Grenville 2009).

Although the development of industrial symbiosis can be promoted (Park et al. 2008; Paquin and Howard-Grenville 2012), it is evident that directing such developments through planned strategies is not always as successful (Gibbs and Deutz 2005; Sakr et al. 2011). The more successful cases of promoting industrial symbiosis are those that position their strategy between the relevant contextual conditions and bottom-up dynamics (Jacobsen and Anderberg 2009; Gibbs and Deutz 2007). Companies in different regions or industries might perceive different opportunities and constraints for their development, and therefore it is unlikely that all contextual conditions such as laws, resource availability and/or labour availability affect each industry equally (Hoffman 2003). For example, increasing energy costs might impact sooner on energy intensive industries relative to industries with limited energy usage.

In sum, the idea that contextual conditions influence the development of industrial symbiosis networks is well-established and important contextual factors have been identified. Furthermore, a rough idea has emerged about combining contextual processes with bottom-up dynamics. For both of these processes, the qualitative understanding about how, i.e. through which steps, context and networks might be mutually affecting and changing each other needs further research. Therefore the connection between context and network will be further discussed in Section 3.4.

To conclude Section 3.2, it could be said that evolution of industrial symbiosis networks is still a relatively new subject that needs considerable theoretical and empirical work. This article will first revisit two network theories, that have provided a foundation for many network studies, and integrate them into industrial life cycles of exploration and exploitation. The qualitative linkages between network and context will be further explored with systems of innovation literature. All sections build up towards a more dynamic
understanding of network evolution which will be completed with a discussion of related and unrelated variety, functional and redundant diversity, and complex adaptive cycles.

3.3 Network development over time

3.3.1 Network theories

Before discussing later work on network analysis, innovation and changes in contextual conditions, this section introduces and assimilates network theories that have been broadly used in academic research (Granovetter 1973; Coleman 1988; Burt 1992). Converse to suggestions in some industrial symbiosis literature (e.g., Doménech and Davies 2011b; Paquin and Howard-Grenville 2012), this section will outline the idea that innovation and the emergence of norms might not be possible under the same network conditions by revisiting two basic network theories.

The structural hole theory (Burt 1992) suggests that access to knowledge is a source of competitive advantage. By strategically positioning themselves in social networks, companies can optimise competitive advantages by ensuring timely access to information through direct and indirect contacts (also see Figure 5.1 in Chapter 5). Burt argues that companies should reduce redundancy in the information that can be accessed through their contacts. The idealised network structure would be open with predominantly dyadic ties, associated with lower network density, although ties within the network can be strong.

The network closure theory (Coleman 1988) focuses on the emergence and persistence of social norms. Social norms would theoretically be better facilitated in closed rather than open social networks such as suggested in the structural hole theory. Arguably, norms can only emerge and persist in dense social networks with predominantly strong triadic ties, and this means that network actors should have ‘redundant’ contacts, because theoretically it would be impossible to collectively sanction and reward behaviour in networks with predominantly dyadic ties.
The structural hole theory and network closure theory have long been presented as opposing theories. However, since the former is about information transfer and the latter about emergence and persistence of social norms, it could be said that the theories might not be that opposing because they are discussing different subjects. In fact, these theories also discuss entirely different processes: While the structural hole theory is about information transfer to enable innovation, i.e. changing practices, the network closure theory is about anchoring practices in social norms, i.e. preventing change to practices. This idea is also reflected by other network analysts: Compared to network actors in open social networks, actors in closed social networks may be more constrained to change their practices and less likely to implement innovations (Granovetter 2005; Day 1994). With this in mind, it is possible to start developing a more dynamic understanding of consecutive periods of change and preservation in which networks with more closed and more open structures develop respectively (Figure 3.4). Indeed, such understanding also started to develop in exploration and exploitation literature which will be introduced in the next section.

![Figure 3.4: Combining the structural hole and network closure theories suggests that norms emerge and persist within closed network structures (left) and innovativeness is better supported in more open networks (right), which implies that the emergence of norms and increased innovativeness could not occur simultaneously (Coleman 1988; Burt 1992).](image-url)
3.3.2 Exploration and exploitation dynamics

Exploration and exploitation dynamics suggest that industries and companies go through phases of radically changing practices followed by phases in which practices are continued although perhaps with some incremental changes (Levinthal and March 1981; March 1991). This theory offers the opportunity to integrate the structural hole and network closure theory into a dynamic view on industries and companies. If this theory is correct, it would be expected that networks during exploration have increasing density and diversity as new practices are investigated and implemented, before stabilising and moving into exploitation as new practices become the norm (network closure); and during exploitation diversity and density start to decrease again to optimise efficiencies (structural hole) before stabilising and eventually moving back into exploration (Figure 3.5) (Coleman 1988; Burt 1992; Nooteboom and Gilsing 2004). This dynamic perspective could perhaps also help explaining why some industrial ecologists did observe changes in collaborative culture during the evolution of industrial symbiosis networks (e.g., Ashton 2009) while others could neither confirm this development nor did collaborative culture contribute to the development of resource synergies (e.g., Pakarinen et al. 2010).

The consideration of exploration-exploitation dynamics raises questions about the evolution of industrial symbiosis. This theory suggests that the self-reinforcing cycle of emerging norms and increased innovativeness in industrial symbiosis networks (Section 3.1) would perhaps not be possible. To explore this issue further, it would be necessary to start developing understanding about the variation in innovation intensities of resource synergies, the changing network characteristics in the period that companies are adopting resource synergies, diversity (Jensen et al. 2011c) and proximity (Velenturf and Jensen 2016; Chapter 2) between companies and the effects on e.g. the persistence of resource partnerships (see e.g., Paquin et al. 2014), the presence and absence of emerging norms, and so on. It also raises the implicit question whether innovative industrial symbiosis is different from other types of innovation. Although this section raised many ideas about the emergent process of network evolution, it did not clarify how exactly the context might trigger innovation processes and hence this will be further explored in the next section.
Chapter 3

3.4 Systems of innovation: Linking context to networks

Industrial ecologists have argued that exogenous influences, such as policies and market developments, can instigate or inhibit the start of the development of industrial symbiosis networks (Chertow 2000; Desrochers 2004; Mirata 2004; Baas 2008; Costa and Ferrão 2010; Costa et al. 2010; Jacobsen and Anderberg 2009; Jensen et al. 2011b). However, as argued in Section 3.2, the exact mechanisms through which macro-factors influence these inter-organisational network dynamics, in other words the qualitative understanding of the effects of macro-factors, merit further research.
3.4.1 Context dependency

To explore the interaction between context and networks, this section turns to systems of innovation literature (Freeman 1987; Lundvall 1992; Cooke et al. 1997). According to the systems of innovations approach, innovation depends on networks that are well-embedded within contextual conditions (Tödtling and Trippl 2005; Asheim et al. 2011b): Innovation and learning during exploration and exploitation requires continuous interaction for knowledge exchange between actors across public and private sectors (Nonaka and Takeuchi 1995; Lundvall and Borras 1998; Chaminade and Edquist 2005). Systems of innovation are composed of organisations, i.e. the actors and their relations, and institutions, i.e. the rules that guide the actors’ relations and interactions (Edquist 2005; North 1990). Formal institutions such as laws and informal institutions such as practices, norms and routines can both promote and constrain learning and innovation (Klein Woolthuis et al. 2005). Institutions shape innovation opportunities and competencies of companies (Smith 2000), while institutions such as policies evolve through interactions between organisations in the innovation system (Flanagan et al. 2011). Key to learning and innovation is the development of networks, both with regards to bringing the right actors and relations in place as well as ensuring that the network functions as intended (Lundvall et al. 2002; Tödtling and Trippl 2005; Chaminade and Edquist 2005).

Similar to industrial symbiosis literature, systems of innovation literature suggests that measures that need to be taken to promote innovation are context-dependent. For example, policies for innovation need to be tailor-made to regional characteristics because innovation potential and the types of innovation activities that are needed differ per region (Tödtling and Trippl 2005; Asheim et al. 2011a): Every region has specific strengths and weaknesses regarding industrial composition and related variety, knowledge bases and capacity to generate/ exchange knowledge, opportunities and barriers to innovation, intra- and inter-regional relations, and formal and informal institutions. In particular, it has been found that policy instruments have to fit to the needs of the companies, and that coordination between national and regional authorities can be a barrier to innovation (Tödtling and Trippl 2005). Policy instruments that are evidently effective in one region, may
not have the same effect in other regions (Fromhold-Eisebith and Eisebith 2005). It would be better if policy interventions were a bespoke combination of top-down measures that are tuned to bottom-up processes within the region (Asheim et al. 2011a).

Some empirical evidence can also be found within industrial symbiosis literature regarding the necessity to match top-down interventions to bottom-up characteristics and processes. Shi et al. (2012) identified six models to promote industrial symbiosis through varying degrees of government intervention, from completely planned to self-organised approaches. Top-down planned approaches have had varying success in different countries, for example more coordinated top-down approaches to develop eco-industrial parks were not successful in the USA whereas successes have been observed in China (Gibbs and Deutz 2005, 2007; Shi et al. 2010). Although eco-industrial developments in China have been strongly led by governmental organisations, bottom-up processes were important too (Mathews and Tan 2011; Velenturf and Jensen 2016; Chapter 2). In the UK, bottom-up approaches played a much bigger role within the National Industrial Symbiosis Programme (Laybourn and Morrissey 2009; Paquin and Howard-Grenville 2012). In other cases, such as Kalundborg, industrial symbiosis networks evolved mostly in a self-organised or spontaneous manner, although an ‘encouraging’ legislative context i.e. the absence of legal barriers was an important contributor to the network’s evolution (Ehrenfeld and Gertler 1997; Christensen 2012). Based on these observations it could perhaps be argued that the approach to promote industrial symbiosis needs to fit to the place where it is to be developed (also see Wang et al. 2015), such as indeed suggested by the systems of innovations literature.

3.4.2 Iterative feedbacks between context and agents

Costa and Ferrão (2010) suggested a series of successive interventions to ensure that the context and development of industrial symbiosis fit to each other. This “middle-out approach” suggests shaping the context for industrial symbiosis by outlining a framework within which synergies can develop, and leaving enough flexibility for companies to differentiate and improve suggested practices. Through monitoring of the context and the
development of industrial symbiosis, feedbacks between these two system components could take place and adjustments could be made as industrial symbiosis evolves. Various actors can influence the context, including government and industry. This idea, of iterative positive feedback loops between actors who are taking turns in changing the context within which innovations take place, shows much resemblance with Flanagan et al.’s (2010) perspective on systems of innovation.

Flanagan et al critiqued systems of innovation literature because it downplayed the role of agency too much (Flanagan et al. 2010, 2011). First, the implementation of policy interventions can have significant effects on the outcomes and not enough understanding was being generated about that (also see, Barrett 2004). Second, systems of innovation literature assumed too often that actors have only one role while in reality actors can have multiple complementary and/or contradictory roles. Linked to that, it is often assumed that one (group of) actors develops and implements policy while other actors are passive in the governance process. Instead, it could be derived from this work that interventions for innovation might go through iterative successive stages in which policies influence industry actors who as a result change practices, i.e. innovate, and consequently change the industrial context. In turn, the industrial context influences policy-makers who adapt interventions and change the policy context within which industries are operating. In this perspective, industrial and policy actors are providing each other with changing contexts and the overall innovation system continues to evolve (Figure 3.6).

A further parallel could be drawn, going back to North (1990) who argued that institutions do indeed evolve through positive feedbacks, as technologies do, and bringing this together it could be argued that there could be positive feedbacks between co-evolving technologies and institutions (Foxon 2011) such as also implied by Costa and Ferrão (2010) and Flanagan et al. (2010).
3.4.3 Active engagement in governance

In line with the previous paragraph, Andrews (2000) argued that not only public actors should take on an active role promoting environmental behaviour, but also companies need to participate in the network through political and social forums to discuss institutions guiding companies’ behaviour. Similarly, changing perceptions and norms regarding waste in public and private organisations requires significant effort and interaction between the actors involved in a waste stream (Bulkeley et al. 2007; Bulkeley and Askins 2009). Although the governance actions that are required may vary between regions, industrial ecologists have suggested some general ideas about the role of governments within the local context (e.g., Bulkeley et al. 2007; Bulkeley and Askins 2009; Laybourn and Morrissey 2009; Paquin and Howard-Grenville 2012).
While some authors recommend that governments only provide a supportive policy and regulatory context for collaboration on and sharing of industrial ecology principles (Hoffman et al. 2014), others recommend a more active role. Governmental organisations could build on existing company- and public-private networks to promote further adoption of specific synergies within the network (Paquin and Howard-Grenville 2012); Coordinate the development of new relations to create more resource synergies and circular industrial systems and promote knowledge exchange (Zilahy and Milton 2008; Kincaid and Overcash 2001; Lehtoranta et al. 2011; Costa and Ferrão 2010); Advice on benefits of industrial symbiosis and remove regulatory barriers (Desrochers 2004), or only remove regulatory barriers for companies that are working in an environmental responsible manner but continue strict regulation for less responsible actors (Elliott 1997). Nevertheless, practical policy instruments for industrial symbiosis are still underdeveloped in Europe (Lehtoranta et al. 2011).

There is a need to develop a better understanding of the smaller steps that should be taken at lower governance levels, and to develop the associated measures such as regulation, economic instruments, and knowledge development (Koskela et al. 2013). Arguably, waste management policy in the EU does support industrial symbiosis theoretically, however, has not been translated into complementary regulation (Deutz and Frostick 2009). Clearly regulation has been recognised as an important driver and barrier for industrial symbiosis, but arguably it needs to be translated into tangible operational targets in conjunction with a broader complementary framework of supporting policies and social norms (Park et al. 2008; Deutz and Frostick 2009). A balance needs to be found between specific enough frameworks to support industrial symbiosis, and a regulatory framework that is not too unpredictable, prescriptive and inflexible to the extent that it could constrain innovative potential in the uptake of resource synergies (Johnstone and Hascic 2009; Park 2014; Costa and Ferrão 2010).

Summarising this section, it has been argued that a balance needs to be struck between providing top-down interventions and giving space to bottom-up processes. Successive
iterative feedbacks between actors involved in the development of industrial symbiosis within networks within a geographic area would contribute to the creation of such ‘dynamic fit’ between co-evolving governance frameworks and industrial actions and innovations. The next section will delve further into the ways in which the industrial systems context could evolve during the on-going adoption of industrial symbiosis practices.

3.5 Changing the industrial system context

This section focuses on the effects of the industrial composition on the uptake of individual resource synergies by companies and, conversely, the effects of these individual resource synergies on the industrial composition within any given area. One pertinent tension within industrial symbiosis literature is the risk of lock-in and reduced adaptive capacity associated with dense networks (Granovetter 2005; Walter and Scholz 2006; Doménech and Davies 2011b), and the urgent need for radical system wide changes in the transition towards industries that are using more renewable materials and energy in an increasingly resource efficient manner (OECD 2009; Laybourn and Morrissey 2009; UNEP 2011; EC 2011a, 2011b). In other words, the evolution of industrial symbiosis might lead to increased stability within industrial systems and as a result constrain radical system changes. This section explores this issue further by linking ideas about related and unrelated variety, functional and redundant diversity, and complex adaptive cycles.

3.5.1 Related and unrelated variety

Related and unrelated variety is about the technological relatedness of sectors (Asheim et al. 2011a). Building on Jacobs (1969) idea that knowledge spillovers could occur between all sectors in a region, Frenken et al. (2007) suggested that spillovers are more likely between technologically related sectors than unrelated sectors. This ties into the idea that learning and innovation requires some cognitive differences between actors, because too much similarity would prevent the need for spillovers, but not too much, as that could constrain interactions and no spillovers would take place (Nooeboom 2000; Nooteboom and Gilsing 2004). Arguably a regional economy would benefit from a varied but related industrial
composition, because that would benefit learning and innovation and thus also economic
growth (Frenken et al. 2007). Moreover, such varied economy would be less sensitive to
external shocks, i.e. diversification of the regional economy would also function as a risk
management strategy (Attaran 1986). But if regions specialise in technologically related
sectors, then how do new sectors emerge? How do sectors that fulfil a similar function i.e.
redundant diversity, contribute to the development of new sectors that fulfil a different
function i.e. functional diversity?

Neffke et al. (2011) observed how technologically related industries were more likely to
enter a region than unrelated industries. Furthermore, Boschma and Frenken (2011) suggest
that related sectors branch into new sectors through for example spin-offs, company
diversification, labour mobility and networking. Within industrial symbiosis literature there
is some evidence that companies do indeed prefer to develop resource synergies with
partners that are already within their network and these synergies are also more durable
(Paquin et al. 2014). However, there is clear evidence that the number of synergies
developing in an area positively correlates with industrial diversity in terms of processes,
companies, organisations and sectors (Mayer 2008; Jensen et al. 2011c), and hence diversity
has been considered to be a pre-condition for industrial symbiosis (Chertow 2000; Baldwin
et al. 2004). This tension resembles the argumentation that has led to the idea of ‘related
variety’. This concept could perhaps explain the apparent opposing views on the role of
diversity in industrial symbiosis. It could be that industrial symbiosis is indeed more likely
and more durable between related but different enough companies, which then become
more closely related as they collaborate. In this way, companies extend the number of
companies within their ‘related variety sphere’ because relative distances (Velenturf and
Jensen 2016; Chapter 2) to their resource partner’s contacts also decrease. Perhaps those
previously unrelated companies are now related enough and further resource synergies
could develop (Figure 3.7). Naturally, this rather vague idea needs to be elaborated through
considerable theoretical and empirical research.
Figure 3.7: Companies might develop new resource synergies with companies that are related but different enough (t=1), which then reduces relative distances to their new resource partners’ relations, bringing new companies within their related variety sphere with whom they could then develop further resource synergies (t=2).

3.5.2 Functional and redundant diversity

Although the idea of related and unrelated diversity provides a useful framework for understanding the development of industrial composition, it seems to contradict the idea that companies explore completely new activities, i.e. activities that they never did before (as discussed in Section 3.3). However, perhaps related variety could be re-framed as complementary variety, i.e. activities, technologies, companies and/or sectors that are complementary to their existing activities. For example, waste processing companies might, in addition to landfilling activities, engage in energy-from-waste activities which would be an exploratory yet complementary innovation for them. In terms of redundant and functional diversity, the waste processing company attracted another function as they now not only deal with waste but also provide energy within the industrial system.

Extending this idea into resilience and complex adaptive systems literature (e.g., Gunderson and Holling 2002; Chapin et al. 2009), broadening functional diversity within a geographic area could contribute to the evolution of the whole industrial system into a new cycle of industrial development. Redundant diversity on the other hand, i.e. companies fulfilling the same or similar functions within an industrial system, could help maintaining system stability when external shocks disturb the system. For example, when a region has several
companies generating energy from different types of waste, then the industrial system would be less sensitive to disturbances in availability of one waste resource.

### 3.5.3 Complex adaptive cycles

Complex adaptive cycles, or ‘panarchy’, provide a useful framework to understand the differences between long-term resilience and shorter-term stability. Panarchy describes how systems evolve through consecutive stages of growth, conservation, release and reorganisation (Gunderson and Holling 2002), in which growth and conservation resemble the exploitation phase and release and reorganisation the exploration phase (Figure 3.8).

![Diagram of Complex Adaptive Cycles](image)

**Figure 3.8:** Exploration and exploitation dynamics, complex adaptive cycles, and functional and redundant diversity seem to be overlapping ideas, suggesting similar consecutive stages in which exploration of new activities is associated with release of resources and prioritising system persistence, followed by exploitation of existing activities while resources accumulate and prioritising system stability (Gunderson and Holling 2002; Nooteboom and Gilsing 2004; Jensen et al. 2011c).

During the growth and conservation stages, the system becomes more productive and accumulates resources. Such resources not only include physical resources but also human and social capacity such as skills and networks. This accumulation of resources leads to lock-in, and when a disaster occurs the system cannot adapt and hence it evolves into the
release stage. Note how this is different from exploration-exploitation dynamics, which suggests that networks open up during the exploitation phase, enabling a more gradual and less revolutionary move into the exploration phase.

During the release and reorganisation stages, maintaining diversity and creating opportunity and inventions are more important. During the release phase a process of creative destruction occurs (for further explanation on this process see, Schumpeter 1934; Abernathy and Clark 1985), and the lowered connectivity between the elements of the system enable “novel re-assortments of elements that previously were tightly connected” (Gunderson and Holling 2002:p40). This is similar to the start of the exploration phase, when network density is low, decreasing the persistence of social norms and with increasing network diversity the opportunities for change emerge. The panarchy idea suggests, however, that diversity in potential future development paths already starts to develop during the conservation stage, as the system might experience small disasters that trigger the need to develop alternative ideas, but the disasters are not large enough to trigger the start of a release stage.

Finally, it is notable that the stages of system stability (growth and conservation) are associated with efficiency of function, similar to exploitation, while the stages of system persistence (release and reorganisation) are associated with existence of function, similar to exploration.

This section has strengthened the idea that there are different types of diversity within systems that could play different roles depending on the development stage of the system. Although diversity is subject of on-going discussion in industrial symbiosis (e.g., Korhonen 2001; Walter and Scholz 2006; Nielsen 2007; Mayer 2008; Ashton 2009; Jensen et al. 2011c; Paquin et al. 2014), the relations between diversity, stability and resilience need further empirical research (Mayer 2008; Jensen et al. 2011c; Paquin et al. 2014).
3.6 Further research directions for industrial symbiosis

This article has presented a theoretical exploration of various bodies of literature. The evolution of industrial symbiosis networks, and eco-industrial parks, can be understood as mutually affecting processes within the network and in its context. The dynamics within network and context need further research. Particularly the qualitative linkages between network and context have remained underexplored so far. Converse to findings in the industrial symbiosis community, Section 3.3 showed how open networks might better support innovation whilst closed networks might better support the emergence and persistence of norms. Positioning these network theories in an industrial life cycle perspective, it was suggested that industrial symbiosis networks might go through cycles of varying network density and diversity. Depending on the characteristics of the industries and their networks, the influence of contextual conditions might also vary. Successive iterative feedback loops between network and context might contribute to the creation of a ‘dynamic fit’ between co-evolving context and industries and networks. Finally, industrial systems might go through phases of maintained stability, supported by redundant diversity of industries performing similar functions within the industrial network, and phases of change when systems need to recover from radical changes or ‘disasters’, supported by functional diversity of industries performing different, although arguably related or complementary, functions within the industrial network. These ideas could be summarised into a new broadened dynamic perspective on the evolution of industrial symbiosis networks (Figure 3.9).
Figure 3.9: Bringing together all ideas explored in this chapter, a dynamic system perspective on the evolution of industrial symbiosis networks could be suggested. NB Note how resources build up during exploitation (grey arrows) and resources are released during exploration (black arrows).

To conclude, the analyses of industrial symbiosis literature on evolution and critical reflections with other bodies of literature revealed the following areas for further research:

- How (through which mechanisms, steps, and activities) do contextual factors influence the development of industrial symbiosis networks?
- How and why relations within industrial symbiosis networks develop (also see, Velenturf and Jensen 2016; Chapter 2).
- How (through which mechanisms, steps, and activities) does network evolution drive changes in contextual factors?
- Are there any particular network structures and characteristics associated with innovative industrial symbiosis and the emergence of new norms? To what extent and at what moments in the evolution of industrial symbiosis are they the same?
What are the effects of industrial symbiosis on the adaptive capacity of industrial systems? How complementary, to the companies or (regional) economy, are the resource innovations that are adopted? How, if at all, do new sectors emerge as a result of the evolution of industrial symbiosis?

In sum, there is a need to develop a more dynamic understanding of immergent processes that are driving, and emergent processes driven by, industrial symbiosis in order to identify potential leverage points to steer industrial systems towards the benefits associated with industrial symbiosis such as improved resource efficiency, reduced carbon emissions and continued business development.
PART B

METHODOLOGY

Chapter 4: Methodology
Methodology

This chapter links the research gaps, aims and questions to the methodology developed for this project. The results articles in Part C of this thesis will also provide concise overviews of the methods that are discussed in this chapter. Some repetition was unavoidable given that the results are presented in the form of completed articles, although they could not cover as much detail as this methods chapter. Finally, the writing style of this chapter is different, presenting a more personal and reflexive perspective compared to the other parts of this thesis.
Chapter 4: Methodology

This chapter will first present the general methodological approach and study area, followed by the details of two research projects that were carried out in this PhD.

4.1 General research approach

4.1.1 Summarising the research gaps

The introductory section revealed two broad research gaps within the industrial symbiosis literature:

1. Understanding how and why social networks developed between resource partners, i.e. waste producers and users, and other organisations.
2. Understanding how top-down and bottom-up processes interact and might contribute to the evolution of industrial symbiosis.

Both research gaps are qualitative in nature and are caused by limited empirical and open observation of industrial symbiosis innovations with a detailed exploration of the context within which the innovations are realised. As argued in Chapter 2 (Velenturf and Jensen 2016), the simple but obvious question How and why did industrial symbiosis develop? is yet to be fully answered. Furthermore, it is evident from the literature that the market and governmental contexts are influencing industrial symbiosis. However, as argued in Chapter 3, exactly how, i.e. through which steps, these contexts influence industrial symbiosis, the emergent processes, and also how industrial symbiosis might drive changes in the institutional context, the emergent processes, needs considerable further research.

It is important to note that I did not arrive at the above research focus through the exploration of academic literature alone. I went through a period of identifying mutually interesting and legitimate research aims that were not only likely to contribute to academic knowledge, but also to: 1) The joined research aims within the Evolution and Resilience of Industrial Ecosystems project within which I carried out my PhD; 2) The interests of our stakeholders and potential research participants in the Humber region which was related to likelihood of data access, and; 3) My own interests and belief that academic research needs to make tangible contributions to the progress of our society. Hence it is fair to say that my...
research focus and aims were established through a participatory process, ethically framed and thoroughly grounded in the relevant academic and practical backgrounds (Mason 2002). The described process also resembles the problem-driven, ‘praxeological’ approach, such as adopted in much transdisciplinary research on sustainability issues (Lang et al. 2012).

Ultimately this process resulted in the combined aim to contribute both to the academic understanding of industrial symbiosis and to practical knowledge on the promotion of these resource innovations, by exploring the following research questions:

*How and why did industrial symbiosis, interpreted as biowaste-to-resource innovation, develop over time?*

a) How and why did collaborations between resource partners develop during biowaste-to-resource innovations?

b) How did the governance of, and policy and regulation implemented by, regional governmental and associated organisations influence biowaste-to-resource innovation?

c) How did top-down processes, such as developments in markets and governance, and bottom-up processes, such as network development during biowaste-to-resource innovation, mutually influence each other over time?

In the remainder of this chapter I will explain how the research questions above were linked to the general and specific methods used in this PhD, and how these methods contributed to answering the research questions.

### 4.1.2 Qualitative, exploratory and empirical research approach

The research gaps, purpose, aims and questions discussed in Part A of this thesis and summarised in the preceding paragraph clearly highlighted the need for qualitative, exploratory and empirical research on the subject of industrial symbiosis. During the process of critically reviewing the relevant literature, the original intention for this project to adopt a quantitative modelling approach had to change significantly. As demonstrated in Part I of this thesis, I felt insufficient evidence and understanding was available to support and justify
quantitative modelling. Hence the research approach transitioned towards a strictly qualitative approach instead.

The transitioning from quantitative modelling to a qualitative approach resulted in a pragmatic combination of deductive and inductive processes. The literature already identified factors and processes that were either very likely or even evidently important for industrial symbiosis. It would not be sensible or even possible to disregard these findings and not take them on board as part of the research design. Hence they were included, as suggested in Chapter 2 (Velenturf and Jensen 2016) and to be elaborated in Section 4.3 and 4.4, and in that sense this study has been partly deductive in nature. However, it was also evident that research had perhaps been too focused on a limited number of factors and processes and hence there was a need for open exploration of industrial symbiosis, and in that sense this study has indeed been predominantly inductive in nature.

Since the research process was mostly inductive, the research design had to be flexible and developed in an organic manner as the research progressed (Mason 2002). Given that inductive research produces new ideas and insights, which some academics would refer to as generating hypotheses or new theory even (Bryman 2012), it was not possible to design a rigid methodology and stick to it throughout the research project. Instead I developed a complete methodology at the start of my study and used it as a ‘living’ document that was shaped and reshaped as my research progressed (Mason 2002). The methods had to be flexible in order to allow adapting them through the on-going data collection, analysis, and comparison to emerging knowledge and existing literature and the research aims and questions, much like the process of theoretical sampling (Glaser and Strauss 2004).

Although the methods were flexible, they were rigorous and systematic nevertheless and efforts were made to maintain trustworthiness throughout the research project, according to the four criteria of credibility, transferability, dependability, and confirmability which Lincoln and Guba suggest indicate the quality of qualitative research (Lincoln and Guba 1985; Guba and Lincoln 1994).
Credibility is about ensuring that the results had truth value for the research participants (Lincoln and Guba 1985; Seale 1999) and this was established in various ways, such as discussing the results with participants and sharing written research outcomes. While I highly respected the participants’ responses to my research outcomes, reinvestigated any issues that they brought forward, and in that sense considered them as expert advisors, I was aware that they could not have a full understanding of my research project and hence should not be engaged as experts regarding my research process (Bryman 2012).

Transferability is about the likelihood that research results might apply to other contexts (Lincoln and Guba 1985; Payne and Williams 2005). This has been operationalised in different ways, first through a multiple case study design (to be discussed in section 4.3) and second through rich descriptions of the Humber context which enables readers to assess whether and how the results might apply elsewhere (to be discussed in section 4.4).

Dependability is about keeping records of the research stages which would allow colleagues to audit whether developed theory was justified (Lincoln and Guba 1985; Seale 1999). During my research I kept track of the changes in my methods through ‘writing-to-think documents’, memos, and notes. I discussed my on-going research with my supervisors and colleagues and received feedback on my thinking and the potential gaps in the research design and results. I have only received partial ‘audits’ but technically I could accommodate a complete review of the research process.

Finally, confirmability is about acting in ‘good faith’ and being aware that complete objectivity is unlikely whilst not letting my own views dominate the research process (Lincoln and Guba 1985; Bryman 2012). As Seale (1999:p470) put it: “Knowledge is always mediated by pre-existing ideas and values, whether this is acknowledged by researchers or not.” While I think it is incredibly challenging to ensure confirmability, I have strived to represent multiple perspectives throughout the data collections and analysis, known as multi-vocal argumentation because I believe that this adds to objectivity, or at least to the range of ‘truths’ presented (Mason 2002).
The argumentation style has been a mixture of mostly evidential (showing the relevant evidence), interpretive (ensuring that the arguments are meaningful and reasonable) and multi-vocal argumentation style. Furthermore, the kinds of arguments that were made were also logically linked to the research questions (Mason 2002). The research questions were predominantly developmental and mechanic in character, meaning that I expected to be able to provide a meaningful analysis of the process through which industrial symbiosis developed as well as an understanding of the ways in which the social process operated and/or what it looked like. The mechanical argument relies on the identification of associations rather than causal relations. I did hope to be able to develop causal arguments, as indicated by the usage of words like ‘influence’, because of the need for predictive knowledge to inform pro-active strategies for industrial symbiosis. However, realistically, causality can be difficult to prove and hence I focused on arguments that were more mechanical in nature.

To develop the arguments that I strived for, I carried out two subprojects to collect and analyse data. First, to understand how and why collaborations developed between resource partners (research question a), I carried out five case studies in the Humber region to analyse how companies were actually identifying and realising these resource innovations in collaboration with others (section 4.3). Second, to understand how the regional governance system might influence the biowaste-to-resource innovation processes (research question b), I interviewed governmental and associated organisations (section 4.4). Both subprojects provided rich data that not only enabled to answer research question a and b, but also research questions c about the immergent and emergent processes. Finally, by answering these three research questions, I could answer the main research question about the ways in which biowaste-to-resource innovation evolved within its dynamic context. Throughout the two subprojects and the formulating of arguments to answer the research questions, understanding how networks developed and how they might be driven by/ driving contextual changes was crucial. Therefore, social network analysis will be introduced next, before discussing the case study region and the two subprojects for data collection and analysis.
4.1.3 Social Network Analysis

Social Network Analysis (SNA) was considered inherently important within the research design. Besides the well-established assertion that social networks are likely to be important in innovation processes (Butts 2009; Borgatti et al. 2009; Friemel 2011; Nooteboom and Gilsing 2004; Scott 2000), it is also clear that industrial symbiosis always requires network development since it can be defined as the development of working agreements between industrial and other organisations that, through the innovative reuse, recycling or sharing of resources, lead to resource efficiency (Jensen et al. 2011a). Industrial symbiosis can involve governmental organisations at national, regional and local level as well as universities and other research institutes (Park et al. 2008; Laybourn and Morrissey 2009). In sum, industrial symbiosis involves the development of social relations and this can be studied with SNA (Scott 2000; Borgatti et al. 2009).

SNA is an interdisciplinary research methodology to study social structures (Scott 1988, 2000). While it can be used to study the dynamics of social structures as a whole, it can also be used to study dynamics within the connections that the social structures are composed of (Borgatti et al. 2009). SNA can be applied in a quantitative and qualitative manner (Wasserman and Faust 1994; Hollstein 2011). In the last decades a shift has occurred from SNA studies that are consequence-focused, i.e. explaining what happened in the past, to more drivers-focused, i.e. understanding how connections are formed to predict how social structures might develop in the future (Borgatti and Foster 2003; Borgatti et al. 2009), making SNA relevant to my research purpose to contribute to pro-active strategies for the development of sustainable industrial systems.

SNA also provides a practical way into distinguishing emergent processes, driven by interactions within networks that eventually may lead to changes in contextual conditions (research question a and c), and immergent processes, driven by changes in the context which may lead to changes in social networks (research question b and c). Network analysts have recognised that the behaviour of network actors may change due to transmission and adaptation (Borgatti et al. 2009), i.e. change caused by flows between organisations and by
shifts in the environment, which gives some tangible idea about how network and context might be connected, adding further relevance of SNA to be used in this research project.

SNA has been rooted in qualitative approaches since it emerged in the 1930s (Scott 1988; Hollstein 2011). Combining SNA and qualitative approaches can be a particularly powerful way to: i) explore networks about which little is known yet, ii) to explore network actions i.e. what actors actually do, also in conjunction with their context, iii) network orientations and assessments i.e. perceptions of relations, iv) network effects i.e. network strategies and their outcomes, v) network emergence and development over time and space, and vi) to validate network data i.e. to support the interpretation of quantitative data (Hollstein 2011). All of these purposes, except purpose vi, are highly relevant to my research questions.

4.2 The Humber region

The Humber region is located in the northeast of England and hosts one of the busiest port complexes in Europe. It is a mature and diverse industrial area hosting a strong agricultural sector and high concentrations of food processing, chemicals, metals, construction, fuel and power production facilities (Jensen et al. 2011c; Penn et al. 2014; NOMIS 2015). The area is of strategic importance for the UK’s energy supply: Nationally it is landing ca. 20% of gas, refining ca. 33% of oil and generating almost 20% of power (Penn et al. 2014; Humber Local Enterprise Partnership 2014). Consequently, the wider Yorkshire and Humber region is responsible for 27% of the total UK’s CO₂ emissions (Yorkshire and the Humber Regional Committee 2010) and hence can play a strategic role in achieving the national carbon reduction targets (Government 2009). Besides the expanding offshore wind sector, the Humber region contributes to the national low carbon strategy through bio-based developments in the energy sector (Humber Local Enterprise Partnership 2014) and has been identified as an area with high opportunity for bio-based chemicals (UKTI 2009).

The Humber region is a known case study in the literature on industrial symbiosis and resource efficiency (e.g., Mirata 2004; Laybourn and Morrissey 2009; Jensen et al. 2011a; Wang 2013). Considerable expertise in waste-to-resource innovations developed in the Humber region over the past 15 years as it has been engaged in efforts to promote
industrial symbiosis such as through the National Industrial Symbiosis Programme (Mirata 2004; Bailey et al. 2008; Penn et al. 2014; Massard et al. 2014; Jensen et al. 2012). In recent years various low carbon innovations have been adopted in this region (e.g., Laybourn and Morrissey 2009; Bondholders 2014). The evident public and private motivation to adopt waste-to-resource innovations in the bioenergy sector made this region suitable to both research and contribute to the progress of industrial symbiosis.

4.3 Case studies into biowaste-to-resource innovation processes

A multiple case study design was adopted to answer research question a and parts of research question c:

a. How and why did collaborations between resource partners develop during biowaste-to-resource innovations?

b. How and why did collaborations between resource partners develop during biowaste-to-resource innovations?

c. How did immergent processes, such as developments in markets and governance, and emergent processes, such as network development during biowaste-to-resource innovation, mutually influence each other over time?

A multiple case study design was adopted because it is a suitable approach to cover the complex qualitative knowledge gaps that were identified, facilitates the integration of inductive and deductive approaches, and supports the process of theory building through consecutive case studies to see if the emerging patterns are replicated in following case studies too (Mason 2002; Yin 2009; Bryman 2012). Each case study detailed one biowaste-to-resource innovation process.

4.3.1 Data collection

4.3.1.1 Exploring case study availability

Prior to the case studies, and while the methodology was developed for the first time, an exploration of potential cases was carried out in order to assess whether and how this study could be feasible in the Humber region. The exploration consisted of:

1) An online search for potential (bio)waste-to-resource innovations

2) Semi-structured telephone interviews with two key stakeholders
3) A questionnaire about (bio)waste-to-resource innovations

4) Follow-up semi-structured interviews with stakeholders to gather further information about specific (bio)waste-to-resource innovations

The exploration resulted in an initial set of (bio)waste-to-resource innovations which provided the confidence that sufficient case studies could be accessed. Moreover, the exploration provided valuable information about the way in which the case studies should be positioned for successful recruitment of participants. Arguably, given the complexity of the research gaps, between 6-8 cases could have been necessary (Yin 2009). Although a sufficient number of potential cases was identified in the exploration, I continued to participate in the regional network to keep track of more potential cases which might be selected in response to the on-going changes in the methods and emerging theory.

4.3.1.2 Purposive/ theoretical sampling of case studies

During the sampling of case studies I strove for selecting cases with strategic relevance to the research questions, also known as purposive sampling, that were also likely to yield new insights for theory development, also known as theoretical sampling (Mason 2002; Bryman 2012). Furthermore, case studies were selected based on the following criteria:

- At least one resource partner was based in the Humber region, whilst I strove to select case studies within the various local authorities within the Humber region.
- Involved the production or usage of a new biowaste and/or new technology for one or both of the resource partners, i.e. it is innovative from the company’s perspective but not necessarily new to the market or region.
- Fit within the focus of the emerging bioenergy sector, which was expected to be a narrow enough focus to provide comparability and coherency in the outcomes whilst being varied in terms of industrial sectors as well as innovation intensity (radical and incremental, further explained in Chapter 5, Velenturf 2016a) and thus to provide insights into transferability of the outcomes across different company contexts.
- Since company size might impact on innovation behaviour, I sought a variety of small, medium and large companies.
- The innovation process took place 2-5 years ago, to ensure on the one hand that innovations were likely to be completed and on the other hand recent enough for participants to remember enough details.

Case studies were identified from the list created during the exploration (as discussed in the previous section) as well as through on-going networking activities. Gaining access to case studies continued to be challenging throughout the field work, mainly due to the commercial sensitivity of the required data (further discussed in the next section) while tangible benefits for the participants, in terms of financial returns, resulting from this research were not immediately obvious. This is also reflected in the time investment of ca. 140 hours in case study recruitment activities (compared to 120 – 220 hours spent on each case). Ultimately, five case studies were carried out which will be introduced in Chapter 5 (Velenturf 2016a). Each case study was based on semi-structured interviews and documents.

### 4.3.1.3 Semi-structured interviews

Semi-structured interviews were carried out with the manager or director who had been most involved in the innovation process within the innovating company that was located in the Humber region. While there is a clear moral grounding for this research project (Chapter 1), the data collection, interpretation and presentation was also carried out in a moral, ethical way (Mason 2002; Oliver 2003).

I spoke with all interviewees before the interview to explain the purpose of the study and answer any questions which they might have. This conversation was followed by an email detailing the study and providing an information sheet explaining the research purpose, deliverables, data requirements, and data usage and confidentiality. All case studies were confidential because of commercial interests of the companies involved, company names, exact locations and resource characteristics were kept out of the case study report and any following articles. The information sheet enabled the interviewees to give informed consent to participate in the study. The interviews took place at the companies’ premises, usually in a meeting room or empty office where the interviewee could speak freely and without being disturbed. Before the interview started, I briefly repeated the information also...
provided in the information sheet, gave interviewees the opportunity to ask questions, and then we signed the consent form which the interviewee already had received in advance. The consent form included statements about recording the interview and the explicit option for interviewees to withdraw at any moment during the study. After the interview, a copy of the transcript was shared with the interviewee, and also at later stages interviewees were engaged in the study to discuss the various outcomes.

The interview questions followed a pattern from open to more structured questions to ensure all relevant subjects were covered while minimising leading interviewees in their answers (Appendix A). This is an innovative interview schedule which was expected to contribute to better data quality as it supported a more natural flexible conversation without having to stick to a rigid order of questioning, although I do not have rigorous evidence to support that claim (also see Appendix C).

The interview focused on one specific biowaste-to-resource innovation and detailed exactly how and why the relation to the resource partner(s) had developed, whilst also collecting information about other actors and developments impacting on the innovation process. The interview questions were designed to explore the role of a number of social factors and processes, whilst remaining open for other potentially important factors and processes.

Directly after the interviews I wrote memos about the interview process, the setting, anything that struck me as important to take on board during the further processing and interpreting of the data.

Originally the case studies were designed to interview both resource partner(s). In practice, however, it appeared challenging to get referrals to partners supplying or using the discussed biowastes. This had much to do with the commercial interests involved and stability of the resource synergies. For example, companies perceived a potential risk that I could share strategically relevant information with the resource partner and hence cause disturbances in the collaboration. I solved this issue by carrying out case studies from the perspective of resource suppliers as well as clients. In that way, both ends of resource synergies were represented in my research.
In some case studies, additional interview data were available because the research participants had been interviewed previously in a related project (Penn et al. 2014; Schiller et al. 2014). These transcripts were used to contextualise the case studies, providing data about general drivers and barriers for (bio)waste-to-resource innovations and about other resource synergies that the companies already had developed.

4.3.1.4 Document collection

To complement the interview data, I collected text-based documents such as sustainability reports, participants and resource partners’ websites, and legislative texts. Arguably, documents are likely to provide a more formal representation of the studied innovation processes and as such provided valuable details. Documents were mainly collected to complement the interview data, for example to understand technical and legislative details.

4.3.1.5 Main subjects in data generation and collection

Qualitative data were collected to improve understanding of factors and processes that may have played a role in the emergence and further development of the networks that eventually led to the realisation of biowaste-to-resource innovations, and to study the functioning of the network in terms of innovativeness and the emergence of new social norms regarding industrial symbiosis and collaboration.

The generating of interview data and documents collection focused on the social factors identified in Chapters 2 (Velenturf and Jensen 2016) and 3 (Table 5.1 and Figure 5.2 in Chapter 5; Velenturf 2016a) whilst staying open to other factors and processes that might also be important. A clear analytical distinction was made between the strength of relations and the absolute and relative proximity of actors (Nooteboom and Gilsing 2004; Boschma 2005), to enable more detailed exploration of the emergence and development of relations between resource partners. Additionally, it was recognised that the role of these factors might vary depending on the industrial life cycle of the innovating company (Nooteboom and Gilsing 2004). Furthermore, information about various contextual factors such as policy and regulation, governance, and markets was collected.
4.3.2 Data preparation, organisation and interpretation

4.3.2.1 Interview transcripts

All interviews were transcribed before further analysis. Spoken communication, the occurrence of pauses in the talking and the occurrence of major disturbances such as someone entering the room were transcribed. The length of pauses, the tone in which interviewees spoke, and other forms of communication such as sighs, moving around on the chair, etc. were not included in the transcript. This was in anticipation of the way in which further analysis would be carried out.

4.3.2.2 Data assessments

Documents tend to be produced by specific people, for a specific purpose and within a specific context (Mason 2002). It is important to be aware of such background information during the data analyses, hence all data were assessed based on four criteria (Scott 1990):

- Authenticity – Is the document original? Who was the author, and when was the document produced? Is it what it purports (means) to be?
- Credibility – Is there any bias? To what extent are the contents distorted? For what reason was the document produced? Why would the author present the document/formulate the writings in this way, given the circumstances? Did the author believe in the contents of the document? Is the document accurate?
- Representativeness – Is the sample of documents theoretically and empirically meaningful?
- Meaning – What do the data literally say? What do I think it says? Meaning was assessed before and during the coding of the data, further explained below.

Using these criteria, I wrote assessments of the data and included them in the further analysis and the relative valuing of the data in comparison to other data available in the case study. This was particularly important when contradictory points were identified during the data analysis, in such occasions I would value the data that received a better assessment more.
4.3.2.3 Data organisation

All data were stored together in one folder. I analysed the strength and weaknesses of the data available for one case study. Were there any subjects that were particularly well represented in this case study? Were there any subjects that were underrepresented in this case study and can I get any additional data? Such assessment was on-going throughout the analysis, in conjunction with the coding and formulating of arguments during the case study. The organisation of data was the first step in making sense of it and starting the interpretation (Mason 2002).

4.3.2.4 Coding

All data were coded in MS Word. I did intend to use the coding and interpretation software NVivo, but I stopped using it because a) it did not give me the overview within the dataset that I wanted and b) it crashed various times while saving thus losing whole projects. Instead of using NVivo, I coded data in MS Word in two steps:

1) “Broad coding”

Broad codes included Network actors, Network relations, Innovation context, Innovation process development, and Innovation process characteristics. I read the data constantly asking myself: Is this fragment about Network actor? Is it about Innovation context? And so on. I read the data literally and interpretively (Mason 2002). Literal coding means that I coded fragments that literally mentioned the conceptual code, unless it was clearly about a different subject i.e. not actually about the conceptual code. This process was supported as I had my on-going interpretation of the conceptual and open codes within vision while I was reading the data. Reading was also interpretive, first because my interviewing strategy had been to ask about factors and processes indirectly, thus reducing the chance that they would be mentioned literally by the interviewee and consequently creating the need to read the data also interpretively i.e. when I thought a fragment was about a particular code/required open coding. Second, reading the data interpretively also increased the chance to
generate a richer understanding of the case at hand (Mason 2002). Codes were placed by selecting text and placing a comment with the code name and any additional thoughts. I coded relatively long text fragments, to capture the text context before and after the fragment to aid further interpretation.

Once the data piece was finished, I would transfer the codes into a “Coding table”. I included the page number for each fragment to easily return to the data piece and check more of the fragment’s textual context when needed. The coding table consisted of five columns: Broad code, Broadly coded data fragments, Refined codes, Refined coded data fragments, Interpretation (Figure 4.1). The coding table also included rows for open codes within each broad code, combining conceptual and open coding (Bryman 2012).

Figure 4.1: Coding table used to code and interpret each data piece individually during the case studies.

2) “Refined coding”: Fragments included in each broad code, which some researchers might have called a “category” (Strauss and Corbin 2004), were then further coded into “refined codes” which were labels for discrete elements within the case study such as specific actors, characteristics of relations, etc. As with the broad coding, data were read both literally and interpretively. During the analysis I constantly asked myself, is this fragment about the focal innovating company? Is it about geographic proximity? And so on. Fragments were copied into the relevant codes before being further analysed and interpreted.
4.3.2.5 Interpretation: Analysing codes and linkages between codes

Having coded all the data fragments into refined codes, I summarised the findings for each code. I also took notes about the role of the code in the innovation process and how it might be linked to other codes. I did this for every individual interview transcript and document. Then I copied the interpretation of each data piece, i.e. the last column of the coding table, into a collective “Interpretation table” for all data in a case study.

The interpretation table had columns with the interpretation of each individual data piece and one column for the overall interpretation of all data pieces together (Figure 4.2). If at that point I felt I did not have enough data about a code, I collected, coded, and interpreted additional documents where possible.

Interpretations were summarised per refined code, when possible I summarised findings per actor or per relation. Then I asked two questions for each code:

i. Why was this code important in the innovation process?

ii. How did this code play a role in relation to other codes?

The answer to both questions could have been, and in some cases was, “not at all, because...”. Nevertheless, for all codes I wrote a complete interpretation. Ultimately this provided a more measured view of the data, seeing more than what was visible when the data were in their unprocessed form; Creating more understanding about each individual code and then analysing the linkages between the codes, leading into a holistic
understanding of the innovation process that was analysed in each case study. This process could also be seen as giving the data “analytical handles” to develop the data and interpretation into arguments (Mason 2002).

The whole process of transcription, data assessment, two-staged coding and copying of fragments, and two-staged interpretation of data pieces meant that I “learned” the data inside out. I had developed a thorough understanding of the data. That learning of the data, together with the written detailed interpretations of each code and the linkages between codes, facilitated the next stage of the analysis.

4.3.2.6 Case study reports

The overall interpretation and my thorough understanding of the case study data was then developed into a holistic understanding through the writing of a case study report. I wrote the case study report according to questions that I felt were relevant to building up to coherent arguments that would ultimately answer research question a. Some questions could be directly answered from the interpretations, while others required more thinking and interpretation (Table 4.1).

The case study report was sent to the research participant. When possible I visited the participant again and explained the main findings of the case study, asked further questions about parts of the report that I was not sure of, and also offered the participant the opportunity to ask questions. These discussion highlighted areas that I needed to revisit for interpretation and added further details to the report, whilst it was also a moment for the participant to reflect on and learn from the way they had carried out the innovation process.

Each case study was concluded with a discussion of similarities and differences to the generalised proximity and exploration-exploitation dynamics (as presented in Chapter 3) and industrial symbiosis (as presented in Chapter 2). I developed explanations through consecutive case studies as proposed by Yin (2009). Rival explanations (p135 Yin, 2009) contribute to understanding by refining or rejecting previous explanations and identifying
parts of the emerging theory that requires further investigation. Based on these comparisons to the ‘theory’ and emerging understanding, it was decided whether to continue carrying out case studies or whether the saturation point was achieved.

Case studies were carried out until the saturation point was reached, i.e. until no significant new understanding was developed with the described case study methodology (Glaser and Strauss 2004; Yin 2009). Saturation was reached after five case studies.

Table 4.1: Building a holistic understanding of the studied innovation processes from the interpretations of individual codes and linkages between codes.

<table>
<thead>
<tr>
<th>Case study report – Sections</th>
<th>Codes from interpretation table</th>
</tr>
</thead>
</table>
| What was the innovation?                                          | • Innovation process \  
• Innovation type (process, product) \  
• Innovation intensity (incremental, radical) |
| When did what happen?                                             | • Order of events                                                                               |
| Who were involved? (Before, during, and after the innovation?)    | List of network actors and their relations, imported into NodeXL to produce network figures     |
| How did the companies (resource partners) get involved?           | • Tie establishment (spontaneous, facilitated, other)                                           |
| Which social factors played a role in the development of the collaboration? (Before, during, and after the innovation?) | Framed in understanding of the order of events, network development and the way in which the resource partners got involved, discussed the social process and factors that played a role as collaboration between resource partners developed and the innovation was realised, including interpretations from codes: \  
• Network actors (actor roles: focal innovating company, industrial symbiosis partner company, and any other actor that played a role in the development of the collaboration) \  
• Organisation age, size and absorptive capacity \  
• Tie strength (scope, duration, frequency, control, trust[trust subject, trust reason], openness, investment in tie, other) \  
• Proximity (Geographical, Social, Cognitive, Organisational, Institutional) \  
• Interaction type (Coordination, Interpretation and development of ideas) \  
• Industrial life cycle (Exploration, Exploitation) \  
• Innovation culture \  
• Other contextual codes where relevant \  
• Innovation driver (other, constraints, markets, policy and regulation) \  
• Overall investment \  
• Knowledge type (tacit, codified) |
| How did the network characteristics impact on the innovation outcomes? (Economic and environmental benefits, changes in industrial symbiosis and collaborative norms) | • Innovation effects \  
• Innovation success (economic, environmental, other) \  
• Change in institutional context (institutionalising industrial symbiosis, collaborative culture, other) |
4.3.2.7 Cross-case comparison and formulating arguments

Building on the comparisons to the generalised ideas for industrial symbiosis and exploration-exploitation dynamics, a comprehensive comparison of the five case studies was carried out. The findings discussed in the case study report were organised into a table according to distinct parts of the mentioned generalised ideas (Table 4.2). Furthermore, during the consecutive case studies the idea had emerged that each company developed relations to their resource partners through similar steps i.e. a social ‘mechanism’ was identified. This social process was also included in the cross-case comparison for further analysis. A number of other similar points emerged from the comparison of the case studies and were included in the analysis.

Table 4.2: Comparison points for the case studies.

<table>
<thead>
<tr>
<th>Theory</th>
<th>IS theory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Network development</td>
<td>is thought to be initiated in response to macro factors such as regulation,</td>
</tr>
<tr>
<td></td>
<td>the network grows denser over time</td>
</tr>
<tr>
<td></td>
<td>and this leads to an increased chance for symbiotic links</td>
</tr>
<tr>
<td></td>
<td>while IS and cooperation become the social norm.</td>
</tr>
<tr>
<td></td>
<td>This process is believed to involve the development of a social network</td>
</tr>
<tr>
<td></td>
<td>with increasing density, strength and</td>
</tr>
<tr>
<td></td>
<td>reciprocity of links,</td>
</tr>
<tr>
<td></td>
<td>and trust between actors.</td>
</tr>
<tr>
<td></td>
<td>The development of such closed dense network is considered beneficial for</td>
</tr>
<tr>
<td></td>
<td>innovation.</td>
</tr>
<tr>
<td>Proximity theory</td>
<td>Exploration</td>
</tr>
<tr>
<td></td>
<td>Exploitation</td>
</tr>
<tr>
<td></td>
<td>Result chapter points</td>
</tr>
<tr>
<td></td>
<td>Network density</td>
</tr>
<tr>
<td></td>
<td>Social mechanism</td>
</tr>
<tr>
<td>Regulation</td>
<td>Resource security</td>
</tr>
<tr>
<td></td>
<td>Economic drivers</td>
</tr>
<tr>
<td></td>
<td>Trust</td>
</tr>
<tr>
<td></td>
<td>Track-records</td>
</tr>
<tr>
<td></td>
<td>Geographic proximity</td>
</tr>
<tr>
<td></td>
<td>Institutionalising norms</td>
</tr>
<tr>
<td></td>
<td>Other important points</td>
</tr>
</tbody>
</table>

General patterns were identified and further explored, explaining the observed differences between the cases as much as possible. These general patterns then formed the ingredients for the arguments presented in the associated results chapter (Chapter 5; Velenturf 2016a).
Finally, although the aim of this study was not to generalise the findings but rather to generate a better understanding of the ways in which industrial symbiosis innovations were realised through collaborations, the study design does support some generalisation. The case studies were all holistic ‘units’ of innovation processes within their separate company contexts, and given that I analysed which findings were similar and different between these contexts i.e. developed cross-contextual patterns and explanations (Mason 2002), some generalisation can be justified i.e. the results might apply to other companies working on similar innovations too.

4.4 Interviews with governmental organisations

In-depth interviews were carried out with individuals in governmental and associated organisations to answer research question b and parts of c:

b) How did the governance of, and policy and regulation implemented by, regional governmental and associated organisations influence biowaste-to-resource innovation?

c) How did immergent processes, such as developments in markets and governance, and emergent processes, such as network development during biowaste-to-resource innovation, mutually influence each other over time?

The knowledge about the role of governmental organisations was even scarcer when compared to the knowledge basis for the case studies. Only very few industrial symbiosis studies actually analysed how governmental organisations promote this kind of innovation and/or implement relevant policy and regulation. Additionally, when I considered focusing on the role of governmental organisations in the implementation of industrial symbiosis, there were no known studies analysing the competencies including the knowledge demands of governmental organisations to enable them to carry out such a task (Roland Clift, pers. comm.). In short, there was not much material to base this study on, and hence I adopted an even more qualitative exploratory methodology: In-depth interviews.

The scope of the interviews developed alongside the case studies and the on-going networking. It became clear that industrial symbiosis and biowaste-to-resource innovations were not a particular focus for governmental and associated organisations in the Humber
region. To engage people within the governmental organisations the scope had to be broadened to include bio-based developments in general in addition to biowaste-to-resource innovation in particular. Still, during the interviews it became evident that not all of the identified governmental organisations actively, or sometimes even passively, contributed to bio-based developments or biowaste-to-resource innovations. Hence the research focus was adjusted again to analyse the current role of governmental organisations and their potential future capacity to support bio-based developments and biowaste-to-resource innovations whilst also analysing more general practices for business interaction and innovation.

The interviews did maintain the focus on network development over time, similar to the case studies and in line with the overall focus of this PhD project. In other words, this study also adopted social network analysis to understand how and why relations within and between governmental and associated organisations developed (Scott 2000; Borgatti et al. 2009; Hollstein 2011).

4.4.1 Data generation through in-depth interviews

Interviewees in governmental and associated organisations were identified through networking activities in the Humber region. Additionally, some interviewees had already participated in a related study (Penn et al. 2014) and were approached for follow-up interviews. Furthermore, the case studies had indicated that local councils could play a role in terms of waste supplier, inward investor, and planning authority – and hence I strived to contact people in the respective departments directly. Finally, snowballing and referrals also added to the identification of interviewees.

Attention was paid to accessing a meaningful sample of individuals in a variety of organisations that had been/ were involved in biowaste-to-resource innovation and/or bio-based developments (Mason 2002; Bryman 2012). I aimed to interview the individuals that were certainly or most likely to be involved in these developments, and attempted to interview at least one person in every relevant regional organisation. I tried to get as complete a perspective as possible on the Humber context to provide a ‘rich’ analysis, which
should aid the assessment of potential transferability to other contexts such as other regions in England (Mason 2002).

I spoke with interviewees in person or via the telephone to explain the purpose of this study and to ask whether the interviewee would be interested to participate. After that conversation I sent them an information sheet that detailed the research purpose, deliverables, data requirements, and data usage and confidentiality. The interviewee also received a copy of the consent form which would be signed before the interview (informed consent, as in the case studies). This confidentiality was considered important because some subjects could be perceived as sensitive, e.g. discussing competency or the quality of work by colleagues in other departments. The offered anonymity facilitated open conversations to get a real insight into the activities and capacity of these governmental organisations.

After receiving the information, most interviewees confirmed their participation and we planned the interview to take place in their organisation, usually in a meeting room or empty office. Before the interview, I briefly repeated the information provided in the information sheet and offered the interviewees the opportunity to ask any questions. Then we would sign the consent form, including consent to record the interview as well as the option for the participant to withdraw at any given moment (Oliver 2003). Some interviews took place via skype and the signing of the consent form would happen via the mail (interviewees printed, signed, and scanned the form). Interviews were recorded and the transcript was shared with the interviewee. Once the study was completed the research outcomes, i.e. the associated article (Chapter 6, 2016b), was shared with the participants.

The interviews revolved around three main areas of questioning (Appendix B):

1) General description and evaluation of their activities regarding biowaste-to-resource innovation and/or the bio-based economy.
2) Network development including interaction with private and other public organisations.
3) Specific collaborations to promote bio-based developments and biowaste-to-resource innovations.
Prior to the interviews I explored documents that seemed relevant for the person in the position that I was going to interview. I explored local strategies, plans, and reports that were produced within the organisation I was about to visit, to analyse whether they had any direct and formal bearing on biowaste/ bio-based developments. All documents were scrutinised using the four criteria also discussed in the case studies i.e. authenticity, credibility, representativeness, and meaning (Scott 1990).

Since the interviews did have some structure, some methodologists might not consider them depth-interviewing (Jones 2004). However, the structure was very open; Interview questions had to be tailored to specific interviewees as they were in different functions with often very different foci. Additionally, the interview schedule had to be flexible as improvisation was necessary during the interviews, because competencies regarding bio-based economy, biowaste-to-resource innovation or innovation in general varied from almost absent to expert level. I also took the liberty to explore subjects brought forward by the interviewees which seemed relevant but were not in my interview schedule. The aim of the interviews was to collect the interviewees’ accounts on the governance of biowaste-to-resource innovations and the bio-based economy in an open and exploratory manner.

After the interviews I would immediately take some notes about the interview settings, any unusual or particularly striking events, etc. When relevant I would take those on board for the analysis.

4.4.2 Data preparation, organisation and interpretation

4.4.2.1 Interview transcripts

All interviews were transcribed before further analysis. Spoken communication, the occurrence of pauses in the talking and the occurrence of major disturbances such as someone entering the room were transcribed. The length of pauses, the tone in which interviewees spoke, and other forms of communication such as sighs, moving around on the
chair, etc. were not included in the transcript. This was in anticipation of the way in which further analysis would be carried out.

Finally, for some interviewees and/or organisations additional transcripts were available because research participants had been interviewed previously in a related project (Penn et al. 2014; Schiller et al. 2014). These transcripts were used to contextualise the new transcripts where possible.

4.4.2.2 Coding

Similar to the case studies, the data were coded and further interpreted in MS Word. Before fully engaging in the coding, I read the transcripts and started to develop a coding tree. I coded two transcripts to ‘test’ and develop the coding tree further, and at that point I felt I had a reasonable list of codes to engage in the coding process for real. I did this first step to draw out most of the codes to prevent having to re-code too many transcripts in case important codes would emerge at an advanced stage. Naturally, some more open codes emerged nevertheless during the coding (Table 6.2 in Chapter 6).

All transcripts were read both literally and interpretively (Mason 2002). Fragments were selected and a comment with the code, and in some cases further ideas with the fragment, was attached. After coding the interviews, all fragments were copied to the relevant codes.

The interviews were organised and analysed with cross-sectional techniques, i.e. the transcripts were coded and the fragments from all interviews for each code were analysed together. An explanation was built from the cross-sectional analysis.

4.4.2.3 Interpreting individual codes

The coding resulted in a large amount of fragments per code and, for a number of codes, I felt they could not be systematically analysed with a computer because there were too many fragments to gain an overview. Hence I summarised the main point(s) within each code regarding the code at hand and printed them. I cut the print-outs so that each
fragment summary was on a separate piece of paper. I then compared and grouped the fragments until general patterns emerged. In other words, I categorised the fragments (Strauss and Corbin 2004) and started to form explanations or arguments for each code. During the interpretation I made notes and after the analysis I developed the notes and the emerged categories into a ‘writing-to-learn’ document which was later combined with similar documents for other codes in the further interpretation of the data.

### 4.4.2.4 Interpreting linkages between codes and formulating arguments

The analysis of the individual codes already helped in identifying potential linkages between the codes. I revisited these potential linkages to review them, to gather further detail and ensure that the argument was strong enough to be included in any forthcoming publications. The patterns that were supported by data from multiple interviewees and where the linkages were very clear were considered the strongest and hence were included in a results report (another ‘writing-to-learn’ document). At this stage in the analysis I also started to develop a storyline to bring the data analysis together into a coherent argument. The storyline was summarised in three questions around which I positioned my on-going interpretation:

- How do local and regional governmental organisations in the Humber region promote bio-based developments and specifically biowaste-to-resource innovations? What do they do? How do they interact with companies, if at all?
- Why do they not promote these developments more actively? Are there any barriers?
- How could local and regional governmental organisations promote bio-based developments and specifically biowaste-to-resource innovations? What capacity in terms of knowledge, network, money and policy and regulatory framework do they have?

The arguments in the results report were then developed into the article included as Chapter 6 (Velenturf 2016b).

The aim of this study was not to produce broad generalisations. It was clearly exploratory in nature, aiming to better understand the regional governance for primarily biowaste-to-
resource innovation. However, the analysis showed such clear relations to dynamics in national governance that I felt it was very likely that the findings would be transferable to other regions in England. Hence the argument in Chapter 6 became increasingly general in tone, particularly towards the discussion and recommendations.
Chapter 5: Promoting industrial symbiosis: empirical observations of low-carbon innovations in the Humber region, UK

Chapter 6: Analysing the governance system for the promotion of industrial symbiosis in the Humber region, UK

Chapter 7: Evolution of industrial symbiosis: Harmonising top-down and bottom-up processes
Promoting industrial symbiosis: empirical observations of low-carbon innovations in the Humber region, UK

This chapter builds on the theoretical explorations in Chapter 2 and the parts of Chapter 3 about emergent processes with empirical results to answer research questions a) How and why did collaborations between resource partners develop during biowaste-to-resource innovations? This manuscript has been published in the Journal of Cleaner Production and the full reference is: Velenturf, Anne P.M. (2016) Promoting industrial symbiosis: Empirical observations of low-carbon innovation in the Humber region, UK. Journal of Cleaner Production, New approaches for transitions to low fossil carbon societies: promoting opportunities for effective development, diffusion and implementation of technologies, policies and strategies, Vol. 128: 116-130, which has been published in its final form at doi: 10.1016/j.jclepro.2015.06.027.
Chapter 5: Promoting industrial symbiosis: empirical observations of low-carbon innovations in the Humber region, UK

Anne P.M. Velenturf

Abstract

Industrial symbiosis has been identified as a strategy to increase resource efficiency, lower carbon emissions and increase business growth. One type of industrial symbiosis is the innovative use of wastes from one company as a resource for another company. However, empirical understanding of implementing waste-to-resource innovations, and hence how they can be promoted by public and private organisations, is still limited. Therefore this study explored how companies implemented waste-to-resource innovations in the Humber region, UK. Five case studies were conducted with companies that used or supplied a secondary biomass resource for power generation or fuel manufacturing. This article discusses how companies developed relations with biowaste resource suppliers or clients. The results expanded operational understanding of waste-to-resource innovation processes as it revealed companies’ activities and their strategic considerations. Comparing the case studies, the social processes through which relations between biowaste resource partners developed were largely similar. However, two different networking strategies were identified. Some companies had to engage new industries and therefore diversified their resource partners during the innovation process, but strived to limit the number of resource partners once the innovation was realised. Conversely, others expanded activities within their network and hence strengthened existing relations during the innovation, but strived to increase the number of resource partners afterwards to manage risky over-dependencies within their supply network. Finally, resource security, economic benefits and policy and regulation were of key importance. To conclude, operational and strategic insights to promote the uptake of waste-to-resource innovations are presented, however, further research is necessary before broad generalizations can be considered.

Keywords: Waste-to-resource innovation; Bio-based economy; Renewable energy; Social network analysis; Social process; Case studies
5.1 Introduction

The turn of the century has been marked by rising resource prices and growing price volatility, a trend that is expected to continue in the foreseeable future (Dobbs et al. 2011; Lee et al. 2012; Morgan 2014). Simultaneously carbon emissions need to be limited to constrain further climate change (IPPC 2014). These economic and environmental conditions necessitate societies to increase resource efficiency and use resources that cycle carbon in shorter time-frames than fossil resources (UNEP 2011; EC 2011a).

Industrial symbiosis has been identified as an important strategy to address the challenge to increase resource efficiency and lower carbon emissions while also delivering business growth (Laybourn and Morrissey 2009; EC 2011b). Industrial symbiosis has been defined as the development of working agreements between industrial and other organisations that, through the innovative reuse, recycling or sharing of resources, lead to resource efficiency (Jensen et al. 2011a). This article focuses on one specific type of industrial symbiosis: Biowaste-to-resource innovations. Such innovations can help decarbonising industries in two ways: 1) By reducing industries’ raw material intake, and 2) By using biomass resources instead of fossil resources which could deliver carbon savings up to 100% (Johnson 2009; European Commission 2009). The benefits and relevance of bio-based and waste-to-resource innovations have been recognised by a broad range of actors (OECD 2009; Laybourn and Morrissey 2009; EC 2011b; Lin et al. 2013; Hoffman et al. 2014; Finster and Hernke 2014; Rowney 2014).

Despite the necessity and benefits of biowaste-to-resource (hereafter called waste-to-resource) innovations, understanding how these innovations are being implemented and, consequently, how they can be promoted is still limited (Velenturf and Jensen 2016; Chapter 2). Implementing waste-to-resource innovations often involves collaborations due to the nature of the process i.e. turning ‘waste’ from one company into a resource for another company (Renner 1947; Frosch and Gallopoulos 1989). However, understanding how collaborations for waste-to-resource innovations develop is still an emerging field (e.g., Ashton and Bain 2012; Behera et al. 2012; Paquin et al. 2014). This article contributes to this emerging body of knowledge, which will be further discussed in the next section, by exploring the following research question: How did collaborations with resource partners...
develop during waste-to-resource innovations? Without such understanding it is difficult to operationalise strategies to promote waste-to-resource innovations. Indeed, this article aims to provide operational understanding of activities that contributed to realising waste-to-resource innovations as well as the strategic considerations made by companies during these innovation processes, by presenting the results of five qualitative inductive case studies of waste-to-resource innovations in the emerging bio-energy sector in the Humber region, UK. Although the generalizability of the outcomes to other regions and industrial activities needs to be verified through future research activities, the results could be used to inform governance strategies promoting low-carbon, resource efficient and economically beneficial practices.

Section 5.2 provides further background information defining the research gap and theoretical starting point for this study. Section 5.3 outlines the methodology used for this study and introduces the five case studies. In section 5.4 the results are presented and discussed. Section 5.5 concludes the article with next steps for academia, business and governmental organisations.

5.2 Theoretical starting point of this study

5.2.1 Social network development
Waste-to-resource innovations, in which the waste from one company becomes the resource for another company (Renner 1947; Frosch and Gallopoulos 1989), as a minimum involves the development of relations between waste producers and their clients. Additionally, realising waste-to-resource innovations can involve governmental organisations at national, regional and local level as well as universities and other research institutes (Park et al. 2008; Laybourn and Morrissey 2009). In sum, waste-to-resource innovations tend to involve the development of social relations and this can be studied with Social Network Analysis (SNA), (Scott 2000; Borgatti et al. 2009), see Figure 5.1a for an explanation of basic network components. SNA is an inter-disciplinary research methodology to study social structures (Scott 1988, 2000). While it can be used to study the dynamics of social structures as a whole, it can also be used to study dynamics within the
connections that the social structures are composed of (Borgatti et al. 2009). SNA can be applied in a quantitative and qualitative manner (Wasserman and Faust 1994; Hollstein 2011). In the last decades a shift has occurred from SNA studies that are consequence-focused, i.e. explaining what happened in the past, to more drivers-focused, i.e. understanding how connections are formed to predict how social structures might develop in the future (Borgatti et al. 2009; Borgatti and Foster 2003); Making SNA increasingly attractive to be used in studies aiming to support the already long-standing need for proactive strategies for the development of sustainable industrial systems (Korhonen et al. 2004).

Figure 5.1: (a) Networks consist of actors (A-H) and their connections which can be undirected or, such as in this example figure, directed. The connections can be any kind of flow including information, money, or materials etc. Connection(s) between two actors is a dyadic relation and between three actors a triadic relation. An ego-network consists of one actor’s connections, such as actor C, and the connections amongst actor C’s connections, hence why actor A and H are in the example outside C’s ego-network. (b) Networks of companies and/or industries go through industrial life cycles, including phases of exploration which are characterised by increasing network density and higher diversity whilst having less stability, and phases of exploitation which are characterised by decreasing network density and lower diversity whilst being more stable (Nooteboom and Gilsing 2004). In this article network density has been defined as the number of connections established divided by the number of maximum possible connections within a network, and network diversity as the number of actors present in a network. (c) Zooming in to relations within a network, various dimensions of relational strength and the similarity of actors involved in waste-to-resource innovations have been identified (Nooteboom and Gilsing 2004; Boschma 2005). While the concept of proximity can be used to explore actors’ characteristics and, based on that information, appraise the differences between actors, relational strength is an indicator of the actual relationships between actors. (d) The various types of actor proximity and relational strength are theorised to vary throughout the exploration and exploitation of business activities (Nooteboom and Gilsing 2004; Boschma 2005), and, as demonstrated here with relational strength, can become stronger in some ways while weakening in other ways depending on the life cycle (Nooteboom and Gilsing 2004).
5.2.2 Developing industrial symbiosis networks

Although industrial ecologists have indeed adopted network approaches (e.g., Ashton 2008; Doménech and Davies 2009), these studies focused on a limited range of social factors and consequently other social factors may have remained under-explored (Velenturf and Jensen 2016; Chapter 2). Furthermore, generalized ideas about the development of industrial symbiosis networks have been echoed throughout this literature, which do not necessarily align with views presented regarding industrial life cycles and innovation networks – further discussed in the next paragraph. Generally speaking, and leaving out some of the nuances presented within the industrial ecology community, industrial symbiosis is thought to start developing in response to changes in contextual factors such as policies and markets (Desrochers 2004; Boons 2008). First, individual symbiotic relations emerge randomly between companies that often are geographically proximate (Baas and Boons 2004; Doménech and Davies 2011a; Chertow and Ehrenfeld 2012). Then awareness and competencies regarding industrial symbiosis start to develop whilst also shared norms of trust and reciprocity, i.e. norms governing collaborations, emerge between companies (Doménech and Davies 2011a; Chertow and Ehrenfeld 2012). This enables the development of more and more complex industrial symbiosis relations (Baas and Boons 2004; Doménech and Davies 2011a; Chertow and Ehrenfeld 2012; Paquin and Howard-Grenville 2012). The industrial symbiosis network grows denser over time (Chertow and Ehrenfeld 2012; Paquin and Howard-Grenville 2012) and this increasingly stable and closed network promotes more innovative industrial symbiosis (Mirata and Emtairah 2005; Doménech and Davies 2011b).

This sequence of factors and processes is the starting point for this study (for a more detailed critique of these factors and processes, see Velenturf and Jensen (2016; Chapter 2). There are, however, some fundamental issues and considerable knowledge gaps in these general ideas about the development of industrial symbiosis networks, which constrains the formulating of effective and efficient approaches to promote industrial symbiosis. The most striking characteristic of these generalised ideas is that all social factors strengthen each other throughout the industrial symbiosis network development. For example it describes consistently positive relations between increasing network density, emergence and institutionalising of norms that support industrial symbiosis, increasing trust and reciprocity,
and increasing innovation capacity. Unravelling these relations and the social factors within it might enable a closer look at what happens during the development of industrial symbiosis relations and networks, including waste-to-resource innovations.

5.2.3 Exploration and exploitation

While industrial ecologists argued that stable high density networks promote innovation (Mirata and Emtairah 2005; Doménech and Davies 2011b), other academics argued that such networks would constrain innovation capacity (Day 1994; Granovetter 2005). Indeed, network stability (i.e. no change) and innovation (i.e. change) seem to be contradicting terms. The middle-ground might be demonstrated by exploration and exploitation dynamics of industrial systems: Industrial systems are thought to go through phases of exploration, during which companies focus on adopting new business activities, and exploitation, during which companies focus on improving current business activities (Levinthal and March 1981; March 1991) – see Figure 5.1b.

At the start of exploration companies strive to identify new business activities, these activities tend to be radical innovations, i.e. activities that the company did not do before (Nooteboom and Gilsing 2004). Companies that have an open, diverse broad ranging network might have the best opportunities to identify such new business activities (Burt 1992). Whilst adopting the radical innovations, the network grows denser to enable the transfer of often tacit knowledge (for a further explanation of tacit knowledge see, Gertler 2003). Once the exploration phase draws to an end, i.e. the radical innovations have been adopted, the dense social network could facilitate the development of new norms (Coleman 1988), and although this is indeed in line with proposed industrial symbiosis network dynamics (e.g., Paquin and Howard-Grenville 2012), Nooteboom and Gilsing (2004) argue that network density then starts to decrease. While companies move into the exploitation phase, they focus more on efficiency and cost-savings through incremental innovations i.e. improving existing business activities (Nooteboom and Gilsing 2004). Moreover, the cost reductions also permeate to reducing networking efforts. During the exploitation phase, companies are thought to spend less on maintaining a broad range of relations and instead focus on core business activities and associated relations. As a result the network density
decreases again and becomes more open, and such network structure is unlikely to support the development of new norms (Coleman 1988; Nooteboom and Gilsing 2004). Instead, in this less dense network, companies might feel less constrained by social norms and hence are more likely to innovate radically (Day 1994; Granovetter 2005) and enter a new exploration phase.

The development of industrial symbiosis networks has not been studied yet in terms of the industrial life-cycles exploration and exploitation and/or associated innovation intensities radical and incremental changes, but clearly has potential to broaden understanding of industrial symbiosis network dynamics and the effects on norms regarding collaboration and industrial symbiosis. Therefore these social factors will be included in this study to guide the empirical observation of waste-to-resource innovations (Figure 5.2).

### 5.2.4 Distinguishing strength and proximity

So far, industrial ecologists have discussed the strength of relations and the embeddedness of industrial actors as being positively related (e.g., Doménech and Davies 2011a; Ashton and Bain 2012) but exploration and exploitation dynamics suggest a less linear relation. Converse to research carried out with the concept of embeddedness (e.g. Boons and Howard-Grenville 2009), this study makes a clear analytical distinction between the strength of relations and the absolute and relative proximity of actors (Figure 5.1c). This enables a more detailed view on social characteristics and processes within network relations. The strength of relations could be explored in six dimensions (Granovetter 1973; Nooteboom and Gilsing 2004): Scope, Frequency, Duration, Control, Trust and Investment in mutual understanding (Table 5.1). Additionally, the concept of proximity was developed to explore the differences between actors and the effects of those differences on inter-organisational interaction for, and coordination of, innovation (Boschma 2005). Boschma (2005) distinguished five analytically separate proximity dimensions, enabling empirical analysis of their separate roles in industrial symbiosis, these are: Geographic, Cognitive, Organisational, Social and Institutional proximity (Table 5.1). Although some of these social factors have been discussed in relation to industrial symbiosis before (Baas 1998; Gibbs 2003; Sterr and Ott 2004; Hewes and Lyons 2008; Ashton 2008; Doménech and Davies 2009; Jensen et al.
2011a), a complete empirical exploration is yet to be carried out to observe if, how and why these indicators of strength and proximity may be important for industrial symbiosis (Velenturf and Jensen 2016; Chapter 2), hence they have been included in this study (Figure 5.2).

In addition to distinguishing relational strength and proximity of actors, they may also vary depending on exploration and exploitation phases in industrial systems (Nooteboom and Gilsing 2004; Boschma 2005). Moreover, contradicting current views presented in industrial ecology, the social factors can show variations in *opposing directions*, e.g. while relations become stronger in some ways, they may weaken in other ways (Figure 5.1d). This can and should be explored more broadly for industrial symbiosis networks because it is likely to have implications for the ways in which waste-to-resource innovations can be promoted (also see, Velenturf and Jensen 2016; Chapter 2).

Exploration and exploitation dynamics, combined with the concept of proximity and a more precise view on relational strength, untangled innovation processes and the associated network dynamics which provides a new perspective to empirically explore waste-to-resource innovations. Given the existing knowledge gaps regarding industrial symbiosis networks (Velenturf and Jensen 2016; Chapter 2), this study adopted a qualitative inductive approach and the next section will outline how the perspective that was introduced in this section was used as a ‘lens’ to empirically observe waste-to-resource innovations.
Table 5.1: Dimensions of relational strength and proximity of actors in a network can have a variety of meanings (North 1990; Cohendet and Llerena 1997; Kirat and Lung 1999; Nooteboom 2000; Gertler 2003; Nooteboom and Gilsing 2004; Wuyts et al. 2005; Boschma 2005; Knoben and Oerlemans 2006; Broekel and Boschma 2012), which were used in this study to observe how relations developed during the waste-to-resource innovations.

<table>
<thead>
<tr>
<th>Relational strength</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Trust/ openness</strong></td>
<td>Trust in competencies and intentions of collaborator.</td>
</tr>
<tr>
<td></td>
<td>Institution-based or person-based.</td>
</tr>
<tr>
<td></td>
<td>Reciprocity-based i.e. expecting that one actor’s effort will be paid back by another actor’s effort.</td>
</tr>
<tr>
<td></td>
<td>Empathy-based i.e. understanding how other actors’ feel and/or think, which can lead to identification-based trust i.e. feeling and thinking the same, and friendship-based trust.</td>
</tr>
<tr>
<td></td>
<td>Routine-based trust i.e. based on a relation working well for a prolonged period of time.</td>
</tr>
<tr>
<td></td>
<td>Openness i.e. perceived importance of internal and external knowledge.</td>
</tr>
<tr>
<td><strong>Control</strong></td>
<td>Opportunity control, about constraining possible actions, identified by presence of contracts.</td>
</tr>
<tr>
<td></td>
<td>Incentive control, about influencing choice of opportunities through inter-dependencies based on uniqueness of relation, costs to switch to other relation or effects on reputation. Note how incentive control overlaps with organisational proximity and the control mechanism of hierarchy.</td>
</tr>
<tr>
<td><strong>Scope</strong></td>
<td>Range of subjects covered in a relation.</td>
</tr>
<tr>
<td><strong>Duration</strong></td>
<td>The time between initiating and breaking the relation.</td>
</tr>
<tr>
<td></td>
<td>Needs to be long enough to make investment in mutual understanding.</td>
</tr>
<tr>
<td><strong>Frequency</strong></td>
<td>The number of interactions during the innovation process.</td>
</tr>
<tr>
<td></td>
<td>Needs to be often enough to make investment in mutual understanding.</td>
</tr>
<tr>
<td><strong>Investment</strong></td>
<td>The amount of time, money and effort invested in the relation to generate mutual understanding.</td>
</tr>
<tr>
<td><strong>Proximity dimension</strong></td>
<td><strong>Description</strong></td>
</tr>
<tr>
<td><strong>Geographic</strong></td>
<td>Absolute or relative traveling distance</td>
</tr>
<tr>
<td></td>
<td>Permanent or temporary</td>
</tr>
<tr>
<td><strong>Organisational</strong></td>
<td>Similarities in routines and incentives</td>
</tr>
<tr>
<td></td>
<td>Degree of autonomy and control resulting from economic and financial inter-dependencies</td>
</tr>
<tr>
<td></td>
<td>Symmetrical or hierarchical</td>
</tr>
<tr>
<td><strong>Social</strong></td>
<td>Degree to which economic relations are socially embedded at the micro level, for example through friendship, kinship and professional acquaintance</td>
</tr>
<tr>
<td></td>
<td>Can facilitate knowledge transfer</td>
</tr>
<tr>
<td></td>
<td>Associated with trust, considered to be a control mechanism against opportunistic behaviour particularly when knowledge is tacit</td>
</tr>
<tr>
<td><strong>Institutional</strong></td>
<td>Formal and informal institutions</td>
</tr>
<tr>
<td></td>
<td>Institutional overlap can ease communication as not all knowledge needs to be made explicit</td>
</tr>
<tr>
<td></td>
<td>Institution-based trust can reduce uncertainty</td>
</tr>
<tr>
<td></td>
<td>Researched at national/regional and the inter-organisational level, in this study focus on national/regional level to prevent overlap with other proximity dimensions</td>
</tr>
<tr>
<td><strong>Cognitive</strong></td>
<td>Norms and values that guide behaviour of economic actors</td>
</tr>
<tr>
<td></td>
<td>Market and technical competencies</td>
</tr>
<tr>
<td></td>
<td>Cognitive diversity between actors is necessary to trigger innovation</td>
</tr>
<tr>
<td></td>
<td>‘Cognitive overlap’ necessary to enable communication and knowledge transfer and absorption</td>
</tr>
</tbody>
</table>
5.3 Methods

A multiple case study design was used to cover the complex qualitative knowledge gap which was outlined in the previous section (Mason 2002; Yin 2009). The following sections will introduce the case study region and case studies and provide details of data collection and analysis.

5.3.1 Case studies in the Humber region

The Humber region is a mature and diverse industrial area with one of the largest harbour complexes of England, hosting high concentrations of food processing, chemical, fuel and power production facilities (Jensen et al. 2011c; Penn et al. 2014). The area is of strategic importance for the UK’s energy supply: Nationally it is landing ca. 20% of gas, refining ca. 33% of oil and generating almost 20% of power (Penn et al. 2014; Humber Local Enterprise Partnership 2014). Consequently, the wider Yorkshire and Humber region is responsible for 27% of the total UK’s CO₂ emissions (Yorkshire and the Humber Regional Committee 2010).
and hence can play a strategic role in achieving the national carbon reduction targets (Government 2009). Besides the expanding offshore wind sector, the Humber region contributes to the national low carbon strategy through bio-based developments in the energy sector (Humber Local Enterprise Partnership 2014). Alongside low carbon energy, optimising material and energy flows, including waste, is increasingly important (European Commission 2008). The Humber region is a known case study in the literature and has developed considerable expertise in waste-to-resource innovations as it has been engaged for over a decade in efforts to promote industrial symbiosis such as through the National Industrial Symbiosis Programme (Mirata 2004; Bailey et al. 2008; Penn et al. 2014; Jensen et al. 2012; Massard et al. 2014). In recent years various low carbon innovations have been adopted in this region (e.g., Laybourn and Morrissey 2009; Bondholders 2014). The evident public and private drive to adopt waste-to-resource innovations in the bioenergy sector made this region suitable to both observe and contribute to the progress of low fossil carbon innovations.

This study included five case studies of waste-to-resource innovation in the bioenergy sector in the Humber region. Each case study focused on one innovative biowaste resource flow between the research participant and the resource partners, i.e. either the client or supplier of the waste biomass (Table 5.2). Research participants were identified and recruited through intensive networking at events organised by industry and local authorities. All case studies were confidential because of the commercial interests of the companies involved in the studied innovations; hence no company names, exact company locations or resource characteristics could be discussed in this article. This, however, does not affect the presented results because the study solely focused on social processes. Where location and technical information regarding the innovation were important, the necessary level of detail has been presented in agreement with the research participants.
Table 5.2: Five case studies of waste-to-resource innovations in the bioenergy sector in the Humber region UK were included in this study.

<table>
<thead>
<tr>
<th>Cases</th>
<th>Research participant</th>
<th>Resource partner</th>
<th>Waste-to-resource flow*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1: Waste oils</td>
<td>Fuel producer</td>
<td>Energy intensive company</td>
<td></td>
</tr>
<tr>
<td>Case 2: Agricultural feedstock</td>
<td></td>
<td>Farmers</td>
<td></td>
</tr>
<tr>
<td>Case 3: Refuse derived fuel</td>
<td>Energy intensive company</td>
<td>Specialist recycler</td>
<td></td>
</tr>
<tr>
<td>Case 4: Waste-wood fuel</td>
<td>Steam producer</td>
<td>Fuel producer (2x)</td>
<td></td>
</tr>
<tr>
<td>Case 5: Waste oils and fats</td>
<td>Specialist recycler</td>
<td>Fuel producer</td>
<td></td>
</tr>
</tbody>
</table>

*Figures of waste-to-resource flows made with NodeXL.

5.3.2 Data collection

Various data sources were used in the case studies to capture multiple actors’ perspectives on the waste-to-resource innovation to construct validity (Mason 2002; Yin 2009). First, each case study was based on semi-structured interviews with the manager or director who had been most involved in the innovation process (Table 5.3). This interview focused on one specific waste-to-resource innovation (Table 5.2) and detailed exactly how and why the relation to the resource partner(s) had developed, whilst also collecting information about other actors and developments impacting on the innovation process. The interview questions were designed to explore the role of the social factors identified in Section 2 (Figure 5.2). Questions followed a pattern from open to more structured questions to
ensure all relevant subjects were covered while minimising leading interviewees in their answers. All interviews were recorded and transcribed prior to analysis (see Appendix A for complete interview schedule). In some case studies, additional interview data were available because the research participants had been interviewed previously in a related project (Penn et al. 2014). These transcripts were used to contextualise the case studies, providing data about general drivers and barriers for waste-to-resource innovations and about other resource synergies that the companies already had developed. Furthermore, in Case 5 ‘Waste oils and fats’ additional interviews were carried out with the relevant process engineer and the resource partner’s environmental manager. Finally, documents such as sustainability reports, participants and resource partners’ websites, and legislative texts were collected to complement the interview data.

Table 5.3: Each case study was based on 1-4 interviews and complemented with documents and feedback sessions where relevant and possible.

<table>
<thead>
<tr>
<th>Cases</th>
<th>Interviews</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1: Waste oils</td>
<td>Environmental manager¹,²</td>
</tr>
<tr>
<td>Case 2: Agricultural feedstock</td>
<td>Environmental manager¹</td>
</tr>
<tr>
<td></td>
<td>Technical director²</td>
</tr>
<tr>
<td>Case 3: Refuse derived fuel</td>
<td>Environmental manager¹</td>
</tr>
<tr>
<td>Case 4: Waste-wood fuel</td>
<td>Planning director¹</td>
</tr>
<tr>
<td>Case 5: Waste oils and fats</td>
<td>Managing director¹,²</td>
</tr>
<tr>
<td></td>
<td>Process engineer³</td>
</tr>
<tr>
<td></td>
<td>Environmental manager of resource partner³</td>
</tr>
</tbody>
</table>

¹Semi-structured interviews about one specific waste-to-resource innovation; ²Semi-structured interviews about industrial symbiosis in general as presented in Penn et al. (2014); ³Additional interviews about project development

5.3.3 Data analysis

All data were coded using conceptual coding (Figure 5.2) and open coding to ensure that all important social factors were identified in this study (Bryman 2012). Coding strategies were both literal and interpretive (Mason 2002). Then the coded fragments about each social factor were further interpreted to identify whether, how, why, when and in relation to what other social factors it had played a role in the innovation process.
The individual interpretations of the role of each social factor were combined in a case study report, building a holistic understanding of the innovation process. Furthermore, the case study reports included an analysis to explore whether and why there were similarities and differences between the observations and the theoretical starting point of this study (Section 5.2). The case study report was shared, and when possible presented and discussed, with the participant to explain and further discuss the results whilst also acquiring feedback.

Case studies were carried out until the ‘saturation point’ was reached, i.e. until no significant new results were generated (Yin 2009). Saturation was reached after five case studies. Then a cross-case comparison was used to identify and/or further explore general patterns, explain the differences between the cases as much as possible, and compare the results to the literature on the subject (Section 5.2). The main results of this comprehensive cross-case comparison will be presented next.

5.4 Empirical observations of social processes during waste-to-resource innovations

5.4.1 Overview of the social processes

The results of this study are highly integrated which means that observations of all activities and strategic considerations need to be discussed in association with each other. Therefore this paragraph provides an overview of the results (also see Figure 5.3) before discussing elements of the innovation process in greater depth in the following sections:

(5.4.2) The case study participants started the innovation process in response to a change in the legislative or;

(5.4.3) Market context which created a problem and/ or opportunity for a waste resource flow.

(5.4.4) The participants contacted the potential resource partner(s), i.e. waste resource supplier or client, that they either already knew, i.e. strengthened existing resource
relations, or otherwise were introduced to new resource partners, i.e. diversified their connections, via a shared contact (Figure 5.4).

(5.4.5) When an initial business case could be made, the collaboration developed further through mutual learning. Shared knowledge and understanding was generated which was the basis for confidence in the collaboration.

(5.4.6) In most cases the confidence in the collaboration was formalised with a contract. As waste-to-resource innovations involve multiple actors (Figure 5.4) including technology providers and governmental organisations, the timing of the agreements about new resource flows had to coincide with agreements regarding the associated technology and permits, and this added another level of complexity to the innovation processes.

(5.4.7) Once the innovation was realised the companies either strived to limit or increase, i.e. diversify, the number of resource partners. Resource security was a key consideration because of its potential impact on economic targets and legislative obligations. Network diversification was a strategy to manage risks associated with dependency on a small number of resource partners.

Figure 5.3: The relation between the case study participant and the resource partner, i.e. waste resource supplier or client, developed through similar steps in each case study. Additionally, governmental organisations, economic benefits and resource security were of key importance during the waste-to-resource innovations.
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Innovation intensity</td>
<td>Incremental</td>
<td>Radical</td>
<td>Radical</td>
<td>Incremental</td>
<td>Incremental</td>
</tr>
<tr>
<td>Proven or Leading-edge</td>
<td>Proven</td>
<td>Proven</td>
<td>Leading-edge</td>
<td>Proven</td>
<td>Proven</td>
</tr>
<tr>
<td>technology</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exploration or exploitation of business activities</td>
<td>Exploration</td>
<td>Exploration</td>
<td>Exploration</td>
<td>Exploitation</td>
<td>Exploitation</td>
</tr>
<tr>
<td>Exploration or exploitation of sectors</td>
<td>Exploration</td>
<td>Exploration</td>
<td>Exploration</td>
<td>Exploitation</td>
<td>Exploitation</td>
</tr>
<tr>
<td>Diversified resource partners during or after innovation</td>
<td>During</td>
<td>During and After</td>
<td>During</td>
<td>After</td>
<td>After</td>
</tr>
<tr>
<td>Self-organised or brokered</td>
<td>Brokered</td>
<td>Brokered</td>
<td>Self-organised</td>
<td>Self-organised</td>
<td>Self-organised</td>
</tr>
<tr>
<td>Company size</td>
<td>Large</td>
<td>SME</td>
<td>Large</td>
<td>SME</td>
<td>SME</td>
</tr>
<tr>
<td>Core or side business</td>
<td>Side</td>
<td>Side</td>
<td>Side</td>
<td>Core</td>
<td>Core</td>
</tr>
<tr>
<td>Legislative drivers</td>
<td>Waste Framework Directive</td>
<td>Renewables Obligation</td>
<td>None</td>
<td>Renewable Heat Incentive</td>
<td>Renewable Transport Fuel Obligation</td>
</tr>
<tr>
<td>Economic drivers</td>
<td>Profit</td>
<td>Cost reduction Stable energy supply and price</td>
<td>Cost reduction Long-term survival</td>
<td>Business growth</td>
<td>Profit Business growth Asset value</td>
</tr>
<tr>
<td>Investment</td>
<td>Data not available</td>
<td>£5,000,000</td>
<td>Ca. £300,000</td>
<td>Data not available</td>
<td>£5,000,000</td>
</tr>
<tr>
<td>Duration innovation process (years)</td>
<td>Ca. 8</td>
<td>Ca. 1.5</td>
<td>Ca. 5</td>
<td>Ca. 2.5</td>
<td>Ca. 2.5</td>
</tr>
</tbody>
</table>
Figure 5.4: Network development while the companies realised the waste-to-resource innovation. Different actors were involved before, during and after the innovation while some actors were involved throughout the innovation process.
5.4.2 The role of governmental organisations

Governmental organisations played an important role throughout the innovation process. At the start of the process, in Case 2 ‘agricultural feedstock’, 4 ‘waste-wood-fuel’ and 5 ‘waste oils and fats’, policy incentives made the innovations economically viable or increasingly attractive (Table 5.4). Converse to such positive drivers, in Case 1 ‘waste oil’ new regulation redefined a former by-product as a waste, and hence the waste-to-resource innovation was sparked to find alternative routes for the new waste resource. Finally, uncertainty about government strategies to ensure long-term affordable energy supply motivated Case 2 ‘agricultural feedstock’ to adopt a diverse set of low-carbon innovations, increasing independent flexible power supply to assure continuity in supply and price. Policy and regulatory drivers for waste-to-resource innovation have indeed been widely reported (e.g., Park et al. 2008; Costa et al. 2010; Lehtoranta et al. 2011; Hoffman et al. 2014).

Once the innovation process had started, environmental regulation generally constrained the resource synergies. Nevertheless, and similar to observations elsewhere in Europe (Salmi et al. 2012), it was suggested that governmental organisations could either help overcoming or worsening regulatory barriers. Generally, environmental regulation was implemented by the Environment Agency while local authorities also played a role. As a minimum, all five participants engaged the Environment Agency because the innovations required a new or adapted environmental permit. Furthermore, the participants, except Case 1 ‘waste oils’, engaged local authorities because new or adapted planning permits were required. Participants made considerable investments in regulatory processes, most notably in environmental and planning permit applications but also end-of-waste procedures, ranging from £130,000 to over £1 million. Besides these permit-activities, Case 2 ‘agricultural feedstock’ and Case 3 ‘refuse derived fuel’ structurally engaged the Environment Agency and local authorities to prevent and manage impacts on the local community. Whilst implementing the waste-to-resource innovations, the participating companies experienced their interaction with governmental organisations as extremely negative up to extremely positive.
The notion that regulation can be a barrier to waste-to-resource innovations is certainly not new (Desrochers 2004), however apparently still relevant in 2014: Case 5 ‘waste oils and fats’ limited contact with all governmental organisations because they perceived them as frustrating business operation and development. Along similar lines, Case 1 ‘waste oils’ perceived the Environment Agency to operate in a procedural and inflexible manner. They could not agree on an economically viable solution for the waste resource within the UK and hence it was send abroad. Case 2 ‘agricultural feedstock’ delayed the uptake of waste resources as an input to their processes, because the administrative burden to use the output as fertiliser would become too high. Instead, the participant decided to continue dialogue with the Environment Agency and wait until regulation changed. The inability of regulation, such as demonstrated in these three case studies, to bring about complementary environmental benefits and economic development was previously observed by Deutz and Frostick (2009). Still, in these case studies the regulatory barriers did not completely stop the innovation processes; instead the companies continued interaction with regulator(s) to solve the regulatory issues because they were motivated by strong market and policy incentives.

These case studies demonstrate the need to integrate policies that promote renewable energy and environmental regulation that protects public health and environment. Perhaps one could learn from Case 3 ‘refuse derived fuel’, who had a better collaboration with governmental organisations. Case 3 exerted strong influence on the emergence of the refuse derived fuel market in the UK. In this process they engaged governmental organisations at local, regional and national level. Due to the policy and regulatory framework, local authorities had to divert more municipal waste from landfill, creating a problem with large quantities of waste. The research participant used this problem to argue 1) to UK companies that the participant could use the municipal waste as refuse derived fuel i.e. explicitly communicating the business opportunity and 2) to governmental organisations, particularly the Environment Agency, that the uptake of refuse derived fuel should be supported and this required changes in the regulatory framework. The refuse derived fuel market did indeed emerge in the UK, while the participant and the Environment Agency learned how the resource could be used safely and efficiently in increasing quantities in their plant. This case demonstrates the environmental and economic benefits
when environmental regulation is implemented in a more flexible manner that is conducive to innovation. Arguably a more flexible implementation could enable the integration of policy and regulation, which would also increase chances of ambitious national carbon reduction, renewable energy and recycling targets being achieved (Arundel et al. 2011; European Commission 2014).

5.4.3 Economic drivers and benefits

Economic benefits, either directly resulting from markets or markets influenced by policy incentives, were crucial in every case study (Figure 5.3). In most cases the innovation was expected to both provide short-term and long-term economic benefits (Table 5.4). Participants for whom the waste-to-resource innovation was core-business mentioned different benefits than participants for whom it was side-business: While Case 5 ‘waste oils and fats’ and Case 4 ‘waste-wood fuel’ adopted the innovation for business growth, Case 2 ‘agricultural feedstock’ and Case 3 ‘refuse derived fuel’ used the waste-to-resource innovation to reduce energy costs and increase chances for long-term survival. These prospective economic benefits were unanimously perceived as the most important drivers for realising the waste-to-resource innovations, ahead of other drivers such as policy and regulation, reputational benefits derived from environmental benefits, and personal motivation. Hence this study suggests that organisations promoting or facilitating waste-to-resource innovations should first explore potential economic benefits for companies that they are engaging and target the innovation process activities accordingly. Although the importance of economic benefits of waste-to-resource innovation and other industrial ecology activities is not a new notion (e.g., Frosch and Gallopoulos 1989; Desrochers 2004; Pakarinen et al. 2010), this study does provide empirical evidence that economic benefits are indeed crucial and, moreover, versatile such as also suggested by Hoffman et al. (2014).
5.4.4 Network diversification during the innovation process

5.4.4.1 Strengthening and diversification strategies

Once the case study participant started the innovation process (Figure 5.3), they generally had two strategies to develop their resource networks (Figure 5.4): Case 1 ‘waste oils’ and Case 3 ‘refuse derived fuel’ diversified their resource partners during the innovation and strived to limit the number of partners once the innovation was implemented, conversely, Case 4 ‘waste-wood fuel’ and Case 5 ‘waste oils and fats’ strengthened existing relations to resource partners during the innovation and aimed to diversify afterwards (Table 5.4). Case 2 ‘agricultural feedstock’ combined both dynamics, as they diversified their resource network both during and after the innovation process. Diversity is subject of on-going discussion in industrial symbiosis literature (e.g., Korhonen 2001a; Walter and Scholz 2006; Nielsen 2007; Mayer 2008; Ashton 2009; Jensen et al. 2011c; Paquin et al. 2014) and this study adds new empirical understanding. This section goes into diversification during the innovation process and Section 5.4.7 will cover diversification after the waste-to-resource innovation.

The data suggest a parallel between diversification during the innovation process and exploration of industrial sectors (Table 5.4). Case 1-3 had to diversify their resource partners: Case 2 and 3 engaged in a new business activity, i.e. radical innovation, and hence had no business contacts in the associated sector. Case 1 innovated incrementally but nevertheless had to engage new sectors to find new outlets for their waste resource. Case 4 and 5 innovated incrementally and already had well-developed networks in their sectors and hence they only had to strengthen existing relations. Having observed that, the association between network diversification and exploration-exploitation of business activities or radical-incremental innovation (Nooteboom and Gilsing 2004) could not be confirmed in this study. Instead this study suggests a nuance in exploration and exploitation strategies, associating network diversification with exploration of new sectors.
5.4.4.2 Self-organised and brokered resource relations

Diversification or strengthening of relations also had implications for the ways in which resource partners met each other (Table 5.4). Case 4 ‘waste-wood fuel’ and 5 ‘waste oils and fats’, who were *exploiting* existing contacts, already knew their resource partner and the waste-to-resource innovation was a self-organised continuation of that relation. Using existing contacts was beneficial because the professional acquaintance, i.e. social proximity, decreased the efforts required in building shared knowledge and understanding (which will be further discussed in the next section).

Case 1-3 had two strategies to contact potential resource partners while *exploring* new sectors: First, Case 2 ‘agricultural feedstock’ and Case 3 ‘refuse derived fuel’ connected to companies that neither they nor their existing contacts knew before, in other words, these connections were completely self-organised. Furthermore, Case 1 ‘waste oils’ and Case 2 ‘agricultural feedstock’ were also introduced to potential clients or suppliers by a shared contact, these new relations were brokered (see Burt 1992 for an explanation of network brokerage). Compared to self-organised relations, network brokerage had advantages. Case 1 ‘waste oils’ had a highly specified waste resource and therefore it was more challenging to find an outlet, thus they collaborated with a specialised facilitator who identified various resource partners for them. Case 2 ‘agricultural feedstock’ and some of their resource partners were introduced to each other by a shared contact on which they both depended for core-business activities. This triadic (see Figure 5.1a for an explanation) inter-dependent relation created network governance, motivating the case participant and their resource partners to collaborate well together since a failure could have consequences for the whole business operation. Perhaps this network governance prevented the numerous changes of resource partners that have been observed in Case 1 and 3 (Figure 5.4).

Extending Paquin et al. (2014) observation that increasing diversity of companies was associated with decreasing likelihood for initiating and completing resource synergies, most relations between resource partners in Case 1 and 3 only persisted for short time periods. Invariably these resource partnerships stranded because of resource security, i.e. getting resources in the right quality and quantity for the right price and in time (further discussed...
This suggests that it is more challenging to keep a resource collaboration going with partners in previously unconnected sectors, and this might indeed imply that companies prefer to develop resource partnerships with companies, or in sectors, that they already know (Paquin et al. 2014). However, not all companies may be able to follow such preference: While Case 4 ‘waste-wood fuel’ and Case 5 ‘waste oils and fats’ had the opportunity to strengthen existing relations and networks, Case 1-3 were necessitated to explore new sectors and relations due to economic and legislative changes. This had implications for the activities during the innovation process, which will be further discussed in the next section.

5.4.5 Building shared knowledge and understanding

5.4.5.1 Confidence in collaboration based on cognitive rather than social proximity

Before realising the new resource flow, the resource partners constructed certainty in the collaboration and innovation (Figure 5.3). As explained above, Case 4 ‘waste-wood fuel’ and Case 5 ‘waste oils and fats’ already knew their resource partners and hence their confidence in the collaboration was partly based on this previous professional acquaintance, covered by some in the broader term ‘social proximity’ (Boschma 2005) or ‘social embeddedness’ (Boons and Howard-Grenville 2009). Although the results indicated that this previous professional engagement was associated with less invested efforts in mutual understanding, i.e. fewer activities during the innovation process, it did not seem to have an effect on the time invested in the innovation (Table 5.4). Despite the certainty in the collaboration that Case 4 and 5 derived from previous professional relations, all Cases 1-5 constructed confidence in the collaboration and the innovation through mutual learning activities, building more shared knowledge and understanding, i.e. generating cognitive proximity between themselves and their resource partners. It was this cognitive proximity that provided confidence in the innovation and the collaboration with the resource partner and thus, converse to industrial symbiosis literature (e.g., Hewes and Lyons 2008; Doménech and Davies 2011a), trust between companies seemed more ‘cognitive-based’ than based on social proximity. Furthermore, this trust developed in dyadic relations (see Figure 1a for explanation), except in Case 1 and 2 where resource synergies partly or completely
developed within triadic relations, and this counters Coleman (1988) who theorized that trust between actors was only generated and maintained in triadic relations.

5.4.5.2 Constructing certainty: What, when, and how?

Although previous research suggested that the absence of knowledge and understanding about a new sector as well as the absence of relations and confidence in managers in that new sector might be a barrier for companies (Ehrenfeld and Gertler 1997; Ashton 2008), this did not stop Case 1-3 from exploring resource synergies in unrelated sectors. Furthermore, the development of shared knowledge and understanding with companies in unrelated sectors did not necessarily require the involvement of a facilitator, converse to previous suggestions (Mirata 2004; Paquin et al. 2014). Nevertheless, having a shared contact did ease the process for the companies involved in the waste-to-resource innovation. Similar to facilitated industrial symbiosis (Laybourn and Morrissey 2009; Jensen et al. 2011a), in the observed cases 1-5 of spontaneous and self-organised symbioses, discussion of potential economic benefits at the start of the innovation process promoted openness between resource partners. This suggests that a relatively narrow trust-basis sufficed to trigger openness and, consequently, mutual learning between the resource partners.

Economic benefits and resource security were crucial in all case studies and had to be further established, while in some cases the companies also actively developed confidence in their resource partners’ ability to deliver their part of the agreement in a well-organised, professional and legal manner. Furthermore, in Case 2 and 4 the resource partners investigated the reliability of the technology to ensure that it was compatible with the resource. The confidence in economic benefits, resource security, competencies of partners, and technology were developed primarily during the period of mutual learning, through a series of activities including site-visits, checking financial records, duty of care audits, and resource sampling (Table 5.5). Site-visits seemed particularly important learning moments regarding production processes and functioning of the site and technologies. On the suppliers-side these visits generated understanding about likely technological and operational problems that might arise if the resource would be out of specification or not supplied in time, while on the users-side understanding could develop about feasibility of
resource specifications, available quantities and transport. Finally, the development of shared knowledge and understanding was usually crowned with the explicit discussion of mutual economic benefits of the innovation, indeed this type of reciprocity was crucial in the innovation process.

The presented findings have implications for the kind of activities that organisations should organise, or participate in, to promote waste-to-resource innovations. Converse to Hewes and Lyons (2008) findings that industrial symbiosis requires development of friendship-like relations between companies through a lengthy process of informal and formal activities, this study suggests that companies could develop resource synergies faster by first focusing on economic benefits and then promoting activities that facilitate the development of further knowledge and understanding about economic benefits as well as resource security, competencies, and reliability of technology (Table 5.5).
Table 5.5: Defining what the case study participants had to trust in their resource partners, and when and how this trust was developed. This information could be used to formulate strategies promoting waste-to-resource innovations.

<table>
<thead>
<tr>
<th>Observed in case:</th>
<th>Certainty about what? Subject.</th>
<th>At which stage in innovation process? When.</th>
<th>How did it develop? Activities.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,2,3,4,5</td>
<td>Economic benefits</td>
<td>Initiation</td>
<td>Meeting with potential resource partner</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Project proposal</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Openness about business strategy</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>and economic benefits</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Check financial records</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Explicit dialogue that neither would</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>benefit if one partner does not</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>deliver agreement</td>
</tr>
<tr>
<td>1,2,3,4,5</td>
<td>Resource security</td>
<td>Building shared knowledge and understanding</td>
<td>Research resource availability in</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>whole market</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Check waste resource supply</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>contracts of potential collaborator</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Negotiate resource specification</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Check production records past months</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Laboratory test of waste resource</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>samples</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Trial waste resource in plant</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Check supplied resources</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Dialogue about the importance of</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>resource security for plant</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>operation</td>
</tr>
<tr>
<td>1,2,3,4</td>
<td>Capability to deliver agreement</td>
<td>Building shared knowledge and understanding</td>
<td>Site-visits to learn about production</td>
</tr>
<tr>
<td></td>
<td>in a professional, organised and</td>
<td></td>
<td>processes and site-functioning</td>
</tr>
<tr>
<td></td>
<td>legal manner</td>
<td></td>
<td>Site-audits</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Check health and safety records</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Duty of care audits</td>
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<td></td>
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<td>Production records past months</td>
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<td></td>
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<td>Dialogue about the importance of</td>
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<td></td>
<td></td>
<td>resource security for plant</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>operation</td>
</tr>
<tr>
<td>2,4</td>
<td>Reliability of technology</td>
<td>Building shared knowledge and understanding</td>
<td>Site-visits to learn about technology</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>operation</td>
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<td></td>
<td></td>
<td></td>
<td>Research technology successes and</td>
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<td></td>
<td></td>
<td></td>
<td>failures</td>
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<td></td>
<td></td>
<td></td>
<td>Check financial records technology</td>
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<td></td>
<td></td>
<td></td>
<td>provider</td>
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</tbody>
</table>

5.4.5.3 Geographic proximity of resource partners

While previous research suggested that confidence in resource partners might be constrained by longer geographic distances (Gibbs 2003; Sterr and Ott 2004; Hewes and Lyons 2008), this study indicates that this is not always the case (also see, Ter Wal 2009). Nuancing current understanding, the results indicated that companies considered geographic proximity when finding a balance between economic benefits and confidence in
resource security. First, distances between resource partners varied from 30-40 miles up to hundreds of miles (Figure 5.4). Additionally, all case study participants were involved in waste resource flows over much shorter and much longer distances.

Having observed that, the participants indicated that resource security, in particular confidence that resources with the right qualities would be supplied, influenced where resources were sourced. Confidence in resource quality could be achieved by both shorter and longer distances. Case 3 ‘refuse derived fuel’ felt more capable to monitor suppliers when they were located at shorter distances from them. They experienced many issues regarding resource quality and hence had little trust in suppliers, therefore they preferred distances that were short enough (ca. 30-40 miles) to check upon the supplier regularly and, moreover, to observe the wastes going to the supplier which were processed into refuse derived fuel for the participant. Conversely, Case 4 ‘waste-wood fuel’ associated increasing resource security with longer distances. Although they could have selected a supplier nearby, they had greater confidence in a supplier at ca. 150 miles distance from their steam facility.

In addition to resource security, economic considerations influenced where resources were sourced. There has been some controversy regarding the relation between resource value and transport distances, e.g. Chertow et al. (2008) and Jensen et al. (2011a), and this study reflects the different views. When considering where to source or send waste resources, the case study companies considered all the costs involved in the waste-to-resource flow, including transport costs, relative to the value that they could generate with the waste. For example, in Case 5 ‘waste oils and fats’ the resource partner was located at 30-40 miles distance, but the distance could have been 200 miles because the value generated with the waste resource was high enough to cover the transport costs. Similarly, in Case 2 ‘agricultural feedstock’ the total costs had to stay below a target value for the produced resources, set by the participant, which was competitive to the price of comparable fossil fuel products. In Case 1 ‘waste oils’ resources were transported hundreds of miles abroad. First because it was difficult to find an outlet for this specialised waste, which supports Jensen et al. (2011c) findings that the more difficult it is to recycle a resource, the further the resource may be transported. Moreover, the profits abroad were higher despite the
increased transport costs. Conversely, Case 3 ‘refuse derived fuel’ initially imported the refuse derived fuel, but when the participant started to increase usage the long transport distances became uneconomic. To conclude, profit margins were considered when assessing distances between resource partners, despite Jensen et al. (2011a) not finding a significant relation between the added value created with waste resource and transport distances, whilst the results also show that geographic proximity was not as inherent to industrial symbiosis as suggested previously (e.g., Chertow et al. 2008).

5.4.6 Negotiating formal agreements to realise the innovation

5.4.6.1 Contract negotiation: The final piece in developing confidence

The shared knowledge and understanding resulted in a feeling of confidence or trust in the collaboration, which was the pre-requisite for negotiating a contract (Figure 5.3). For example, in Case 3 ‘refuse derived fuel’ this trust was not strong enough and hence the supply from various consecutive resource partners took place without a contract.

Moreover, the results suggested that trust and contracts were complementary and could not fully substitute each other as has been suggested in Nooteboom and Gilsing (2004). Nevertheless, some substitution between trust and contracts did take place. For example in Case 4 ‘waste-wood fuel’ the subjects that the collaborators had less confidence in, were discussed in more detail during the contract negotiation. In other words, less informal certainty, i.e. trust, resulted in more efforts to construct formal certainty, i.e. longer contract negotiation and more detailed contracts.

5.4.6.2 Timing the agreements with multiple actors

Besides engaging resource partners, companies also collaborated with governmental organisations, technology providers, consultancies, maintenance providers, and some other organisations that influenced, or were affected by, the innovation (Figure 5.4). Multi-actor management was crucial because the outcomes of these collaborations had to come together at the right time, particularly regarding technology. Most of the technologies could
only handle a narrow range of resources. Otherwise they might operate below optimum which can increase operational and maintenance costs as well as cause emissions that are not covered in the permits. Thus resource specifications and technologies had to be discussed and agreed simultaneously in parallel processes with the resource partners and technology providers respectively.

5.4.7 Network diversification after innovation

5.4.7.1 Managing resource security

Once the innovation was realised, some companies perceived the increased dependency on resource partners as a potential risk which was then managed through network diversification strategies (Figure 5.3, Figure 5.4). For example, Case 4 ‘waste-wood fuel’ and Case 5 ‘waste oils and fats’ strived to have multiple suppliers or clients to increase resource security, i.e. being more assured that resources with the right specifications, in the right quantities would arrive/taken away in time and for the right price. They were mainly driven by economic targets. Converse to Case 4 and 5, Case 2 ‘agricultural feedstock’ adopted the waste-to-resource innovation as a side business (Table 5.4). Nevertheless, they also diversified their resource supply once the innovation was realised. Their motivation, however, was policy related. They were anticipating policy changes that might inhibit using their current resources for the purpose of energy generation. Hence they already started developing alternative supply relations to enable quick adaptation to policy changes and uninterrupted energy supply. Alternative resources were also already included in the environmental permit which would further expedite adaptation. In sum, these three participants strived to generate redundant diversity (also see, Jensen et al. 2011c) i.e. various resource partners that fulfilled the same role for them. This limited the impact that the loss of one resource partner could have on the continuity of the resource flow, thus provided greater certainty to meet operational, economic and regulatory targets. Conversely, Case 3 ‘refuse derived fuel’ and Case 1 ‘waste oils’ preferred to maintain less resource partners at a time, although both did have back-up options should any interruptions in the resource flow occur. Perhaps these companies wanted to limit efforts for this business activity as it was not their core business. Alternatively, network
diversification after the innovation process could be related to company size and associated cash flow: Only the small-medium sized companies (SME) diversified their resource networks after the innovation, while the companies that preferred to limit the number of resource partners were both large (Table 5.4). With less cash flow available than large companies, the SME’s would need to adapt faster to prevent financial issues.

5.4.7.2 Effects of network strategies on ego-network dynamics

Network diversity has been associated with increased stability and adaptability (also referred to as resilience) at various system levels (e.g., Korhonen 2001a; Nielsen 2007; Mayer 2008), whilst simultaneously network density is thought to increase when more resource synergies are established (Doménech and Davies 2011a; Paquin and Howard-Grenville 2012). In other words, network density and diversity are considered positively correlated. The results of this study, however, showed no clear relationship between network diversity and density, if anything network density in ego-networks (Figure 5.5) seemed to decrease when the companies diversified their network (Table 5.6) (also described by Walter and Scholz 2006).

Furthermore, although increasing network density was previously linked to increasing innovativeness (Mirata and Emtairah 2005; Doménech and Davies 2011b), this was not be confirmed in this study. If anything, the opposite was observed, since the most radical innovations were implemented by companies that opened their networks, which was associated with slightly decreasing network density. However, Case 4 and Case 5 did suggest that the first innovation between resource partners could lead to more innovations, but since these innovations happened within existing dyadic relations there was no effect on network density.

The divergence of the results when compared to some of the literature might be caused by a focus on different system levels as this study focused on the exchange level (such as, Paquin et al. 2014) and others on the regional level. It is not clear how the observed networking strategies at exchange level would manifest themselves at, for example, the regional level, and what impact this might have on regional network density, stability and
innovation performance. Such multi-level empirical exploration still needs to be carried out in industrial ecology (Mayer 2008; Paquin et al. 2014), and the results could be relevant when planning strategies for innovation.

![Figure 5.5: Ego-networks of the five participating companies. Although the data used for this figure are incomplete, this figure indicates that governmental organisations, and some companies, are in a central network position and could introduce companies to each other to promote waste-to-resource innovation. (Figure made with NodeXL)](image)

**Table 5.6: Network diversity, here represented as the number of actors in the ego-network at the different stages in the innovation process, and density, the number of established relations divided by the number of possible relations, in the ego-networks (see Figure 5.5) varied between the stages in the innovation process.**

<table>
<thead>
<tr>
<th></th>
<th>Before</th>
<th>During</th>
<th>After</th>
<th>Diversity</th>
<th>Before</th>
<th>During</th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1 'waste oils'</td>
<td>0.1168</td>
<td>0.1103</td>
<td>0.1108</td>
<td>27</td>
<td>30</td>
<td>29</td>
<td></td>
</tr>
<tr>
<td>Case 2 'agricultural feedstock'</td>
<td>0.1310</td>
<td>0.1200</td>
<td>0.1203</td>
<td>28</td>
<td>32</td>
<td>33</td>
<td></td>
</tr>
<tr>
<td>Case 3 'refuse derived fuel'</td>
<td>0.0471</td>
<td>0.0407</td>
<td>0.0407</td>
<td>66</td>
<td>76</td>
<td>72</td>
<td></td>
</tr>
<tr>
<td>Case 4 'waste-wood fuel'</td>
<td>0.3071</td>
<td>0.2717</td>
<td>NA</td>
<td>21</td>
<td>24</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Case 5 'waste oils and fats'</td>
<td>0.1190</td>
<td>0.1174</td>
<td>0.1174</td>
<td>32</td>
<td>33</td>
<td>33</td>
<td></td>
</tr>
</tbody>
</table>
5.5 From observation to promoting waste-to-resource innovations

This article made two main contributions: First, the results shed light on the actual activities and strategic considerations of companies that have realised waste-to-resource innovations and these results can be used to operationalise business strategies and government policies to promote such innovations in the future. Second, the results empirically review some general academic ideas about promoting waste-to-resource innovations i.e. industrial symbiosis and this opens new directions for future research.

5.5.1 Next steps for academia

The results indicate various avenues for further research but some stood out more than others, for example:

- Diversity and density network dynamics throughout the exploration and exploitation phases, including quantitative empirical research, studying multi-level network dynamics and effects on innovation performance.
- Extend the qualitative exploration to get a similar detailed understanding of the development of relations between companies adopting waste-to-resource innovations and governmental organisations, technology providers, network brokers and other organisations involved in the innovation process (Figure 5.4).
- Testing the idea that the geographic proximity between resource partners might be the result of a trade-off between economic benefits and resource security.
- The integration of policies for renewable energy and regulation to protect public health and environment in England needs urgent research to formulate solutions.

Besides these research suggestions, it is necessary to repeat (parts of) this study in other locations and/or on other types of industrial symbiosis (such as utility sharing and waste-to-resource innovations higher up the waste hierarchy) before making any wider generalisations. This study was mainly inductive and generalisations of the results can only be made with care.
5.5.2 Implications for governmental organisations

While developing a resource efficient economy would arguably be the result of many small steps (Koskela et al. 2013), the practical instruments for governmental organisations to make these steps are generally underdeveloped in Europe (Lehtoranta et al. 2011). This study provided practical insights into the actions that governmental organisations can organise and/or promote (e.g. Table 5) to help realising waste-to-resource innovations. Practical insights about the actions taken to support industrial symbiosis have been published before (e.g., (Bulkeley and Askins 2009; Laybourn and Morrissey 2009; Costa and Ferrão 2010; Paquin and Howard-Grenville 2012) but could be elaborated using insights from the ‘spontaneous’ symbioses observed in the case studies presented in this article. The success of top-down interference of governmental organisations has been variable (Gibbs and Deutz 2005; Mathews and Tan 2011; Behera et al. 2012), hence promoting waste-to-resource innovations bottom-up would be preferred (Desrochers 2004; Mayer 2008). For example, policy incentives such as the renewables obligation (Adams et al. 2011; Woodman and Mitchell 2011) were evidently important drivers in the presented case studies.

The results suggested some directions in which governmental organisations could promote waste-to-resource innovations. It is immediately clear from the network data (Figure 5.5) that governmental organisations are in key positions between companies. Particularly the Environment Agency, who regulates waste flows, is in a key position to analyse waste resource movements. That information could be used to identify larger waste streams and target sectors for waste-to-resource innovations. Companies in sectors that produce considerable amounts of certain wastes could be engaged in workshops to explore technical possibilities, emphasise potential economic benefits and discuss legislative possibilities. Additionally, information about waste resource movements could support companies that are already implementing a waste-to-resource innovation, for example to construct confidence about resource availability.

Governmental organisations could also help companies to develop track-records. Track-records were important during the innovation processes. For example, governmental organisations could help companies writing health, safety and environmental policies and
provide training to enable companies to monitor their performance in these areas. This kind of information was essential in almost all observed waste-to-resource innovations. Furthermore, governmental organisations could act as a credible information source regarding the performance of companies.

Finally, environmental regulation needs to be more flexible and evolve with the changing technical abilities to use wastes as resources in England. Naturally, regulatory bodies will need to ensure that no health and environmental risks are created, and for that they will need evidence. Companies can provide such evidence if they were given the chance to trial new waste resources and/or technologies. This evidence in turn could be used to adapt regulation rather than blocking safe and sound waste-to-resource innovations that could otherwise have contributed to the development of lower-carbon lower-material economies. In other words, waste-to-resource innovations could benefit from flexible progressive regulatory frameworks within which companies and regulatory bodies co-produce regulation (HarmoniCOP 2004; Richards et al. 2004; Breman et al. 2008). Rather than detailing extensive procedures, it could be more productive for both governmental organisations and companies to agree long-term targets and frameworks to ward health, safety and environment in its broadest sense, and then leave the ways in which these targets can be achieved open because such an approach is more conducive to innovation.

5.5.3 Implications for companies

Waste-to-resource innovations are collaborative processes that involve some degree of social learning. Hence experiences from participation processes could be used to optimise waste-to-resource innovation processes (HarmoniCOP 2004; Richards et al. 2004; Breman et al. 2008). In participation processes, activities and strategies are tailored towards process aims as well as multi-actor attitudes and knowledge, to manage a more efficient, effective and legitimate delivery of aims. One key consideration in participation processes is at what level actors are involved in the delivery of aims, varying from informing up to complete authority to make decisions (Breman et al. 2008). Generally, when an actor is engaged at a higher level, they would start to feel more responsible for the process delivery. Translating that into waste-to-resource innovations, if a potential resource partners, or other actors
such as governmental organisations and technology providers, would be engaged in the innovation process from an early stage and would be allowed to co-produce solutions for, or co-decide about, the innovation, then experience from participation processes suggests they feel more responsible to deliver their part of the agreement. Taking this even further, the same resource partner could be engaged to supply and use a (waste) resource, which was observed in Case 2 ‘agricultural feedstock’, because in this way the resource partner has a direct interest in supplying the resources as agreed.

To conclude, this article has demonstrated how companies have implemented waste-to-resource innovations. Although further research is required to justify broader generalizations, the coherency in the social processes during the observed waste-to-resource innovations show potential to develop a tool or guidelines for the development of these innovations. Such guidelines could help governmental organisations and companies to promote business activities, such as waste-to-resource innovations, that contribute to the transition to a lower fossil-carbon society.
Analysing the governance system for the promotion of industrial symbiosis in the Humber region, UK

This chapter builds on the theoretical explorations that were introduced in Chapter 3, and the results in Chapter 5, regarding the ways in which immergent processes of government actions may influence industrial developments. In doing so, research question b) How did the governance of, and policy and regulation implemented by, regional governmental and associated organisations influence biowaste-to-resource innovation? will be answered. The manuscript has been published in People, Place and Policy and the full reference is: Velenturf, A.P.M. (2016) Analysing the governance system for the promotion of industrial symbiosis in the Humber region, UK. People, Place and Policy, 10 (2):146-173. It can be found at doi 10.3351/ppp.0010.0002.0003.
Chapter 6: Analysing the governance system for the promotion of industrial symbiosis in the Humber region, UK

Anne P.M. Velenturf

Abstract

Government and industry increasingly recognise the need to develop a more circular, resource efficient and bioeconomy that is less dependent on fossil resources. Industrial symbiosis, in this study interpreted as biowaste-to-resource innovation, is a proven strategy to limit carbon emissions whilst increasing resource-efficiency and business growth. However, the effects of governance on the implementation of industrial symbiosis have remained under-explored. Hence this study analysed the governance system for biowaste-to-resource innovation in the Humber region, UK. Key individuals within governmental and associated organisations were interviewed in 2014. The results revealed that, since 2012, public sector cuts and sub-national governance changes resulted in the removal of several organisations from the regional governance network, while capacity within the remaining organisations decreased in terms of connectivity within and between governing organisations, delivered governance activities, and crucial resources including people, money, and knowledge and skills to promote resource innovation. Formal governance to specifically monitor, plan and promote (bio)waste-to-resource innovation is now virtually absent in the Humber region. This study recommends strengthening the governance for biowaste-to-resource innovation by a) increasing integration and flexibility of the regulatory ‘landscape’ across governmental departments at all governance levels; b) building better connections between national and regional level governmental organisations as well as within the Humber region; and c) investing in knowledge and skills as well as operational capacity of regional governance actors. These recommendations should contribute to restoring the balance between regional capacity and the national ambitions to promote biowaste-to-resource innovation as part of the circular bioeconomy.

Key words: Policy and regulation; Network governance; Industrial ecology; Resource efficiency; Biowaste-to-resource innovation; Circular and bio-economy
6.1 Introduction

6.1.1 Industrial symbiosis in the bio-economy

In the face of increasing resource scarcity and climate change, society urgently needs to move towards a more circular, resource efficient and bio-based economy\(^1\) that is less dependent on fossil resources (OECD 2009; Laybourn and Morrissey 2009; UNEP 2011; Dobbs et al. 2011; EC 2011a, 2011b; Lee et al. 2012; Lin et al. 2013; Finster and Hernke 2014; Hoffman et al. 2014; IPCC 2014; Morgan 2014; Rowney 2014). In the UK the development of a waste-based bioeconomy\(^1\) has been suggested as a strategy to reduce dependency on fossil and other finite resources, and constrain carbon emissions whilst generating economic benefits including increased sustainability and energy security (DEFRA and BIS 2012; Science and Technology Select Committee 2014; Government 2014, 2015a; Allen et al. 2015). Simultaneously, industrial symbiosis has been recognised as a strategy to promote resource efficiency and business development whilst limiting carbon emissions (Laybourn and Morrissey 2009; EC 2011a). Industrial symbiosis can be described as the development of working agreements between industrial and other organisations that, through the innovative reuse, recycling or sharing of resources, lead to resource efficiency (Jensen et al. 2011). Industrial symbiosis could contribute to the development of the bioeconomy through biowaste-to-resource innovation (Figure 6.1) (Velenturf 2016a).

![Figure 6.1: One kind of industrial symbiosis is biowaste-to-resource innovation which is similar to the waste-based bioeconomy, i.e. there is an overlap between industrial symbiosis and the bioeconomy (Science and Technology Select Committee 2014; Allen et al. 2015; Velenturf 2016a; Chapter 5).]
6.1.2 Governance of industrial symbiosis

Although the benefits of industrial symbiosis have been broadly recognised, understanding how it can be promoted by governmental organisations is limited (Velenturf and Jensen 2016; Chapter 2). Literature from the field suggests that successful promotion of industrial symbiosis requires a combination of top-down interventions that fit to bottom-up characteristics and processes, tailored to the context within which these innovations are to be developed (Ehrenfeld and Gertler 1997; Desrochers 2004; Gibbs and Deutz 2007; Park et al. 2008; Laybourn and Morrisset 2009; Costa and Ferrão 2010; Shi et al. 2010; Mathews and Tan 2011; Christensen 2012; Paquin and Howard-Grenville 2012; Jensen 2016). Although some practical insights to inform governance of industrial symbiosis have been published (e.g., Zilahy and Milton 2008; Laybourn and Morrisset 2009; Costa and Ferrão 2010; Paquin and Howard-Grenville 2012), practical instruments to support the implementation of resource efficiency policy and regulation, including measures to promote industrial symbiosis, are generally under-developed in Europe (Lehtoranta et al. 2011). Indeed, the effects of governance, particularly the actual activities of governmental organisations, on the implementation of industrial symbiosis have remained under-explored and need to be researched (Jiao and Boons 2014; Deutz and Loppollo 2015).

Empirical results have suggested that governmental organisations can either help or hinder in overcoming regulatory barriers during the implementation of industrial symbiosis (Velenturf 2015; Salmi et al. 2012). In other words, the way in which policy and regulation is implemented is important for the success of industrial symbiosis (similar to findings of e.g. Bulkeley et al. 2007; Flanagan et al. 2010, 2011). Yet the challenges governmental organisations face in the implementation of industrial symbiosis have rarely been documented (an exception is Geng et al. 2010). They need the knowledge and skills to make the many small steps that eventually lead to a more resource-efficient economy in which industrial symbiosis plays a key role (Koskela et al. 2013; Lehtoranta et al. 2011). The extent of such necessary knowledge and skills within governmental organisations requires further research (also see Deutz and Frostick 2009), in order to assess what roles and activities
could reasonably be expected from them and to formulate realistic recommendations for the promotion of industrial symbiosis.

Given the limited understanding of the governance of industrial symbiosis, literature suggests that it would be sensible to facilitate learning between governmental organisations and other stakeholders whilst governing in a flexible and adaptive manner. Such governance through network steering, involving partnerships between state- and non-state stakeholders (Bulkeley et al. 2007), is reflected in systems of innovation literature. Systems of innovation consist of 1) institutions guiding innovation and 2) the innovation network. While systems of innovation acknowledge the role that markets play in innovation, they emphasise the importance of networks. Innovation occurs through continuous interaction between actors. Hence, bringing the right actors and relations in place, whilst ensuring the effective functioning of the network, is key to learning and innovation (Tödtling and Trippl 2005; Chaminade and Edquist 2005; Lundvall et al. 2002). Systems of innovation have been adopted in research on sustainable transitions. In addition to technological innovation, transitions also require changes in institutions and social practices (e.g., Geels and Schot 2007; Bergh et al. 2011). In other words, transitions pertain to innovations that disrupt existing regimes (such as the linear and fossil-dependent economy) and instead contribute to emerging regimes (such as the growing circular bioeconomy). This focus on new disruptive industries puts transition governance in contrast to governance of innovation focused on strengthening existing industries (Alkemade et al. 2011). Industrial symbiosis can range from incremental innovations in existing industries up to more radical changes requiring regulatory changes or even the emergence of new markets, the latter showing resemblance to sustainable transitions (Velenturf 2016a; Velenturf et al. Submitted). These degrees of innovation may require a different governance focus, such as indicated by research on systems of innovation and sustainable transitions. However, both approaches require networks of heterogeneous actors that continuously interact during the implementation of policies in a flexible and adaptive manner (Bergh et al. 2011; Alkemade et al. 2011). Hence, similar governance structures and practices may be encountered in the exploration of governance systems for industrial symbiosis.
6.1.3 Empirical exploration of governance for biowaste-to-resource innovation

This article builds on Velenturf’s (2016a; Chapter 5) observations of how companies in the emerging bioenergy sector in the Humber region (UK) realised one specific type of industrial symbiosis: biowaste-to-resource innovations (Figure 6.1). In this study the interaction between the actors involved in the innovation process, such as the innovating company and governmental organisations, was identified as crucial. While some interactions between companies and local and regional governmental organisations worked well for the innovation at hand, others required improvement. It was suggested that knowledge of the industries, technologies, and (waste) resources within the governmental organisations played a central role in the ability to support the innovation processes. The way in which governmental organisations interacted with companies during the innovation process also proved to be important, for example in some cases interaction was perceived as extremely procedural while in other cases a more collaborative attitude was observed.

This paper builds on these findings and aims to extend understanding of the role played by local and regional governmental organisations in the Humber region in biowaste-to-resource innovations. Given the modest knowledge base for the governance of industrial symbiosis, this article presents a qualitative study analysing the governance system and exploring the following questions: 1) Who was involved in the governance; 2) What role governmental and associated organisations perceived themselves and others to play; 3) Through what activities they carried out their role; and 4) Why governance was delivered in this way. Ultimately this article aims to formulate recommendations for the governance of biowaste-to-resource innovation in the Humber region and beyond.

The next section introduces the Humber region, followed by the methods used to analyse the qualitative research gaps. Key findings are presented in “Perspectives from regional governmental organisations on the governance of biowaste-to-resource innovation”. The article concludes with a discussion and recommendations for governmental organisations.
6.2 Research setting: the Humber region, UK

The Humber region is located in the northeast of England. The Humber ports (Immingham, Hull, Grimsby and Goole) form one of the busiest port complexes in Europe. The region is a mature and diverse industrial area; in addition to the well-developed agricultural sector, main industries include food and wood processing, chemicals, metals, fuel and power facilities (Penn et al. 2014; NOMIS 2015; Jensen 2016). The high concentration of industries contributes to the wider Yorkshire and Humber region being one of the largest CO₂ emitters in the UK (Yorkshire and the Humber Regional Committee 2010). Hence this area could be pivotal in achieving the UK’s carbon reduction targets (Government 2009). Indeed, the Humber region has committed itself to the expanding offshore wind sector and identified opportunities in the bioenergy sector (Humber Local Enterprise Partnership 2014). Additionally, the Humber region has been identified as an opportunity-rich area for growth in the biochemicals sector (UKTI 2009). Finally, significant expertise regarding the uptake of (bio)waste-to-resource innovation has accumulated in the area. The Humber region is a known case study in the literature on industrial symbiosis and resource efficiency (e.g., Mirata 2004; Laybourn and Morrissey 2009; Jensen et al. 2012; Wang 2013; Velenturf 2015). In recent years various biowaste-to-resource innovations have been adopted in this area including, for instance, industrial plants converting fatty food wastes into biodiesel and anaerobic digesters converting food wastes into biogas and fertiliser (Laybourn and Morrissey 2009; Bondholders 2014).

The region is divided into four local government authorities situated around the Humber estuary. These are the North East Lincolnshire, North Lincolnshire, Hull City, and East Riding of Yorkshire Councils. Each largely has their own planning and development agendas and goals. Rooted in the fishing industry, the north and south bank of the Humber have been competitors in the past and the respective local authorities have been reluctant to collaborate on economic development. However, the fishing industry has dwindled and both sides of the estuary have been increasingly urged to collaborate on economic regeneration. The shared estuary with its strategically important geography for port development and offshore industry is seen as key to economic growth. In 2012 the Regional
Development Agency (RDA), which collaborated with the local authorities and worked on the development of the wider Yorkshire and Humber region, was dissolved. Instead, since 2012, the local authorities around the estuary, industry and various other organisations collaborate in the government-backed Humber Local Enterprise Partnership (Humber LEP).

While economic development and structural change are urgently needed, the region faces several innovation challenges. The Humber region has performed below the UK average for innovation and was characterised as an innovation follower (BIS 2011; EU 2012). In particular, it scored low in the uptake of environmental technologies (EU 2012). This is problematic given the central position the region aims to play in renewable energy supply, including bioenergy (Humber Local Enterprise Partnership 2014; Bondholders 2014). In contrast to other regions in the UK, Research and Development (R&D) is typically carried out within companies rather than being contracted out to other facilities (BIS 2011). Nevertheless, companies did collaborate for product and process innovation, for which knowledge was predominantly sourced within business groups or from suppliers and clients (BIS 2011). This may adversely affect potential for (bio)waste-to-resource innovation for two known reasons. First, given that companies in the Humber region mainly trade to regional and national markets, innovation may be negatively affected as evidence suggests that companies with both local and global connections have higher innovation performance (Asheim and Isaksen 2002; Broekel et al. 2010). Second, (bio)waste-to-resource innovations are likely to involve collaboration with a more diverse range of resource partners from previously unconnected industries (Chertow 2000; Jensen 2016). The National Industrial Symbiosis Programme (NISP) (Table 6.1) practitioners previously employed their in-depth knowledge of local businesses to develop cross-industry partnerships and promote (bio)waste-to-resource innovation (Laybourn and Morrissey 2009; Jensen et al. 2011). However, in 2012 NISP lost governmental support for its activities in the region.
6.3 Methods

6.3.1 Research approach

In the introduction it was argued that governance of industrial symbiosis is still a nascent area of research (also see Velenturf and Jensen 2016; Chapter 2). Qualitative research gaps were outlined, including practical governance instruments and the actual activities through which industrial symbiosis is governed, understanding challenges for governmental organisations, and the knowledge and skills that they need to support industrial symbiosis. Hence this study adopted a qualitative exploratory research approach (Mason 2002).

The realisation of industrial symbiosis involves waste-resource suppliers and clients, technology providers, governmental organisations and various other actors who may be engaged in the innovation process (Velenturf 2016a). As a result the governance of industrial symbiosis also needs to be collaborative in nature involving state- and non-state actors who are engaging through networks in a flexible and adaptive manner (as discussed in the introduction). Given the significance of understanding such networks, this study uses network analysis to explore how and why relations within and between governmental and associated organisations developed (Scott 2000; Borgatti et al. 2009; Hollstein 2011).

6.3.2 Data collection

During 2014, 17 interviews were carried out with individuals working in key roles within nine governmental organisations or organisations delivering tasks for/ supporting governmental organisations. Interviewees were identified through regional networking activities as well as online searches and referrals. Interviewees were selected on the basis of their job title/description and/or involvement in (biowaste-to-resource) innovation in the Humber region. The interviews were carried out in an open and exploratory manner in order to gather the interviewees’ accounts on a number of subjects. Interview questions had to be tailored to specific interviewees as they had different functions with often very different foci. Additionally, improvisation was necessary during the interviews, because competencies regarding biowaste-to-resource innovation, bio-based developments, or innovation in
general varied from almost absent to expert level. As such, the interviews could be characterised as edging towards ‘in-depth’ on the continuum from structured to semi-structured and depth interviewing techniques (Jones 2004; Bryman 2012).

Building on Velenturf (2016a), the initial plan was to focus the interviews on biowaste-to-resource innovation. However, in the engagement with potential interviewees it became clear that this focus was too narrow and it created a barrier in the recruitment of participants from some organisations. Hence the research focus was broadened to include all bio-based developments in the Humber region. This made the topic more familiar for potential participants and helped them identify and engage with the research. During the interviews, however, interviewees tended to either speak specifically about biowaste-to-resource innovation or, if this was not a particular focus in their work, about innovation and economic development in general. This was related to the interviewees’ roles, which will be further explained when presenting the key findings.

The interviews revolved around three main areas of questioning:

- General description and evaluation of the interviewees’ activities regarding biowaste-to-resource innovation and/or the bio-based economy.
- Network development including interaction with private and other public organisations.
- Collaborations to promote bio-based developments and biowaste-to-resource innovations.

All interviewees were assured of anonymity thus no personal names or job titles can be presented in this article. The regional governance network is relatively small and hence there is a risk of interviewees being identified through their statements. As such the use of direct quotes is also necessarily constrained in an effort to maintain interviewee anonymity.

6.3.3 Data preparation and analysis

The interviews were recorded and transcribed in full before the analysis. For some interviewees and/or organisations additional transcripts were available because research participants had been interviewed previously about general drivers and barriers for
industrial symbiosis in a related project (Penn et al. 2014; Schiller et al. 2014). In total 24 transcripts were available from 11 organisations (Table 6.1).

All data were analysed with conceptual and open codes through literal and interpretive coding strategies (Mason 2002; Bryman 2012). The final coding tree included codes to analyse network structure, interactions between actors, actor roles and activities, and capacity to support (biowaste-to-resource) innovations (Table 6.2).

The data fragments were interpreted for every code separately whilst also analysing relations between the codes. The multiple perspectives in the coded data were used to construct a valid and accurate argument (Mason 2002). In other words, the interviewees’ views on their own and on each other’s governance contributions were combined through the systematic analyses of coded fragments. The coded data were organised into a logic and coherent argument to gain insights into the governance system, according to the four introduced research questions (also see Table 6.2). The main argument that emerged from the analysis will be presented in the next section.
Table 6.1: Participants in 11 organisations were interviewed. Although the table provides a brief introduction to the organisations, this study questions and analyses their roles and activities in the promotion of industrial symbiosis.

<table>
<thead>
<tr>
<th>Research participants’ organisations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environment Agency (EA)</td>
</tr>
<tr>
<td>Delivering environmental regulation including Environmental permits; Waste; Low carbon energy; Energy efficiency; and more (Government, 2015d).</td>
</tr>
<tr>
<td>Humber Local Enterprise Partnership (Humber LEP)</td>
</tr>
<tr>
<td>The Humber LEP was formed by the four local councils around the Humber estuary and it is tasked with promoting regional economic development (Government, 2015c).</td>
</tr>
<tr>
<td>North Lincolnshire Council</td>
</tr>
<tr>
<td>Northeast Lincolnshire Council</td>
</tr>
<tr>
<td>Local councils are responsible for a broad range of services, including waste collection and recycling, planning permits, and environmental safety (Government, 2015b).</td>
</tr>
<tr>
<td>East Riding of Yorkshire Council</td>
</tr>
<tr>
<td>Hull City Council</td>
</tr>
<tr>
<td>Humber Chemical Focus (HCF), now HCF Catch</td>
</tr>
<tr>
<td>Supporting process, energy, engineering and renewable industries through networks, training, funding, and more – collaborating with local councils, Humber LEP, EA and other governmental organisations (HCF-Catch, 2015).</td>
</tr>
<tr>
<td>University of Hull</td>
</tr>
<tr>
<td>Delivering research and education, collaborating for knowledge exchange with businesses as well as local councils, Humber LEP and other governmental organisations (University of Hull, 2015).</td>
</tr>
<tr>
<td>National Industrial Symbiosis Programme (NISP)</td>
</tr>
<tr>
<td>Identifying and delivering business development opportunities through industrial symbiosis, in collaboration with businesses, Regional Development Agencies, local councils, EA and others (Laybourn and Clark, 2004).</td>
</tr>
<tr>
<td>Link2Energy</td>
</tr>
<tr>
<td>Waste and Resources Action Programme (WRAP)</td>
</tr>
<tr>
<td>Delivering research and funding whilst collaborating with industries, governmental organisations and others to promote resource efficiency and the circular economy (WRAP, 2015).</td>
</tr>
</tbody>
</table>

Table 6.2: Conceptual and open codes were developed during the data analysis to answer the research questions

<table>
<thead>
<tr>
<th>How was (biowaste-to-resource) innovation governed?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Who were involved in the governance system?</td>
</tr>
<tr>
<td>Activities</td>
</tr>
<tr>
<td>Interaction with companies</td>
</tr>
<tr>
<td>• How initiated</td>
</tr>
<tr>
<td>• Going well</td>
</tr>
<tr>
<td>• Needs improvement</td>
</tr>
<tr>
<td>• Important points</td>
</tr>
<tr>
<td>Interaction with governmental organisations</td>
</tr>
<tr>
<td>• Internally</td>
</tr>
<tr>
<td>• Externally</td>
</tr>
<tr>
<td>Collaborative culture in Humber region</td>
</tr>
<tr>
<td>Why was governance delivered in this way?</td>
</tr>
<tr>
<td>Available resources</td>
</tr>
<tr>
<td>• Time (to build relations)</td>
</tr>
<tr>
<td>• Money</td>
</tr>
<tr>
<td>• Knowledge and skills</td>
</tr>
<tr>
<td>• Demonstrated</td>
</tr>
<tr>
<td>• Discussed bio-based developments</td>
</tr>
<tr>
<td>• Gaps</td>
</tr>
<tr>
<td>• Attitude</td>
</tr>
<tr>
<td>• Policy and Regulation</td>
</tr>
<tr>
<td>• Supporting</td>
</tr>
<tr>
<td>• Constraining</td>
</tr>
<tr>
<td>• Sectoral governance, integrated industrial developments</td>
</tr>
<tr>
<td>• Suggested improvements</td>
</tr>
<tr>
<td>Geography</td>
</tr>
<tr>
<td>Recommendations to improve Humber context</td>
</tr>
</tbody>
</table>

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6.4 Perspectives from local and regional governmental organisations on the governance of biowaste-to-resource innovation

In this section findings from the interviews are used to answer the four research questions posed (Table 2), explaining who were involved in the governance system, followed by a comparison of roles and activities of governmental and associated organisations, revealing mismatches that will then be linked to resources and competencies present in the region.

6.4.1 Governance network

While participants agreed to be interviewed about biowaste-to-resource innovations and bio-based developments, discussion mostly broadened to economic development and innovation in general. Interviewees identified organisations involved in the governance network (Figure 6.2) and drew attention to how this had changed over time.

Since 2012 important changes occurred in the governance structure at local and regional level. Most notably, the RDA and various associated delivery bodies were dissolved. Additionally, NISP lost public support and, although it continued to exist, the services were no longer freely available and hence were not or could not be accessed by most of the organisations in the network. Simultaneously, the Humber LEP was initiated to bring together the four local councils, businesses and various other organisations involved in the economic development of the region. The changes in the governance system, which will be further discussed throughout the results, have had important consequences for strategic regional resource planning and delivery of associated industrial development, as demonstrated by this quote:

(...) there’s a lack of vision associated with that [investment in the economy] at the minute. There isn’t one from the government, because the government structures are no longer in place to be able to say this is the vision, this is the regulation, this is the direction that we want you to go in. The direction now needs to be articulated from people like the enterprise partnerships or from the sectors to be able to say, this is what we want in the Humber, this is where we want it, and then to work with local authorities to enable that to happen. (Local council interviewee 2014)
Figure 6.2: Network of governmental organisations and other organisations engaged in the governance of economic development and innovation in general, while some of these actors were also involved in biobased-developments and biowaste-to-resource innovation. Legend: Black boxes are organisations active in governance system in 2014; Silver boxes are organisations not active in governance system since 2012; Black lines are active connections; Black dotted lines are active connections since 2012; Silver dotted lines are inactive connections since 2012.

6.4.2 Roles of actors involved in the governance network

Interviewees identified a diverse range of roles when discussing economic development and innovation, under which they generally grouped bio-based developments and biowaste-to-resource innovation (Figure 6.3). The roles could be organised into regulatory and facilitative roles, which could have a more strategic or operational focus (Table 6.3). Aside from interviewees from NISP (and their regional delivery partner), EA, and WRAP who have worked on biowaste-to-resource innovation specifically, most interviewees could only play a general role in governing economic development and innovation as reflected in this quote:

Yes there probably are an awful lot of those synergies that should be happening, that maybe are (…), as a local authority it isn’t something that we would necessarily get so involved with (…) because we’re just not specialist enough to do that [initiating biowaste-to-resource innovation]. (Local council interviewee 2014)

Since 2012 there were no dedicated governmental organisations, departments or publicly funded programmes for regional waste-resource planning, bio-based developments, or (bio)waste-to-resource innovation in the Humber region. That is not to say that organisations did not dedicate resources to these developments, such as reflected in the bottom-right quote in Table 6.3.
Figure 6.3: Governmental organisations perceived to have a broad diversity of roles to support economic development and innovation, within which they usually included bio-based developments and biowaste-to-resource innovation. The roles could be organised into four categories (also see Table 6.3).

Table 6.3: Roles could be divided into regulatory and facilitative functions, and strategic and operational roles.

<table>
<thead>
<tr>
<th>Role</th>
<th>Regulator</th>
<th>Facilitator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strategic</td>
<td>Provide long-term framework within which economic development can take place</td>
<td>Forward planning through democratic processes, knowledge generation and lobby activities</td>
</tr>
<tr>
<td></td>
<td>“Now because of the way government subsidised different renewable energy schemes, the movement between kind of different opportunities renewable energy has shifted. And it is fair to say that the government subsidies had a huge shift in terms of what type of energy from waste or renewable energy take place, and originally there were high hopes for biomass type developments and they haven’t come to as big a fruition as we thought, and instead things like offshore wind have become the very big players, and that’s really because government subsidy which has been key to that.” (Local council interviewee 2014)</td>
<td>“It’s making sure that the place is right, so making sure that the infrastructure is right, that we are creating the right environment for business to either thrive, that our local business grow, or invest in the area from the outside. It’s making sure that people, workforce, is right.” (Humber LEP interviewee 2014)</td>
</tr>
<tr>
<td>Operational</td>
<td>Deliver and evaluate regulation</td>
<td>Deliver economic development through business support and network activities</td>
</tr>
<tr>
<td></td>
<td>“So we are a delivery body, which means we don’t set policy, and we don’t if you like set some of the initiatives that you referred to like renewable energy ROCs and things like that. Because we’re a delivery body and because we are specifically tasked with delivery of certain regulations that are given to us and a corporate strategy that has been given to us, protection of the environment, guardians of the environment, that is our role. Now we have checks and balances to ensure that we are risk-based, that we are proportionate and that we support not only environmental protection but appropriate sustainable development.” (EA interviewee 2014)</td>
<td>“So things like [large-scale bio-based development], for example, there was a team member within the economic development department of [local council], almost exclusively working with [large-scale bio-based development]. Because they want that development, so there will be a planning officer and an economic development officer and potentially somebody from employment working with that company to help them through that process to just get it in and to make it happen.” (Local council interviewee 2014)</td>
</tr>
</tbody>
</table>
6.4.3 Activities to deliver governance roles

This section analyses how the governmental organisations, and associated organisations, carried out the roles that were identified in the previous section. The main activities put forward by the interviewees were the organisation of, and participation in, network activities; Sign-posting companies towards others involved in the governance within the region, and linked to that, communicating between companies and governmental organisations; Attracting funding into the region and cascading it through the governance system until it reaches e.g. companies; And finally the commissioning and carrying out of research (Table 4). A local council interviewee outlined the character of their activities:

So our role is very much hand holding, making connections, networking, supporting through planning processes, through the project process, through recruitment of the workforce, it’s signposting as well... (Local council interviewee 2014)

It is notable that for almost all activities, interviewees reported that capacity had reduced since 2012 (Table 6.4).

Comparing the roles (i.e. what governmental and associated organisations perceived they should be doing) to the activities (i.e. what they were actually doing) revealed mismatches which presented themselves in a variety of forms. Most interviewees talked about innovation in terms of having a role in research, R&D and business development. However, it was much harder for them to explain how innovation was actually promoted through their activities. Similarly, while various local strategies discuss the promotion of innovation, interviewees questioned whether enough operational capacity was available within the governance system to implement such strategic aims (further detailed in the next section).

For example, in some councils R&D facilities have been prepared for companies, as captured in Table 6.4 under ‘Provide research facilities’, but these facilities have never been used for R&D purposes to the best of the interviewees’ knowledge:

...that [R&D spaces] was developed in the days of the Regional Development Agencies which in our case was Yorkshire Forward, and prior to Yorkshire Forward being dissolved along with all the other RDAs, there should have been two funding streams. One was the capital funding stream which basically got the building built, which happened but there should also have been a revenue funding stream which was there to develop the higher end [i.e. higher-end uses for by-products] and that never happened. (Local council interviewee 2014)
While a mismatch was perceived between roles and activities for innovation specifically, the mismatch between roles and capacity to deliver on technical, environmental and resource management advice was even more visible (see e.g. ‘Regulatory advice’ in Table 6.4). These roles were partly carried out by NISP, whose public funding was stopped. Moreover, funding cuts also reduced capacity within the local councils and the EA (further discussed in the next section) to deliver on environmental planning, protection and management which also affects the ability to support biowaste-to-resource innovation, as expressed in the following quote:

Ten years ago (...) the Environment Agency had all the expertise it needed to support industrial symbiosis and development. In terms of technical expertise, people who had experience of all the industry sectors which had potential opportunities. (…) Unfortunately now, ten years later, particularly right now this year, I don’t feel it has either the technical expertise, or even the number of people now that it would need to support industrial symbiosis. (EA interviewee 2014)

A different kind of mismatch could be identified in the EA’s roles and activities. While the organisation’s core role is to prevent pollution and harm to the environment and human health, part of the activities (such as during permit applications/exemption procedures) is the assessment of economic benefits, which seems to go beyond their role as it does not contribute to assessing environmental effects of industrial activities.
Table 6.4: Activities carried out by governmental organisations and associated organisations. Legend: Black means activity carried out by the organisation, Dark grey is activity carried out by fewer people/departments in that organisation since 2012, and Light grey is activity not carried out anymore by that organisation since 2012 in the Humber region. In the bottom row, downward arrow indicates reduced capacity, and 0 means capacity remained similar.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Local councils</th>
<th>Environment Agency</th>
<th>University &amp; other research institutes</th>
<th>HCF Catch</th>
<th>Humber Local Enterprise Partnership</th>
<th>National Industrial Symbiosis Programme</th>
<th>Regional Technical Advisory Body</th>
<th>Aggregates Working Party</th>
<th>Regional Development Agency</th>
<th>Governance system overall</th>
</tr>
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An important mismatch was observed between generalist governance activities and the specialist activities required to support biowaste-to-resource innovation. Network activities were an important part of delivering governance within the Humber region. General open networking activities could be distinguished from subject-specific forums. This nurtured the idea that perhaps two broad types of governance processes and associated networking activities could be distinguished: General governance activities to maintain basic processes, such as infrastructure maintenance and general education, and activities to govern specific changes, such as structural regional economic development including the emergence of new sectors and/or the (re)development of industrial areas. This idea needs further thought, but there were indeed various projects and programmes within the Humber region to deliver specific changes, such as the Green Port Growth Programme which is focused on supporting businesses to capitalise on large-scale developments particularly in the offshore wind industry. Business support activities, such as presented in Table 6.4, are offered through this programme. Although the motivation to provide bespoke and even specialist support was observed in the organisations involved (local councils, Humber LEP and universities), it was difficult to achieve with the funding available within the programme. Funding enabled generalist activities which led to identifying the need for specialist support, such as for research and training, but additional funding application was often necessary to deliver it, as described in the following quotes outlining the generalist and specialist support:

*With the Green Port Growth programme we have a number of partners. The business support strand should really be the first interaction. And what the business support will do, it will go into a company and do an audit of that company to see where it is now, where it needs to be, where it wants to get to, where its opportunities are. And then from the initial audit it will then maybe draw specialist consultancy (...) It may well have a technology that needs to develop, so the University of Hull lead on that programme (...) We’re generalist, we don’t specialise in, go in with one particular thing.* (Local council interviewee 2014)

*It might be that they just need a couple of days specific consultancy from an academic or an R&D professional and it might be the University of Hull that can provide that, or it might be that they need a bit of proof of concept work doing and we can help them with that or it might be that it’s obvious that they need a bigger piece of funding that the R&D director and his pot of money will be used to help develop that even bigger research bid.* (University of Hull interviewee 2014)

The predominantly generalist approach, and the associated funding allocation, seems to be inconsistent with the delivery of specialist activities required for specific projects and
programmes. However, operationalising and delivering specific targets requires resources such as money, people and knowledge, which were not always present within, or could not be acquired by, the organisations involved (further explained in the next section).

Summarising the comparison of perceived roles and actual activities, there seem to be issues with delivering sufficiently specific innovation support, environment, and waste and resource management at the regional level, all of which are directly relevant to biowaste-to-resource innovation.

6.4.4 Competencies in governance network

Competencies within governmental organisations were perceived by companies as important in overcoming or strengthening legislative barriers (Velenturf 2016a). Additionally, the preceding results indicate that there have been some dynamics in the competencies. Hence this section further analyses the three components of competencies, attitude, knowledge, and skills, within governmental and associated organisations and implications for biowaste-to-resource innovation.

6.4.4.1 Attitude

When discussing attitude, the importance of flexibility was brought up almost unanimously by the interviewees. While interviewees perceived some departments of governmental organisations as more flexible, which was also associated with openness, being proactive, collaborative and entrepreneurial, others were considered inflexible, which was associated with working in a highly structured, rigorous, precautionary and sometimes overly bureaucratic manner. Flexibility varied because of 1) role and focus, 2) policy and regulation, 3) knowledge and skills, 4) people and money, and 5) timing of interactions.

Role and focus: The degree of flexibility that a department could provide was associated with their role. For example, regulatory departments were generally perceived to have less flexibility than economic development departments. This was also related to the focus of a department which was partly determined by the policy and regulation being developed
and/or implemented (compare for instance quotes about regulators and facilitators in Table 6.3).

**Policy and regulation:** Different actors have varying degrees of power and responsibility to develop and/or implement policy and regulation. Furthermore, despite what might seem intuitively right, the *amount* of policy and regulation did not appear to be directly related to the flexibility that a department could provide. For example, it was suggested that the EA had to implement much new waste regulation since 2007 which arguably made them less flexible in their interaction with companies. Conversely, the councils’ planning departments saw regulation for waste developments being withdrawn (Government 2014), and perhaps this decreased amount of regulation should have sped up planning applications, but in reality it incapacitated them to make decisions as expressed in the following quote:

> All of those [planning policy statements] went and they were replaced by something called the NPPF, the National Planning Policy Framework and that covers everything, it covers residential, it covers environment, it covers minerals, it covers every aspect of planning, but it doesn’t cover waste, because waste is intended to have its own separate national policy but we’re still waiting for that, so we’re just in a policy vacuum really. (Local council interviewee 2014)

**Knowledge:** Simultaneously, planning departments also increasingly experienced knowledge gaps necessary to satisfy their regulatory obligations during planning applications. Interviewees in other departments and organisations also observed how knowledge gaps appeared in recent years (further discussed below in “Knowledge and skills”). Generally, knowledge of policy and regulation as well as markets and industrial processes supported a more flexible attitude towards potential economic developments, although knowledge requirements did vary between departments. Acquiring and processing knowledge requires the right amount of people with the right competencies. However, particularly the EA (see quote on p16) and local councils have lost knowledge capacity because restructuring and austerity measures led to redundancies in these organisations (also see, EA 2015a; LGA 2014; NAO 2014).

**People and money:** The number of redundancies, particularly visible in EA and councils’ environmental departments, coincided with the stop in public funding for a) NISP and b) the network meetings for local council planning officers working on waste (Regional Technical
Advisory Board in Figure 6.2). It appears that environment and waste have been downgraded as a priority at national government level, and as a result lower government levels have reduced resources to work in a proactive and flexible manner with companies on (bio)waste-to-resource innovations. However, with circular economy and resource scarcity rising on the political agenda, interviewees suggested that these measures should be reviewed as there is a need to improve governance of waste and resource management such as suggested by this interviewee from the EA:

> What the Environment Agency needs to do is train its staff to be regulators. By that I don’t mean people who just go out and visit sites and inspect sites and stop everything, that’s not what I mean by being a regulator. I mean to be able to go onto a site and say to a site operator, what you’re doing is causing a problem, let’s work together to solve that problem. (...) So what we need to do is have in place people who can hold those conversations and work in that collaborative way, cause we solve our environmental problem, they solve their waste disposal or financial problem. (EA interviewee 2014)

**Timing:** Timing was important in relation to flexibility, because regulators could be more flexible and open before permit application processes start. During permit applications they need to follow procedures and have less flexibility to advice applicants. Conversely, as one local council interviewee explained, before the application process there is more space to collaborate and provide guidance to increase chances for a successful permit application:

> (...) definitely best beforehand when they’re still in that development stage where (...) they’re still kind of at the drawing board almost. (...) whereas obviously once it’s at planning application stage it’s either take it or leave it but there isn’t much chance to kind of redesign it. So from my point of view that’s best to do it up-front. (Local council interviewee 2014)

However, regulators often perceived to be engaged too late and as a result they could not be as flexible as they might want to be. As a result companies and other departments, such as economic development, perceived the regulators as too inflexible and engaged them even later in subsequent developments which worsened the interaction. This suggests that breaking this spiral could benefit proposed economic developments. At the moment, however, interviewees suggested that government employees do not have any performance indicators for collaboration. In other words, no performance boxes are ticked by spending time and resources collaborating within and between governments. Instead, whether or not collaboration takes place comes down to the individual employee.
6.4.4.2 Knowledge and Skills

The previous section indicated that knowledge availability could impact on attitudes within governmental and associated organisations. This section will first outline knowledge and skills gaps regarding bio-based developments involving biowastes, and then analyse knowledge and skills that were available within the governance network. The results will suggest that some issues with knowledge and skills could perhaps be resolved by ‘rewiring’ the regional governance network.

The interviewees identified a broad range of knowledge gaps regarding bio-based developments (Table 6.5). The gaps can be grouped into questions regarding social and metabolic networks. Understanding social network developments pertains to knowledge about promoting innovation, particularly through collaboration between governmental organisations across all governance levels and also within the Humber region through public-private interactions. Understanding metabolic networks pertains to knowledge about existing and future resource flows, such as expressed in the following quotes respectively:

*We have some technical knowledge gaps. One of the difficulties is, we have to make these risk-based decisions and the more uncertainty we have, the more tendency there is to have the precautionary approach. And the precautionary approach is an area where conflict can exist with industry because they want to be more risk-taking and they perceive us to be risk-averse (...) So some complex wastes, it’s quite difficult to be confident that we’ve identified all the hazards and then as a result managed appropriate risks from that hazards. So we are at the moment doing some research work trying to improve that knowledge gap, but that is one aspect where we speak to industry and we say, you need to better characterise your waste, then we can reduce our uncertainty and as a consequence we will be less risk averse. (EA interviewee 2014)*

*What I think is missing is a, almost a strategic plan or overview of what is happening in the whole of the waste sector (...) with a view to actually, I guess plan into the future in terms of what those waste streams are going to be and what facilities are going to be available. (Local council interview 2014)*

Analysing the knowledge gaps regarding metabolic networks, the demand for knowledge on quantity and quality of resources was directly present in council departments such as inward investment (for example: is a development using a certain resource flow viable?) and planning (for example: is it safe?). This demand could not be satisfied at all times. Councils could only meet these knowledge needs if they had the network and budget to acquire
knowledge via a specialist consultancy, but this was not within range of all local councils. Councils previously obtained information on resource and waste flows via, amongst other routes, the RDA and NISP, but these disappeared from the regional governance system in 2012.

Having observed significant knowledge and skills gaps, the results also suggested that these knowledge and skills were partly present within the regional governance network already (Table 6.5). For example, interviewees generally were well-aware of the bio-based developments in their (local) area. Some interviewees also had good knowledge of technologies and resources which supported their varying governance activities, particularly when combined with understanding the associated market and/or regulatory environment and collaboration skills to overcome challenges. However, the data on knowledge and skills present in the governance network was much thinner and more scattered over various subjects and organisations when compared to the fairly coherent knowledge gaps. Nevertheless, a comparison of the missing and present knowledge and skills suggests that a part of the problem could be solved by ‘rewiring’ the governance network, i.e. connecting people who do have the knowledge and skills with people who also need them.
Table 6.5: Comparison of missing and present knowledge and skills within the regional and local governance network.

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<thead>
<tr>
<th>Knowledge and Skills Gaps</th>
<th>Metabolic networks: Understanding current and future resource flows.</th>
<th>Social networks: Understanding innovation and collaboration across governance levels and within the region.</th>
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<td>What are the resource characteristics exactly?</td>
<td>How do people innovate?</td>
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<td>What are the environmental benefits and potential risks?</td>
<td>How can innovation be planned for?</td>
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<td></td>
<td>Which resource flows are present?</td>
<td>How are people collaborating now for (bio-based) innovation?</td>
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<td></td>
<td>Which bio-based developments are realised?</td>
<td>What role do individual people/organisations play in innovation?</td>
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<td>Who produces what? Who uses what?</td>
<td>How much capacity, (people and their skills and knowledge) is needed to support bio-based innovation?</td>
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<td>What does the whole resource network look like?</td>
<td>How much money and time is needed?</td>
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<td>How could resource flows ‘fit together’ better?</td>
<td>What is industrial symbiosis/(bio)waste-to-resource innovation and how can it help achieving policy/regulatory and economic targets?</td>
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<td>What are the future economic challenges and opportunities?</td>
<td>How can strategic and operational governance levels be linked:</td>
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<td>Which industries could be attracted into the region and how could they fit in the resource network?</td>
<td>How can bio-based plans be implemented?</td>
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<td>How can ‘technical’ knowledge about innovation processes and bio-based developments be accessed/made known to strategic governance levels?</td>
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<td>Knowing what industries look like now.</td>
<td>Understanding how to collaborate, innovate, network, and/or learn.</td>
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<td>Network knowledge of industrial symbiosis/ bio-based collaborations.</td>
<td>Knowing how to innovate and where knowledge and money could be sourced.</td>
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<td>Technical knowledge of bio-based developments.</td>
<td>General understanding of business support.</td>
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<td>Resource knowledge enabling the regulating of developments.</td>
<td>Understanding how regulators and business could collaborate.</td>
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<td>Planning control knowledge about bio-based developments.</td>
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<td>Insider understanding of bio-based/industrial symbiosis developments.</td>
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<td>Experienced-based advanced collaboration skills regarding waste-to-resource and bio-based activities.</td>
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<td>Understanding how the waste market works.</td>
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<td>Understanding the strategic, technical and commercial challenges and knowledge requirements to bring developments into practice.</td>
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Skilled networkers have left/ are leaving councils, EA and NISP; When RDA and NISP disappeared from the regional network, not all critical skills were maintained or transferred to other organisations.

Table 6.5 demonstrates the need to generate new knowledge through research activities. Interviewees distinguished academic, regional, commercial and R&D knowledge. It was suggested that different actors were better positioned to deliver these knowledge types. However, in general, interviewees perceived that universities are expected to deliver on all these knowledge types, while universities might actually be neither best positioned nor
have an interest in participating in all research activities. For example, commercial knowledge was observed to be developed by companies during their trading activities and this did not require a research institute at any time. In other words, it was suggested that the generation of various knowledge types, and the organisations that need to be involved, requires rethinking at a strategic and operational level. This observation is linked to the knowledge gap about effectively linking strategic and operational levels in the governance network (Table 6.5), which is linked to the discussed network changes (Figure 6.2). Having discussed roles, activities and competencies, the next section will expand on the effects of the network dynamics on the functioning of the whole regional governance network which also affected biowaste-to-resource innovation.

6.4.4.3 Effects of network changes on governance for the biowaste-to-resource innovation

Elaborating the knowledge gap regarding ways to effectively link EU/national and regional/local governance levels (Table 6.5), there are various high-level legislative drivers to promote economic development, carbon reduction, waste reduction and resource circulation, but these ambitions seem disconnected from an understanding of regional/local level governance responsible for the implementation of (parts of) these ambitions. The interviewees did indeed indicate that councils do have strategies covering subjects relevant for biowaste-to-resource innovation, such as sustainable development, climate change, resource efficiency, natural resources, and innovation. However, there is insufficient capacity in terms of staffing, money and competencies to operationalise these strategies, educate the staff involved and ultimately to deliver the strategies. Similarly, Eadson (2008) observed that the responsibility for the climate change mitigation strategy was devolved to local authorities, while the power to achieve carbon reduction targets remained with the national government. He continued to argue that the potential to achieve such targets needs to be present at each governance level. Before 2012, the RDA played an important role in connecting the higher and lower governance levels through the creation and exchange of knowledge, since then the Humber LEP could only partly take over this function.
The dissolving of the RDA and creation of the Humber LEP had positive and negative consequences for the regional governance network. The main advantage of the Humber LEP is that they are based in the region and perceived to be much more involved in the development of the Humber region when compared to the RDA, which was perceived to be based too far away (in Leeds) and to prioritise economic development in other parts of Yorkshire and the Humber. Conversely, the dedicated Humber LEP has promoted more joined-up thinking and aligning of visions and objectives within the region as expressed in the following quote:

*Internal politics can be detrimental for the Humber region. I do think it’s improved under the LEP (...) I think there is still work to be done around the different councils, the different councils and the LEP. I think there still needs to be more of this unification, more a single voice from the Humber, so everybody on the Humber working together, that can only be better for industry.* (University of Hull interviewee 2014)

However, being an organisation almost completely consisting of public and private partners active in the Humber region at this moment in time, they are also constrained by their own perspectives. The organisations involved in the Humber LEP are experts on what they are doing in the region now, not on what might happen in the Humber region in the longer term. In contrast, the RDA was better placed to develop a more global and longer term perspective on regional development relatively independent from current public and private actors, and as such it was in a position to identify potentially important future structural economic changes that were not necessarily in the interest of private partners active in the region already. One interviewee detailed how the RDA could bring new technologies to market:

*Well I think that you had experts [in RDA] in kind of energy field, chemicals field, who were not tied to a single company, who kind of had one thought in a research type camp, so they understood new technologies coming along but then had public funding and money to try then to collaborate with industry, trying to bring some of that stuff to fruition.* (Local council interviewee 2014)

This operational capacity tied into more ‘independent’ strategic planning capacity has now largely disappeared from the regional governance system and this could impact on the long-term economic resilience of the region.

Besides the changes associated with the dissolution of the RDA, interviewees suggested that the local councils and EA also had experienced important changes in the operational capacity to support (biowaste-to-resource) innovations. The EA had to make a large
proportion of officers redundant (also see EA 2015a). Consequently interviewees indicated that they had to focus on their core task, which is regulating, leaving less space to deliver other tasks such as engagement and providing guidance. This was considered to be an issue particularly for the emerging and growing biowaste sector (also see EA 2015b), which has seen many start-ups and an influx of new companies as well as continuously emerging innovations and new challenges:

*I mean the waste sector is a developing sector, it’s becoming more technically difficult in the waste sector with increasing waste-to-energy plants. But if you look at traditional waste sector, which is skips and general waste disposal or landfill sites, it doesn’t tend... it is regulated a lot stricter because the law itself, for waste, is a lot more prescriptive, it is a lot more black and white, you will do this or you will do that. Whereas for chemical sites, you will do this somehow, it’s left more open to the actual individual site to determine what they should be doing.* (EA interviewee 2014)

Moreover, NISP previously played a key role in solving regulatory problems, particularly regarding innovative resource flows, in collaboration with the EA. The EA anticipated issues arising from the resource innovations facilitated by NISP:

*We thought there could be all sorts of issues that would come our way anyway as the environmental regulator and that it would be better to be handle it early in the discussion rather than having to fire fight when problems came along.* (EA interviewee 2014)

However, that collaboration to solve regulatory issues ended when public funding for NISP was stopped.

The EA also faces increasing challenges because of biowaste developments coming forward, which tend to require involvement of various teams. Interviewees indicated that these developments tend to involve a wide range of diverse activities which tend to be regulated by different teams. In some cases also referrals outside the EA were required. Hence these integral developments within a largely sectoral governance system present both networking and regulatory challenges for the EA and the companies involved.

Concluding this section, it is clear that rather than reducing network connectivity and capacity within and between governmental and associated organisations, there is a need to increase capacity within the whole network and enable better network connectivity through the provision of required resources in order to promote biowaste-to-resource innovation.
6.5 Discussion and recommendations

Summarising the results, since 2012 organisations such as NISP, the Regional Technical Advisory Board for waste planners, and the RDA lost public funding and/or were dissolved whilst simultaneously the EA and local councils faced severe funding cuts. As a result, capacity to deliver the majority of governance activities decreased, which included activities that are of key importance to biowaste-to-resource innovation such as researching and producing and managing data on resource flows. Indeed, knowledge gaps regarding these activities and other subjects were identified. Knowledge gaps were linked to less flexible attitudes which were also reflected in the reduced capacity to solve regulatory problems. The introduction of the Humber LEP into the governance network did improve connections between the actors around the Humber estuary which promoted more joined-up thinking for economic development. This increasing connectivity within the governance network could contribute to channel knowledge and skills from places in the network where it is present to places where it was perceived to be missing. However, aside from economic development, the Humber LEP seems to have less capacity than the RDA to support implementation of government policy and regulation on for instance innovation for carbon reductions and increased resource efficiency in collaboration with the local councils and the existing business community. As such, the linkages between EU/national and regional/local level governance have weakened on subjects that are important for the promotion of biowaste-to-resource innovation. Finally, it should be concluded that formal governance to specifically monitor, plan and promote biowaste-to-resource innovations or other bio-based developments is almost completely absent in the Humber region.

6.5.1 Network governance and biowaste-to-resource innovation

This research was an attempt to gain an understanding of a complete regional governance system for industrial symbiosis from the perspective of the governmental organisations that were involved. It documented practical insights in the form of perceived roles and activities while registering the challenges summarised above. The adverse effects associated with decreasing capacity within the network gives some weight to the envisioned importance of network governance (Lundvall et al. 2002; Chaminade and Edquist 2005; Tödtling and Trippl
2005; Alkemade et al. 2011; Bergh et al. 2011). Furthermore, it explained some of the variations in government attitudes when engaging in industrial symbiosis, which either help overcome or, alternatively, strengthen barriers when companies implement resource synergies (Salmi et al. 2012; Velenturf 2015). Consequently it can be concluded that this research has made original contributions to industrial symbiosis literature.

The contributions are, however, inductive in nature and require further research to consolidate the findings. Transferability of this research needs to be studied because, although all English regions were affected by similar changes in the organisational composition of the networks, the austerity measures for the EA and local councils may have been received and dealt with differently in other areas of the country. For example, Wells et al. (2011) argued that the, relatively deprived, councils in the Yorkshire and Humber region were particularly vulnerable to public spending cuts as they had fewer reserves to buffer the effects of austerity measures on a wide range of services. Furthermore, a more comprehensive comparison of the role of network governance and other forms of governance (see e.g. Bulkeley et al. 2007) within England would be valuable in understanding how resource innovation and particularly industrial symbiosis can be governed most effectively. Additionally, it would also be valuable to repeat such comparison in countries where models of promoting industrial symbiosis, ranging from self-organised to fully planned, have had varying success (Shi et al. 2012). Finally, the more practical question pertaining to improving the existing governance system for industrial symbiosis deserves further attention (discussed in the next section).

### 6.5.2 Recommendations for the governance of biowaste-to-resource innovation

This research has analysed how capacity within the governance network in the Humber region has decreased since 2012 and explored the ways in which this was perceived as problematic. Therefore this final section turns to the question: how can the governance network for biowaste-to-resource innovation be strengthened?

Within a context of decaying politics acting upon climate change and environmental protection (While 2013), the results showed decreasing governance capacity within the
regional network. Nevertheless, biowaste-to-resource innovation (as part of a growing movement towards the circular and bioeconomy) has been gaining momentum at the EU and, arguably, national levels of government (DEFRA and BIS 2012; Science and Technology Select Committee 2014; Government 2014, 2015a; EC 2015; Velenturf et al. Submitted). Plans to promote the bioeconomy focusing on waste, i.e. biowaste-to-resource innovation, are still at an early stage. An initial strategy has been outlined and potential governance measures have been analysed and recommended to national government (Government 2015a; Allen et al. 2015). The government’s strategy largely focuses on promoting collaboration between industry and academia whilst the strategy itself is a collaborative result from various governmental departments (including DEFRA, BIS, DECC, DFT and DCLG). It is certainly encouraging to see actions being taken to build the innovation ‘ecosystem’ for the bioeconomy as well as the governmental collaborations which could lead to more integration of the relevant areas of policy and regulation. However, the current plans do not recognise the limited capacity within the regional governance system to engage in the proposed collaborations and to operationalise national government strategies and plans. In fact, the crucial role of the regional governance system in terms of planning and environmental permits and attracting inward investment, for instance for the envisioned innovations, does not seem to be recognised at all. Hence it would be worthwhile for the national level governmental departments to engage more directly with the actors in the regional governance network to gain a more realistic understanding of present capacity. To increase regional capacity, the results of this research suggest that the UK government needs to work with the regional governance actors to dedicate the resources for attracting expert knowledge on both technical and social aspects of biowaste-to-resource innovation and also for training regional governance officers in emerging technologies.

Increasing regional capacity is essential in the uptake of biowaste-to-resource innovations. A range of policies and regulations come together at the regional level when a company initiates a biowaste-to-resource innovation – consider for example the Renewables Obligation, Landfill Tax, Environmental Permitting regulations, and the National Planning Policy for waste (introduced shortly after interviews for this study were completed, see DCLG 2014). These policies and regulations are not necessarily aligned with each other, (Rotherham 2010: p35) reports an ‘almost total absence of a genuine joined-up vision for
the future’, or with the innovation at hand. Therefore regulatory constraints need to be solved (Material Security Working Group 2015; Allen et al. 2015; Velenturf 2016a; Chapter 5). This requires flexibility from governmental organisations which, as pointed out in this study, depends in part on the knowledge and skills of the officers involved \(^2\). Moreover, it may require collaboration within and between governmental organisations in the Humber region as well as the associated departments at the national level (for instance, local councils and DCLG; Environment Agency and DEFRA), particularly when regulatory changes need to be carried through in an efficient manner (similar to suggestion by Zhu et al. 2014). A new regional working group/coordinator to solve regulatory problems and, when necessary, communicate with the national level departments could be useful to streamline the processes and concentrate expertise on this subject \(^3\) (such as York North Yorkshire and East Riding LEP 2015). Interviewees suggested that this task used to be carried out by the RDA and NISP but the connections and expertise dispersed or completely disappeared in 2012. The suggested working group or coordinator could also contribute to the implementation of national level strategies and plans for the bioeconomy (also see Allen et al. 2015).

In sum, it could be suggested that the governance for biowaste-to-resource innovation in the Humber region needs strengthening by a) increasing integration and flexibility of the regulatory ‘landscape’ across governmental departments; b) building better connections between national and regional level governmental organisations as well as within the Humber region; and c) investing in knowledge and skills as well as operational capacity of regional governance actors. These recommendations should contribute to restoring the balance between regional capacity and the national ambitions to promote biowaste-to-resource innovation.

Notes

1 In this study the bio-based economy was interpreted as the usage of biomass for materials, chemicals, fuels and power, and the bioeconomy also includes the use of biomass for food and feed.

2 Knowledge and skills gaps of regional governance actors were unfortunately overlooked in the “Skills for a green economy” report (Government 2011).

3 Interviewees recommended a ‘NISP 2.0’ (see, (Laybourn and Morrissey 2009).
Evolution of industrial symbiosis: Harmonising top-down and bottom-up processes

This chapter draws together and extends the findings on bottom-up (Chapter 5) and top-down (Chapter 6) processes, to explore whether, and if so how, these processes are influencing each other during the evolution of industrial symbiosis, and in doing so it answers research questions c) How did top-down processes, such as developments in markets and governance, and bottom-up processes, such as network development during biowaste-to-resource innovation, mutually influence each other over time? This manuscript builds on published and on-going research into macro-, meso, and micro-level dynamics during the evolution of industrial symbiosis and is in the final stages of formulation for submission for publication. Paul Jensen has written parts of the analysis about NISP’s development (7.4.1.1) as well as providing general feedback on the whole manuscript. Richard Murphy contributed to the argumentation outline and reviewed earlier versions of the article. The policy analysis used in this manuscript was built on Frank Schiller’s original unpublished analysis used within the ERIE project, who also reviewed the manuscript.
Chapter 7: Evolution of industrial symbiosis: Harmonising top-down and bottom-up processes

Anne P.M. Velenturf, Paul D. Jensen, Richard J. Murphy and Frank Schiller

Summary

The evolution of industrial symbiosis is a relatively new subject that needs further theoretical and empirical work. This research presents empirical results on the relations between context dynamics, industrial symbiosis network evolution, and the developments within companies engaging in the resource synergies. Analysis of top-down processes resulting from economical, governmental and industrial context dynamics are combined with results on bottom-up processes of companies responding to changing contexts via the uptake of industrial symbiosis practices within their evolving networks. This research demonstrates the variation in the responses of UK-based companies to contextual dynamics, drawing attention to the significance of understanding these micro-perspectives in the evolution of industrial symbiosis. By analysing these symbiotic innovations from the perspective of long-term on-going developments within the companies, it is demonstrated that the studied resource synergies and development of associated collaborations are part of longer-term processes of increasing innovation while collaboration and industrial symbiosis were already common practices. In the uptake of industrial symbiosis some companies experienced challenges resulting from poor integration of dynamics within the governmental and economical context, such as contradicting policy and regulation, bottlenecks in the governance to realise symbiotic innovations, and less advanced development of recycling markets compared to the European mainland. Companies could overcome such challenges by cultivating network relations at multiple governmental levels. To conclude, harmonising dynamics within the contexts, networks and companies is important in order to realise industrial symbiosis successfully and contribute to the on-going transition to a more sustainable, resource efficient and circular economy.

Key words: Emergence and immergence; Network analysis; Context analysis; System analysis; Innovation; Sustainable transitions
7.1 Introduction

Industrial symbiosis can be understood as the innovative usage of waste from one organisation as a resource for another organisation (Frosch and Gallopoulos 1989; Jensen et al. 2011a). It has been identified as a strategy to limit carbon emissions whilst promoting resource efficiency and business development (Laybourn and Morrissey 2009). Such benefits of industrial symbiosis have been widely recognised (e.g., EC 2011b; DEFRA and BIS 2012; Science and Technology Select Committee 2014; Allen et al. 2015), however, understanding how resource synergies are implemented and consequently how they can be promoted is still limited (Velenturf and Jensen 2016; Chapter 2).

It has been argued that industrial symbiosis starts to develop in response to changes in the business’ context such as policy and regulation as well as markets (Desrochers 2004; Boons 2008). Generally speaking (and in the provision of a concise overview admittedly excluding some fine detail in work presented within the industrial symbiosis community), starting from individual resource synergies within a region, a network of industrial symbioses is thought to emerge (Baas and Boons 2004; Domenech and Davies 2011a; Chertow and Ehrenfeld 2012). The network is expected to grow, ultimately leading to the emergence of an industrial ecosystem. In the process actors become aware of the industrial ecosystem of which they are part off, called the “uncovering of industrial symbiosis” (Chertow 2007). Indeed, the development of industrial symbiosis has been associated with cultural changes, such as establishing industrial symbiosis and the associated collaborations as conventional practices (Domenech and Davies 2011a; Lombardi and Laybourn 2012; Chertow and Ehrenfeld 2012). Moreover, the increasingly dense and diverse network enables companies to identify opportunities for synergy replication with additional resource partners (Baas and Boons 2004; Mirata and Emtairah 2005; Doménech and Davies 2011b; Paquin and Howard-Grenville 2012). Furthermore, the on-going development of new inter-sectoral network relations also creates niches which open further opportunities for new resource synergies. For instance, it has been observed that once a given business experiences a successful synergy, they are open and willing to explore opportunities for further symbiotic innovations (Jensen et al. 2012). In summary, a self-reinforcing cycle seems to be suggested, in which industrial symbiosis contributes to changes in the cultural and industrial context.
that then go on to induce further resource synergies as the industrial symbiosis network develops over time.

The conventional view of the evolution of industrial symbiosis networks presented above indicates the existence of individual symbioses that are part of a wider network, which in turn is embedded in contextual conditions. This system perspective, demonstrated in Figure 7.1, is widely adopted in industrial ecology literature (Schiller et al. 2014a). As outlined above, industrial symbiosis is thought to be initiated in response to changes in contextual conditions (macro-level), which can be understood as top-down processes (Figure 7.1). The resulting resource synergies are associated with network development (micro- and meso-level), which can be understood as bottom-up processes (Figure 7.1) that could, in their turn, could drive context changes. Whilst understanding about top-down and bottom-up processes associated with industrial symbiosis clearly started to develop, the introduced perceptions on self-reinforcing cycles of on-going industrial symbiosis network evolution and contextual changes presently contain theoretical inconsistencies, gaps in understanding, and mismatches with empirical observations (e.g., Nooteboom and Gilsing 2004; Pakarinen et al. 2010; Zhang et al. 2013; Velenturf and Jensen 2016; Chapter 2).

Figure 7.1: Industrial systems can be seen as part of the socio-economic system, which depends on the physical environment and the biosphere. Macro factors can influence industrial systems through top-down processes, and industrial systems can influence the macro-level through bottom-up processes. Within industrial systems, inter-organisational and intra-organisational networks can be distinguished through which energy, material and information can flow (White 1994; Erkman 1997; den Hond 2000; Chertow 2000; Howard-Grenville and Paquin 2008; Korhonen et al. 2004; Chertow et al. 2008; Jensen et al. 2011c; Jensen 2016).
This research builds on various strands of published and on-going research into macro-, meso, and micro-level dynamics during the evolution of industrial symbiosis. It provides an overview of contextual processes including economic, governmental and industrial developments (Velenturf 2016b; Chapter 6; Velenturf and Jensen Forthcoming; Appendix F), responses of companies to the changing context as well as the network dynamics resulting from the uptake of industrial symbiosis (Chapter 5; Velenturf 2016a; Velenturf Under review; Appendix H). This paper aims to draw together these insights into the various processes operating at the macro, meso, and micro-level in order to explore their relations and impacts on the evolution of industrial symbiosis.

Section 7.2 discusses current understanding within the industrial symbiosis literature regarding the relations between processes at the three system levels. Section 7.3 provides an overview of the methods that were used in the various strands of research. Section 7.4 presents the empirical results as introduced above, followed by an analysis of their relations in Section 7.5. Section 7.6 concludes the article with the main findings on harmonising dynamics at the researched system levels.

7.2 Macro-, meso-, and micro-level dynamics during the evolution of industrial symbiosis

Evolution is a relatively new subject within both the industrial symbiosis and associated eco-industrial park community. Although many authors have alluded to evolution in their published research, there is a growing body of literature that specifically focuses on evolution of industrial symbiosis and eco-industrial parks.

7.2.1 Top-down processes: The influence of context on industrial symbiosis networks

Following considerable debate, positioning and counter-positioning, industrial symbiosis is generally considered to start in response to changes in the context, such as market and/or government action (Desrochers 2004; Boons 2008). Additionally, a number of contextual...
conditions have been suggested to benefit the development of industrial symbiosis networks over time, including the presence of a collaborative culture, an industrial community in a geographically confined area, high industrial diversity, growing resource scarcity, and increasing regulatory pressure (Chertow 2007; Boons et al. 2011; Doménech and Davies 2011a; Jensen 2016). Hence it is no surprise that industrial ecologists have recommended the analyses of the context within which industrial symbiosis is to be developed (e.g., Jacobsen and Anderberg 2009; Costa and Ferrão 2010; Jensen et al. 2011b).

Although contextual conditions are evidently important in the initiation and realisation of industrial symbiosis, and hence should be taken into account when promoting such developments, it is equally important to understand how companies might respond to the contextual changes. It is unlikely that all contextual conditions such as laws, resource availability and/or labour availability affect each industry equally, and therefore various industries might perceive different opportunities and constraints for their development (Hoffman 2003). For example, increasing energy costs might impact sooner on energy intensive industries in comparison to industries using less energy. It seems likely that successful cases of promoting industrial symbiosis are those that position their strategy between the relevant contextual conditions and bottom-up dynamics (Jacobsen and Anderberg 2009; Gibbs and Deutz 2007).

Governments can choose to remain passive or take on a more active role in the promotion of industrial symbiosis. Shi et al. (2012) identified six models to promote industrial symbiosis through varying degrees of government intervention, from completely planned to self-organised approaches. Top-down planned approaches have had varying success in different countries, for example more coordinated top-down approaches to develop eco-industrial parks were not successful in the USA whereas successes have been observed in South-Korea and China (Gibbs and Deutz 2005, 2007; Shi et al. 2010; Behera et al. 2012). Although eco-industrial developments in Korea and China were led by governmental organisations, bottom-up processes were important too (Mathews and Tan 2011; Velenturf and Jensen 2016; Chapter 2; Park et al. 2015). In the UK, bottom-up, demand-led, approaches played a much bigger role within the National Industrial Symbiosis Programme (NISP). This model for the facilitation of resource synergies generated various benefits and is being replicated in
countries around the world (Paquin and Howard-Grenville 2012; Laybourn and Morrissey 2009). In other cases, such as Kalundborg, industrial symbiosis networks evolved mostly in a self-organised or spontaneous manner, although an ‘encouraging’ legislative context i.e. the absence of legal barriers was an important contributor to the network’s evolution ( Ehrenfeld and Gertler 1997; Christensen 2012).

Governments need to choose which level of intervention or engagement is appropriate for a given region. To develop effective strategies, Costa and Ferrao (2010) suggested the middle-out approach. A series of successive interventions was recommended to ensure that the context and development of industrial symbiosis fit to each other by outlining a framework within which synergies can develop, and leaving enough flexibility for companies to differentiate and improve practices. Through monitoring the context and the development of industrial symbiosis, feedbacks between these two system components could take place and adjustments could be made as industrial symbiosis evolves. Various actors can influence the context, including industry and government. Governments could provide a supportive policy and regulation framework, solving regulatory constraints for industrial symbiosis (Hoffman et al. 2014; Deutz and Frostick 2009; Desrochers 2004; Elliott 1997). Governments could also build on existing company- and public-private networks promoting collaboration and knowledge exchange for industrial symbiosis (Kincaid and Overcash 2001; Zilahy and Milton 2008; Costa and Ferrão 2010; Lehtoranta et al. 2011; Paquin and Howard-Grenville 2012; Hoffman et al. 2014). A balance needs to be found between specific enough frameworks to support industrial symbiosis, and a regulatory framework that is not too unpredictable, prescriptive and inflexible to the extent that it could constrain innovative potential in the uptake of resource synergies (Johnstone and Hascic 2009; Park 2014; Costa and Ferrão 2010). However, practical policy instruments to develop such balanced strategies for the promotion of practices such industrial symbiosis are underdeveloped in Europe (Lehtoranta et al. 2011). There is a need to develop a better understanding of the smaller steps that could be taken at lower governance levels, and to develop the associated measures such as regulation, economic instruments, and knowledge development (Koskela et al. 2013; Uyarra et al. 2016). Feedbacks between government and industry are important in the development and implementation of such strategies to promote industrial symbiosis, because not only the government context but also companies might be changing too (e.g.,
Short et al. 2014), as well as the characteristics of their networks (e.g., Chapter 5; Velenturf 2016a) and their broader contextual conditions (e.g., Paquin and Howard-Grenville 2012).

7.2.2 Bottom-up processes: Companies’ actions and network developments driving contextual dynamics?

Andrews (2000) argued for the need to develop a ‘micro-foundation’ in industrial ecology to improve understanding of the perspectives of companies and individuals within those companies. However, 15 years later such understanding still seems to be underrepresented in the industrial symbiosis literature. Perhaps this is indeed caused by the known difficulties of accessing and publishing data that companies might consider competitively sensitive (Hoffman et al. 2014), particularly data relating to operational by-products and wastes. While various articles discuss the fact that companies respond to contextual changes, this has rarely been subject of explicit research efforts that outline exactly what activities companies carried out in response to contextual dynamics and why they responded in that way (also see, Chapter 5; Velenturf 2016a; Madsen et al. 2015). Recent studies provided interesting insights into the variation in micro-perspectives on industrial symbiosis. Yang et al. (2014) suggest how a company adopted industrial symbiosis practices as part of a broader transition towards low-carbon production, in anticipation of climate change leading to demand for such products. Conversely, other companies seem to be driven mainly by a need to reduce costs and meet environmental requirements, suggesting a less far-reaching change for the companies’ practices (such as, Park and Park 2014). The exploration of the variation in companies’ responses to contextual changes is an area that needs further research within the industrial symbiosis literature.

In response to context dynamics and internal drivers, companies develop their collaborations for industrial symbiosis through network diversification or by strengthening existing relations (Chapter 5; Velenturf 2016a). The realisation of industrial symbiosis tends to be a result of the concerted effort of companies whilst governments, NGOs, communities, and knowledge institutes might also be involved (Korhonen et al. 2004; Boons et al. 2011; Velenturf 2016a; Chapter 5). Actors involved might exchange materials, energy and/or information (Chertow 2000; Korhonen et al. 2004) and therefore it could be said that
industrial symbiosis involves the development of social and metabolic networks. Indeed, the development of industrial symbiosis has been studied using social network analysis\(^1\) (e.g., Ashton 2008; Doménech and Davies 2009; Paquin and Howard-Grenville 2012; Zhang et al. 2013).

Previous studies have suggested that industrial symbiosis networks increased in density and diversity over time. Network diversification is inherent to industrial symbiosis, which has been described as engaging “traditionally separate industries” (Chertow 2000:p314) although interpretation of what is considered traditionally separate has varied within the industrial symbiosis community (Lombardi and Laybourn 2012). Moreover, Paquin et al. (2014) suggest that the relative difference between sectors affects the initiation and completion rates of resource synergies. Furthermore, Short et al. (2014) suggest that companies might start with resource synergies that are relatively incremental but which promote the development of know-how and market access whilst also lowering management, organisational and cognitive barriers. Eventually these foster resource synergies that constitute larger changes to the core business operations of companies. While these observations suggest a certain level of choice in the degree of network diversification strived for by companies involved in industrial symbiosis (Paquin et al. 2014; Short et al. 2014), Velenturf (2015) suggest that for some companies the engagement of new sectors was not optional but instead was necessitated by an acute problem solvable by the observed resource innovations. Conversely, some companies indeed did have the choice to adopt new resource synergies through the strengthening of their existing relations. In sum, companies adopted diversification or strengthening strategies which, moreover, also varied over time. Interestingly, increasing network diversity within the companies’ ego-networks\(^2\) seemed to be associated with decreasing density dynamics. This supports Hardy and Graedel (2002) who observed the same phenomenon albeit at the regional level. Furthermore, the effects that network strategies within the ego-networks might have on the evolution of larger scale networks such as at the regional network is yet to be studied (also see, Zhang et al. 2013), to answer questions such as: Does increasing network diversity

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\(^1\) Social network analysis is an interdisciplinary research method to study social structures as a whole and the dynamics within the relations that are part of these social structures (Scott 1988, 2000; Borgatti et al. 2009).

\(^2\) Ego-networks consist of all direct contacts of an actor and the relations between those contacts (Scott 2000).
within ego-networks also translate into decreasing network density within the region? This is an important subject for further research because characteristics that are considered crucial to the success of industrial symbiosis, such as trust between resource partners, have been associated with increasing network density (Nooteboom and Gilsing 2004; Velenturf and Jensen 2016; Chapter 2).

Arguably, understanding companies’ choices for network strategies (micro-level in Figure 7.1) and the effects of these strategies on the companies’ as well as the larger scale network characteristics is important. First, the idea that network density and diversity increases over time, while innovation increases simultaneously with the emergence of industrial symbiosis and associated collaboration as common practices, requires particular attention. Theoretically, the transfer of information to enable business development and innovation, i.e. changing practices, would be best facilitated in networks with an open structure and low density (Burt 1992). Conversely, the anchoring of practices in social norms, i.e. establishing a new common practice and preventing further change to practices, would be best maintained in networks with a closed structure and high density (Coleman 1988). In other words, compared to network actors in open social networks, actors in closed dense social networks may be more constrained to change their practices and thus less likely to implement innovations (Granovetter 2005; Day 1994). These theories imply that the suggestion made in industrial symbiosis literature regarding the increased innovativeness simultaneously with the establishment of new common practices would be unlikely. This suggests that further research is required to identify whether there are indeed particular network structures beneficial for the uptake of industrial symbiosis and to ascertain it as a common practice.

Literature on industrial life cycles provides a more dynamic understanding on network structure which could integrate the perspectives outlined above. Industrial life cycles are thought to consist of exploration and exploitation phases, theorising that industries and companies go through phases of radically changing practices followed by phases in which practices are continued although incremental changes might still be made (Levinthal and March 1981; March 1991). Admittedly excluding much of the complexities discussed in the literature, industrial life cycles would arguably consist of an exploration phase in which networks increase in density and diversity while new practices are investigated and
implemented, before stabilising and moving into exploitation at which point the new practices become the norm; and during exploitation diversity and density start to decrease again to optimise efficiencies and eventually move back into exploration (Coleman 1988; Burt 1992; Nooteboom and Gilsing 2004). However, this theory still does not explain the association between increasing diversity and decreasing density during the evolution of industrial symbiosis, suggesting a need for more fundamental research (Hardy and Graedel 2002; Velenturf 2016a; Chapter 5). Moreover, such study should also cover the qualitative steps through which the on-going development of industrial symbiosis might be driving contextual changes such as the growing ‘cultural embeddedness’ consisting of shared norms regarding the usage of waste and resources as well as trust and a ‘culture of cooperation’ (Ashton 2009; Pakarinen et al. 2010; Doménech and Davies 2011a; Paquin and Howard-Grenville 2012).

In summary, Section 2 suggested that the evolution of industrial symbiosis is still a nascent subject that needs further theoretical and empirical work. The research presented below adds to the on-going development of new understanding on this subject by presenting empirical and mostly qualitative results on the relations between the context, industrial symbiosis networks, and the companies engaging in the resource synergies.

### 7.3 Methods and data

This research was based on context analysis and case studies of industrial symbiosis, here interpreted as biowaste-to-resource innovations, in the Humber region, UK. This region is a known case study in the industrial symbiosis literature (e.g., Mirata 2004; Laybourn and Morrissey 2009; Jensen et al. 2011a; Wang 2013; Velenturf 2016a; Chapter 5). Indeed, many resource synergies have been realised in the Humber area and it was suggested that particularly the bio-chemicals and bio-energy sectors offer further opportunities for industrial symbiosis (Laybourn and Morrissey 2009; UKTI 2009; Humber Local Enterprise Partnership 2014; Jensen 2016). The Humber region has been a case study area for the Evolution and Resilience of Industrial Ecosystems project (see e.g., Schiller et al. 2014; Penn et al. 2014) under which this research was carried out, and consecutive context analyses were completed at various stages in the project.
7.3.1 Context analysis

The context within which industrial symbiosis develops has been described as “the social, economical, technical, and political conditions embedded in a geographical setting” (Costa and Ferrão 2010: p985). This interpretation of context shows high resemblance to industrial localisation factors (Renner 1947) and such influence of macro-factors on the development of actors can also be researched with the “DESTEP” method including Demographical, Economical, Social, Technological, Ecological, and Political factors (see e.g., Voort et al. 2013). All six factors were explored at the start of this research to outline macro-developments in the UK and the Humber region. They were also included in the coding design for the case studies on biowaste-to-resource innovation (Velenturf 2016a; Chapter 5), however, they were refined or excluded from the presentation of the results and further context analyses depending on their apparent (un)importance for the companies that adopted innovative symbioses. Important contextual factors could be grouped in market and government dynamics, as indeed suggested by earlier publications (Desrochers 2004; Boons 2008). The matrix of methods and data used to analyse the contextual dynamics are shown in Table 7.1.

Table 7.1: Methods used to analyse the market and government context.

<table>
<thead>
<tr>
<th>Contextual factor</th>
<th>Market</th>
<th>Government</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economic development</td>
<td>Review statistical data and supporting reports on: a) UK economic growth (Office for National Statistics) b) Availability of commodities (World Bank)</td>
<td></td>
</tr>
<tr>
<td>Industrial development and innovation in the Humber region</td>
<td>Review statistical data and supporting reports on: a) Industrial composition (Office for National Statistics) b) Innovation and collaboration activities (UK Innovation Survey)</td>
<td></td>
</tr>
<tr>
<td>Policy and regulation in the EU and UK</td>
<td>Policy analysis to explore EU and UK policy and regulatory developments Case studies’ analyses of policy and regulatory drivers and constraints (this also pertains to governance in the Humber region)</td>
<td>Exploration of development strategies published by the local councils and Humber Local Enterprise Partnership Summary from governance analysis in Velenturf (Submitted)</td>
</tr>
<tr>
<td>Governance in the Humber region</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NISP and NISP Humber and Yorkshire</td>
<td>Literature review Co-author’s NISP practitioner experience</td>
<td></td>
</tr>
</tbody>
</table>

7.3.2 Case studies

Case study data (presented in part in Velenturf 2016a; Chapter 5) were revisited for this network evolution analysis. Qualitative case studies of biowaste-to-resource innovations were carried out in the Humber region, UK, aiming to explore how and why companies
implemented these innovations and how the associated collaborations developed. Semi-structured interviews and supporting documentation were collected and organised with conceptual and open coding techniques (Mason 2002; Bryman 2012). The role of each coded factor and process (Figure 7.2) was interpreted in isolation and in relation to each other. Case study reports were written to construct a holistic understanding of the innovation processes. A cross-case comparison was carried out to identify important similarities and differences and formulate the main arguments.

Here we are interested in the innovation processes as part of the broader development of the companies within their contextual conditions. First, the micro-perspective analysed in Section 7.4.2 draws upon data that was coded and interpreted as: Actor role, Absorptive capacity, Innovation culture, Order of events, Industrial life-cycle, Drivers and barriers, and Outcomes (Figure 7.2). Second, network data was derived from fragments coded as: Network actors and relations. This data was entered into the open-access software NodeXL. Actor and relation types were further characterised as appeared relevant in the qualitative analysis, before visualising the data for further observations on the network structure. We present three case studies showing variation in engagement with contextual dynamics and the associated networking strategies that were employed.

Figure 7.2: Coding tree including social factors identified in industrial symbiosis, proximity and innovation networks literature (Nooteboom and Gilsing 2004; Boschma 2005; Von Stamm 2008; Paquin and Howard-Grenville 2012) that were used in this study to observe waste-to-resource innovations, while open coding was also applied. (Figure made with NodeXL)

https://nodexl.codeplex.com/
7.4 Results: Evolving contexts, companies and networks

This section first presents the context analysis and then places the case studies of biowaste-to-resource innovations into their longer-term perspective.

7.4.1 Context analysis: Top-down processes driving industrial symbiosis

7.4.1.1 Global, EU, and national level context dynamics

In the period 1980-2014 the UK economy has generally grown, although three periods of decline occurred in 1980-81, 1991, and 2008-2009 (Figure 7.3). Global commodity prices showed a decreasing trend in the past century (Dobbs et al. 2011; ECORYS 2012). However, the period 1996-2000 marked a change from decreasing to increasing commodity prices and intensifying price volatility (Figure 7.3). After 2000, price volatility was extremely high in the areas of minerals (e.g. phosphate rock), metals (e.g. iron ore) and energy and fuel (e.g. crude oil and biofuels), with knock-on effects on food (e.g. potatoes, maize and wheat in the UK) (Dobbs et al. 2011; ECORYS 2012). However, since ca. 2011 commodity prices have been decreasing again. Finally, energy prices fell particularly sharp in 2014-2015 (WorldBank 2015a).

In the period after 2000 various recycling markets emerged in the UK. As the cost of landfilling waste increased and several outbreaks of livestock disease created large quantities of animal by-products requiring disposal (further discussed in the next paragraph), sectors such as the biofuels, anaerobic digestion and refuse derived fuel started to emerge (such as observed in the case study companies in Section 7.4.2). The emerging sectors did face challenges. In some cases the (waste) resources were already part of a well-established value chain. Hence the emerging supply chains had to compete on the one side to source secondary resources, while on the other side their alternatives had to compete with well-established products (also see e.g., Dam et al. 2005; Faaij 2006). Furthermore, attracting investment for new developments was challenging because high price volatility in secondary resource markets generated uncertainty about returns on investment.
Government exerted a strong influence on the emergence of recycling markets and following industrial developments such as low-carbon energy alternatives. Policy analysis within the ERIE project revealed four main areas of government-influence on industrial symbiosis and biowaste-to-resource innovations: Circular and bio-economy, Waste, recycling and resource security, Climate change and energy, and Other (Appendix E: Overview results policy analysis; Also see, Deutz and Ioppolo 2015).

Carbon reduction targets formally appeared in UK governance with the introduction of the Climate Change Programme (1994; Lovell et al. 2009). Urged by a growing body of scientific evidence on climate change, the UK government updated the Climate Change Programme. At the same time there were concerns about energy security, which reached a peak between 2004 and 2006 when foreign gas supplies were distorted and UK oil and gas supply appeared to decrease. The problem of energy security offered an arena in which to discuss carbon reduction solutions through alternative energy supplies (Lovell et al. 2009). Around 2006 support for lower-carbon energy was proposed and this included stimulating the bioenergy sector. The bioenergy sector was already supported through the Renewables Obligation since 2002, but it was revised to promote usage of specific biomass and the uptake of newer technologies, and measures for research and knowledge exchange (Laurentis 2015). Despite the increasing convergence of climate change and energy policy, a multitude of government activities aiming for carbon reductions emerged and created a complex environment for companies (Figure 7.4; Appendix E).

In parallel to the developments in the climate change and energy security arenas, important changes unfolded in the areas of waste management and resource scarcity (Appendix E). Waste management policy and regulation evolved from a predominantly linear focus on public health towards a system-focus which also addressed environmental protection, resource security and carbon emission issues (Deutz and Frostick 2009; Hill 2015). At the end of the 1990s and early 2000s several changes were implemented in waste management in the UK. The centralised waste strategy was devolved to country assemblies who developed their own strategies focusing on landfill reduction (Morrissey and Phillips 2007). In England this included the support for various schemes and strategies, such as for the development of innovative plants for energy recovery from waste and for NISP, for
increased resource efficiency and carbon reductions. These developments in waste and resource management provided momentum for the emerging circular economy, encompassing industrial symbiosis and resource efficiency approaches.

The development of NISP is a useful case study in its own right (Velenturf and Jensen Forthcoming, article outlined in Appendix F). NISP was a business initiative that was piloted in a number of regions, including the Humber Industrial Symbiosis Programme (HISP) (Bailey et al. 2008). After a stuttering initiation period between 2000-2002, the Humber Industrial Symbiosis Programme (HISP) gained momentum by attracting business and government funding, engaging an increasing number of companies (including the case study companies discussed in Section 4.2), and meeting and exceeding their funding targets (Bailey et al. 2008; Gibbs 2000; Mirata 2004; Laybourn and Clark 2004). The success of HISP and two other regional symbiosis programmes created the groundswell needed for the creation of a national programme (Laybourn and Clark 2004). NISP was funded through DEFRA’s Business Resource Efficiency and Waste (BREW) programme and officially launched in 2005 (Bailey et al. 2008; CIWM 2015). Despite continuously exceeding their assigned targets (Laybourn and Morrissey 2009), since 2008 NISP were subject to a series of government driven funding reductions eventually leading to the complete removal of public funding, for most UK regions, in 2012 (Figure 7.4). Despite the cease in funding, the empirical and tested success of the likes of NISP led to the inclusion of industrial symbiosis in various strategic documents such as the Resource Security Action Plan (DEFRA and BIS 2012), the Roadmap to a Resource Efficient Europe (EC 2011b), and the EU circular economy package (EC 2015).

In summary, the circular economy seems to have linked in to on-going developments in waste policy and regulation, while bioenergy has been part of the solution for carbon emission challenges. In the UK, the integration of these four subject areas has progressed towards connecting the visions of a circular and bio-economy into the ‘waste-based bio-economy’ (Government 2015a). However, more understanding is needed about bringing such vision into practice (Allen et al. 2015; Velenturf 2016b; Chapter 6).
7.4.1.2 Regional level context developments

The cease of NISP funding coincided with various other changes in the governance structure at local and regional level in the Humber region (Velenturf 2016b; Chapter 6). The Regional Development Agency (RDA) and various associated delivery bodies were dissolved. Its successor, the Humber Local Enterprise Partnership (Humber LEP), brought together the four local councils (who had been traditionally reluctant to collaborate), businesses, and various other organisations involved in the economic development of the Humber region. While governance efforts became more concerted, the Environment Agency and local councils were faced with austerity measures (EA 2015b; LGA 2014; NAO 2014). Overall, the result of the austerity measures was reduced capacity in terms of money, organisations, people and competencies to engage with companies when biowaste-to-resource innovations were brought forward. Furthermore, since 2012 there have been no dedicated governmental organisations, departments or publicly funded programmes in the Humber region to support industrial development through (bio)waste-to-resource innovation or other types of industrial symbiosis.

The Humber region on the north-eastern coast of England has a mature diverse industrial structure (Appendix G; NOMIS 2015) which contributed to a multitude of opportunities for industrial symbiosis (Jensen 2016). The area hosts one of the busiest port complexes in Europe. Overall, construction and manufacturing are the largest industries, including companies in food and wood processing, chemicals, metals, and fuel and power facilities (Mirata 2004). Manufacturing and processing were the largest contributors to the regional Gross Value Added in 2010 (Hull University Business School 2013). Professional, scientific and technical services also form a large proportion of the regional economy. Additionally, the predominantly rural East Riding of Yorkshire and North Lincolnshire have strong agricultural sectors, while the more urbanised Hull and Northeast Lincolnshire have higher proportions of wholesale outlets and retail. Despite the well-developed industrial structure, the wider region has been affected by long-term economic downturn through crises in the mining and fishing sectors while the construction industry dwindled during the economic crisis in 2008-2009 (Jarvie et al. 1997; Gibbs et al. 2001; EUC2C 2008; NOMIS 2015). Nevertheless, other sectors started to emerge. The government and market push for
renewable energy and reduced carbon emissions, in conjunction with available
development-space alongside deep-water channels, offered opportunities for the offshore
wind-industry (Humber Local Enterprise Partnership 2014). Additionally, the region has seen
growth in the bio-energy sector with various fuel and power facilities being developed and
converted since 2003, indeed coinciding with the introduction of the Renewables Obligation
followed later by Renewable Transport Fuels Obligation (Bondholders 2014). Moreover, the
region was highlighted as one of the most opportunity-rich areas in the UK for the
development of the bio-chemicals industry (UKTI 2009). Furthermore, the waste-based bio-
economy also provides economic development opportunities (Science and Technology
Select Committee 2014). Indeed, resource security issues and the increased government
drive for waste recycling may have contributed to the growth of the waste management
sector in the Humber region (EA 2015a; NOMIS 2015).

The economic developments were reflected in the innovation activities and collaborations
within the region. Innovation and collaboration have been monitored since 1998 through
the UK Innovation Survey. The wider Yorkshire and Humber region grew from one of the
least active innovators in the UK in 2001 to one of the country’s top innovators in 2005,
after which innovation efforts decreased again although performance was still average to
high (DTI 2002; DTI 2005; DIUS 2007; BIS 2011, 2014). Spells of increased innovativeness
were particularly visible in the new-to-market product innovations. Especially the fuels,
chemicals, plastics, metals and minerals sector were highly active (DTI 2006) as indeed
reflected in the industrial developments discussed above. In parallel with increased
innovation efforts, the proportion of companies with collaborative innovation efforts also
grew. Companies typically collaborated with partners within their business group as well as
suppliers and clients that were based locally/ regionally or within the UK. This focus to
collaborate with existing partners could be particularly challenging for industrial symbiosis,
because it requires the engagement with resource partners from previously unconnected
industries (Chertow 2000; Jensen et al. 2011a). Perhaps this has become even more
challenging now that NISP is less accessible for companies to help in the development of
cross-industry linkages.

Figure 7.4: Overview of contextual dynamics clearly showing the results of the economic crisis around 1991 in decreasing sectors, while the regulatory induced challenges due to animal by-product regulation in 2003 and the economic crisis in 2008 were associated with increased innovation performance. Also note the diverging trends of circular bio-economy gaining momentum while at the regional level associated delivery capacity on these subjects was reduced.

7.4.1.3 Overview of the top-down processes

Figure 7.3 and 7.4 provide an overview of the top-down processes that were discussed above. This section has shown that up to 2012 the developments in the global economy, resource markets, government and NISP appeared to be challenging but relatively harmonised. The dynamics in these dimensions of the system context were logically linked and appeared to be moving in the same direction, creating a favourable environment for
industrial symbiosis. However, after 2012 some divergence in the dynamics was manifested. Arguably, policy and regulation continued to develop towards a more integrated view on the circular bio-economy, suggesting that far-reaching innovations would need to be realised in the industrial sector. Conversely, austerity measures created bottlenecks in the regional governance system resulting in decreased capacity to engage with companies implementing biowaste-to-resource innovations (Figure 7.4). Simultaneously, innovation activity in the Humber region peaked and then decreased again, although the waste management sector (arguably a key actor for waste-to-resource innovation) did continue to grow.

7.4.2 Case studies: Bottom-up processes for symbiotic innovation, network development, and feedbacks to the system context

This section presents results from the case studies of biowaste-to-resource innovation by discussing a) Associations between business development, innovation and collaboration and the context dynamics, b) How industrial symbiosis was adopted in response to the context dynamics and in terms of network development, and c) Whether there were any feedbacks to the macro-level dynamics resulting from the symbiotic innovation.

7.4.2.1 Finding new outlets for a ‘waste’ oil

This case study was about a large multinational with a production site in the Humber region, who contracted a waste-agent to identify and realise alternative outlets for a waste oil.

This company was founded on the proposition to create valuable products from a waste material. Hence industrial symbiosis has been part of their core business from the start. However, since founding the company they diversified into a large number of markets and products, not all were industrial symbioses. Around the economic crisis in 1980-1981, they perceived to be diversified so much that they became vulnerable to hostile takeovers. Hence, rather than further diversification they started to specialise on one product group. This new business strategy came to fruition directly after the next period of economic downturn in 1991 (Section 7.4.1.1).
The multinational has a track-record of innovating and patenting new products. Their innovation strategy combines the exploration of new markets and products within their product-group whilst raising market-entry barriers for other companies, and the exploitation of existing market positions through growth and maintenance of market shares. Particularly the first part of their innovation strategy requires the collaboration with governmental bodies in multiple countries, memberships of an increasing number of associations, and contributing to the development of product standards (Figure 7.5). This enables them to shape their regulatory and market context. This may be a form of strategic risk management in which the risks of leading-edge innovation, such as regulatory barriers to the introduction of new products, are managed up-front rather than waiting for them to manifest themselves when products are presented to the market.

While the company may have managed sustainability issues for a longer period of time, they only started to incorporate it as a business opportunity since 2008. Interestingly, this strategy change was again associated with a period of global economic issues, while governmental changes to promote recycling and carbon reductions were also on-going (Section 7.4.1.1, Appendix E). Sustainable products were identified as a business opportunity through a process of researching and reviewing sustainability issues that might affect long-term business survival such as climate change, resource scarcity and regulation, followed by strategic planning for sustainability performance targets and business opportunities. Evidence suggests that sustainability has become common practice at all levels in the company, anchored in strategic documents, codes of conduct, and product and process standards. Furthermore, the company used their network to transmit and develop these practices to suppliers, customers, and to governmental organisations through trade associations/ committees (Figure 7.5) which also ties into the innovation strategy of raising market-entry barriers and strategic risk management as discussed above.

Within this company’s context, the biowaste-to-resource innovation took place on a production site in the Humber region. Before this particular symbiotic innovation, the plant had already engaged in various other industrial symbiosis activities. The Landfill Directive (1999) provided an economic incentive to divert waste from landfill more actively. This also
contributed to their engagement with NISP and the particular waste agent involved in the studied waste oil synergy (Velenturf 2016a; Chapter 5). With the implementation of the Waste Framework Directive (2006) in England a number of former by-products were redefined as wastes. While the company continued to consider the waste oil as a by-product, legally it was now a waste and had to be dealt with accordingly. The waste agent assisted the company to diversify their network by finding new outlets and, given the specific resource characteristics and the tight regulation in the UK, the waste oil was finally sent to a partner in mainland Europe (Figure 7.5 shows the number of resource partners that were considered). At the same time, other companies in England lost their value proposition due to the new definitions of waste and hence saw themselves forced to take legal action against the Environment Agency and DEFRA. As a result, the government had to develop more guidance, which became the Quality Protocols allowing end-of-waste tests for a selection of resources. Resources that were not included in the protocols could still apply for an exemption and ultimately reach end-of-waste status. However, the perception is that exemption applications were largely unsuccessful. With the Quality Protocols in place, the company considered symbiotic connections to anaerobic digesters (AD) in the UK but, both from a regulatory point of view (resource requiring exemption application) and market perspective (AD was more expensive than landfill), this was not attractive. Instead they applied for end-of-waste status for all combustion processes which was granted only for the resource partner in mainland Europe. Overall it could be said that the innovation process and the interaction with the regulator did not lead to the preferred outcome – a symbiosis that was as valuable as their resource partnership before the implementation of the Waste Framework Directive. Despite this process, the company’s perception to consider the waste oil as a by-product rather than a waste never changed. There were some indications, however, that the willingness to collaborate with new resource partners reduced because various proposed partnerships had been unsuccessful (also see, Velenturf 2016a; Chapter 5). Nevertheless, this did not seem to affect the innovation and collaboration culture of the company as a whole.
7.4.2.2 Orchestrating the uptake of Refuse Derived Fuel (RDF)

This case study was about a large multinational with an energy intensive plant in the Humber region where refuse derived fuel (RDF) was adopted.

The plant in the Humber region experienced multiple ownership takeovers and eventually became part of a large multinational with hundreds of production sites. In this global arena, cost reductions were essential for survival of the site in the Humber region. To save costs on high energy prices, the plant had already started to explore waste-based fuels since the 1990s which finally resulted in the uptake of Secondary Liquid Fuel in 2002. However, energy costs still had to be reduced even further and this led to the adoption of RDF in 2006. In addition to these resource synergies, they also participated in NISP and various innovative projects to valorise waste resources. Further collaborations included long-term engagements with the local community, local councils, and Environment Agency. At the national level, the multinational also had long-term relations with various governmental bodies. These long-term collaborations with governments from local to national level turned out crucially important in the adoption of RDF (Figure 7.5).

The plant started the adoption of RDF in 2006. At the time the RDF market was virtually non-existent in the UK (also see, Garg et al. 2007). Indeed, DEFRA launched a demonstrator programme for non-mainstream waste management options, including RDF, expected to be commissioned in 2006 (Morrissey and Phillips 2007). Despite the Environment Agency still ‘sitting on the fence’ regarding RDF, they gave permission for a trial at the plant. After the first trial some RDF production facilities started to emerge in the UK. The market started to develop and soon was in full exploration-phase with many small companies establishing themselves. The emergence of the RDF market co-evolved on the one hand with the increasing demand for this fuel, and on the other hand the growing waste-problem for councils that were forced by regulation to search for alternatives to landfill. Around 2013 the RDF market started to stabilise and consolidate with larger companies that increasingly treated waste as a commodity.
While the market developed rapidly during 2006-2013, the collaboration with governmental organisations was characterised as slow. The plant collaborated with the regional officers of the Environment Agency to acquire permits for a series of consecutive trials. Simultaneously, the multinational plant-owner engaged DEFRA and the Environment Agency directly to increase pressure on councils to divert waste from landfill, to be recognised as a sector that could use RDF, and to speed up the permitting and trialling process. This interaction was built on on-going connections between the multinational and governmental organisations, since the multinational explicitly communicated to continuously interact with governmental bodies with the purpose to control regulatory and tax-based pressure on the company’s activities (Figure 7.5). The economic downturn in 2008 strongly motivated the plant, and owner, to speed up the RDF uptake because of the acute need to reduce costs. Moreover, the crisis coincided with the introduction of the Climate Change Act (2008) and other strategies demanding reductions in carbon emissions. In response, the multinational formulated sustainability targets and suggested a wider uptake of RDF usage and production throughout their company. Finally, in 2011 the plant received their environmental permit to permanently use large quantities of waste-derived fuels. By that time the usage of RDF had become normal for the employees working in the plant and it was not perceived anymore as ‘alternative’. Similarly, for the Environment Agency it also became more of a routine fuel. Both observations suggest that the use of RDF became common practice. Furthermore, the plant had developed a new routine to collaborate with RDF suppliers although, given the already existing well-developed collaborative culture within the company, significant changes in the collaborative culture seem unlikely.

To conclude, this innovation process shows how developments at plant and multinational level as well as dynamics in market, government and economy were orchestrated by the company which indeed ultimately led to contextual changes such as common practices, regulation and the emergence of a new market. This is similar to observations on system innovations where changes at micro, meso and macro-level had to be aligned (Gaziulusoy et al. 2013).
7.4.2.3 Upscaling waste oils and fats processing for biodiesel production

This case study analysed the on-going collaboration between a specialist recycler and a fuel company to increase the volume of waste oils and fats prepared for biofuel manufacturing.

The specialist recycler used to process waste oils and fats for the animal feed industry. The Animal By-product regulation (2003) was introduced following a series of animal disease crises in the UK and Europe. Some oils and fats could not be used in animal feed and hence the specialist recycler had to diversify into other sectors. This required an increase in innovation efforts. They entered the biofuel market, exporting to Europe mainland since the market was yet to develop in the UK. Initially the recycler collaborated with smaller biofuel companies. The resource partnership with the larger fuel company was initiated later with the help of NISP. The fuel company was driven into biofuel production by the Renewable Transport Fuel Obligation (2007), which committed UK road fuel suppliers to include annually increasing percentages of biofuels in their blends. As a result, the UK biofuel market grew.

The growing market created on the one side challenges in the sourcing of the increasingly scarce waste oils and fats. The specialist recycler had to become more innovative and explored the usage of a wider range of food wastes, developing new collaborations with supply chain partners, knowledge institutes, and business innovation hubs. Overall it could be said that the collaborative culture was strengthened. On the other side, the specialist recycler had to grow with the unfolding biofuel market in order to reduce costs, stay ahead of competitors and increase market share. Companies that could not grow with the market went out of business. The partnership with the fuel company was vital for the specialist recycler. The fuel company increasingly dedicated themselves to waste-based biofuel, converse to biofuel from primary feedstock. The primary biofuel market received growing criticism from society and competition was strong as well. Hence their focus turned to growth in secondary biofuel, fitting in with the growth needs of the specialist recycler. The resource partnership grew stronger up to the point where operations in the separate plants were under shared management and a new plant was commissioned to process larger quantities of more diverse waste oils and fats.
The strengthening of the collaboration was associated with increased dependency on the fuel company. The specialist recycler perceived this as a business risk and generally their willingness to collaborate on core business activities reduced. There were no indications that other norms changed as well. The specialist recycler’s foundation in waste valorisation did not alter due to the entry and expansion into the biofuel market. Moreover, it is worthwhile noting that this business proposition was not intrinsically motivated by environmental reasons. Finally, unlike the other two cases, the specialist recycler engaged only a few trade associations and avoided direct contact with government altogether, because they neither expected to influence policy and regulation nor anticipated other benefits from such network relations (Figure 7.5).

7.4.2.4 Overview of the bottom-up processes

Table 7.2 provides an overview of the contextual drivers for the companies’ on-going business development and the initiation of the biowaste-to-resource innovation, and the extent to which changes occurred in innovation and collaboration culture, the establishment of industrial symbiosis and sustainable development as common practices, regulatory changes, and the emergence of new markets (further discussed in Section 7.5).

Figure 7.5 reveals the differences in network composition which seem to be associated to the strategies for government engagement in the biowaste-to-resource innovation processes. In the case of waste oils, the multinational had a well-developed network of trade-bodies and committees to influence governance proactively, but fewer established government connections regionally to collaborate with in response to the regulatory change that created the waste oil problem. Instead, they worked with the Environment Agency to manage waste oil solutions, closely following the development of the quality protocols but not leading it through for instance legal action. In sum, while the company has a generally pro-active strategy to engage in the development of regulation, in the case of waste oil they were more reactive. The opposite could be observed in the RDF case. Here, the company had cultivated long-term connections to multiple levels of government to respond to (upcoming) governance changes. Conversely, in the development of the RDF market they
had a leading proactive role. They worked with regional Environment Agency officers on trials to co-produce evidence that was used in the permitting process, while they also lobbied the government and participate in consultations to increase pressure on councils to divert waste from landfill, to be recognised as a sector that could use RDF, and to speed up the permitting and trialling process. Finally, in the case of waste oils and fats, the company minimised contact to governments as much as possible and they only made limited attempts to change regulation to interactions with a small number of trade associations.

![Ego-networks of the three case study companies.](image)

Figure 7.5: Ego-networks of the three case study companies. Although the network data are likely to be incomplete, there are still clear differences in the network characteristics that relate to the innovation and collaboration strategies of the individual companies. Legend: The four rectangles are case study companies; RP are resource partners; TA are trade associations; CO are other companies; Black disks are Humber-based governments; Grey disks are national governments; White disks are EU/ outside EU governments; Triangles are local communities/ NGOs. Lines are social/ metabolic relations; Dotted are relations involved in the biowaste-to-resource innovation cases.

### 7.5 Linking top-down and bottom-up processes

The results demonstrate the relations between context dynamics, the evolution of industrial symbiosis networks, and the developments within companies. Their analysis reveals the variation in the responses of companies to contextual dynamics, drawing attention to the significance of understanding these micro-perspectives in the evolution of industrial symbiosis. In the attempt to clarify whether innovation could increase simultaneously with the establishment of collaboration and industrial symbiosis as common practices, the results
indicate that the time-scale over which these processes were analysed can significantly influence the outcomes. By analysing these symbiotic innovations from the perspective of long-term on-going developments within the companies, it demonstrates that the studied resource synergies and development of associated collaborations are part of longer-term processes of increasing innovation while collaboration and industrial symbiosis were already common practices. Finally, in the uptake of industrial symbiosis some companies experienced challenges resulting from poor integration of dynamics within the governmental and economical context, such as contradicting policy and regulation, bottlenecks in the governance to realise the symbiotic innovations, and less advanced development of recycling markets compared to the European mainland. Companies could overcome such challenges by cultivating network relations at multiple governmental levels. Such strategy would support the harmonisation of context-, network- and business-dynamics, which appeared important for the development of industrial symbiosis.

7.5.1 Variation in companies’ responses to contextual dynamics

This research demonstrated variation in the responses of companies to contextual dynamics (Andrews 2000). The three companies were active in different sectors and markets, consuming and producing different resources, and with different innovation strategies as well as engagement strategies for government. Hence it is no surprise that companies were not equally affected by the contextual dynamics, resulting from the UK government’s actions regarding climate change, waste, and energy and resource security as well as the large-scale economic trends of energy and resource prices and economic growth (also see, Hoffman 2003). For instance, in the waste-oil and waste oils and fuels cases (Section 7.4.2.1 and 7.4.2.3) the innovation processes were initiated in response to regulatory changes and the companies continued to innovate for economic reasons. Conversely, in the RDF case (Section 7.4.2.2) the increasing energy prices motivated the company to search for alternative energy supply, carbon taxes increased prices further and then the economic crisis sped up the adoption of the identified innovation. This also shows a more detailed and complex combined role of economic and government contextual changes; both were important though in different proportions for different companies (Desrochers 2004; Boons 2008). It also suggests that it is not only important to understand context sensitivities
(Jensen et al. 2011b), but also to understand how the diversity in companies’ context dependencies and management strategies results in emergent ‘replies’ to context dynamics. This is an area, also referred to as the ‘micro-perspective’, which requires further research (Andrews 2000; Hoffman 2003).

### Table 7.2: Overview of the case study results that were discussed in 7.4.2.1 – 7.4.2.3

<table>
<thead>
<tr>
<th>Contextual drivers for change business strategy</th>
<th>7.4.2.1: Waste oil</th>
<th>7.4.2.2: Refuse Derived Fuel</th>
<th>7.4.2.3 Waste oil and fat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Market threats, Opportunities for sustainable production</td>
<td>Increasing energy costs</td>
<td>Regulation change</td>
<td></td>
</tr>
<tr>
<td>Regulation change</td>
<td>Need to limit energy costs to secure business survival</td>
<td>Increased competition in growing market</td>
<td></td>
</tr>
<tr>
<td>Business practices/ strategy changed</td>
<td>Between 1982-1991 and since 2008</td>
<td>Plant since 1990s, Corporate level unclear</td>
<td>Since 2003</td>
</tr>
<tr>
<td>Company adopted more sustainable practices</td>
<td>Since ca. 2008 full integration</td>
<td>Increasingly since 2008</td>
<td>No</td>
</tr>
<tr>
<td>Company became more innovative</td>
<td>Increasingly since 1990s</td>
<td>Since 1990s for alternative fuels</td>
<td>Increasingly since 2003</td>
</tr>
<tr>
<td>Collaboration culture of company changed</td>
<td>Possibly since 1990s</td>
<td>No</td>
<td>Yes since 2003</td>
</tr>
<tr>
<td>Industrial symbiosis became common practice in the company</td>
<td>Since ca. 2000</td>
<td>Founded as IS company, and impulse since 2001</td>
<td>Founded as IS, and impulse since 2003</td>
</tr>
<tr>
<td>Industrial symbiosis became common practice due to the studied innovation</td>
<td>No</td>
<td>RDF became common practice</td>
<td>No</td>
</tr>
<tr>
<td>Network strategies for studied innovation</td>
<td>Diversify during the innovation process and consolidate afterwards</td>
<td>Diversify during the innovation process and consolidate afterwards</td>
<td>Consolidate during innovation process and aim to diversify afterwards</td>
</tr>
<tr>
<td>Synergies were replicated after the studied innovation process</td>
<td>Attempted</td>
<td>Yes</td>
<td>Attempted</td>
</tr>
<tr>
<td>More innovative synergies followed the studied innovation</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Collaboration culture changed due to studied innovation</td>
<td>No, but slight decrease for studied innovation</td>
<td>Collaboration routine emerged but no cultural change</td>
<td>Slight decrease for collaboration on core business</td>
</tr>
<tr>
<td>Policy and regulation changed due to company actions</td>
<td>Tried at national level and EU but effects unclear</td>
<td>Tried at regional and national level and succeeded</td>
<td>No</td>
</tr>
<tr>
<td>New markets emerged due to company’s studied innovation</td>
<td>No</td>
<td>Yes leading role</td>
<td>Yes contributed</td>
</tr>
</tbody>
</table>
The results also clearly show that companies had to act, or had to evolve, it was not a choice whether to innovate or not. This necessity to adopt resource innovations differs from previous studies which suggested scenarios in which these innovations were optional (Paquin et al. 2014; Short et al. 2014) and mirrors the ‘develop or decay’ processes that take place within biological systems that are undergoing succession (Jensen et al. 2011b). The companies had to innovate because they were presented with potentially terminal crises in terms of economic recession or government regulation demanding acute changes in supply chains. This is similar to Pakarinen et al. (2010) analyses that times of crises motivated the uptake of industrial symbiosis. This indicates that, despite the many negative sides those crises may have had, crises can have positive side-effects because they can function as starting points for increasing resource efficiency or even whole transitions towards increased innovativeness and sustainability. It was as if the crises created a window of opportunity for lasting change in business strategies (perhaps giving more empirical weight within industrial symbiosis to ideas of ‘creative destruction’ during the ‘release’ phase in the complex adaptive cycles in, Schumpeter 1934; Gunderson and Holling 2002).

### 7.5.2 Occurrence of innovativeness and common practices

This study attempted to shed new light on the question whether innovation could increase simultaneously with the establishment of collaboration and industrial symbiosis as common practices (Coleman 1988; Burt 1992; Nooteboom and Gilsing 2004). The results indicated that the time-scale over which these processes were analysed could significantly influence the outcomes. Table 7.2 shows that the studied industrial symbioses were replicated and/or followed by more innovations with the same resource. At the same time the studied industrial symbiosis practice evolved to become a common practice in the case of RDF. Furthermore, in the case of RDF and waste oil, the companies developed a large number of new collaborations which might perhaps be interpreted as the development of a collaborative culture. Such interpretation, however, would be based on the assumption that the companies did not have such collaborative practices before. This research indicated that such assumption would be incorrect. In fact, the companies all had been on long-term journeys towards more innovation which, moreover, already included collaborations with a variety of actors. On top of that, both the companies in the waste oil and waste oils and fats
cases were founded on the proposition of valorising waste resources. Similarly, the company in the RDF case was already engaged in industrial symbioses for several years. In sum, taking into account the long-term business processes, while the studied resource synergies did contribute to increased innovation, it could not be concluded that collaboration and industrial symbiosis became common practices as a result of these innovative synergies within the companies, let alone within their region or wider network (countering suggestions made by e.g., Ashton 2009; Doménech and Davies 2011a; Paquin and Howard-Grenville 2012). Consequently, no conclusions can be drawn regarding the question whether innovativeness increases simultaneously with establishing collaboration and industrial symbiosis as common practices. This gap in understanding requires further research, for instance with companies that had not been engaged in industrial symbiosis practices already, in combination with a more detailed analysis of the collaboration and innovation culture before and after the realisation of the synergy.

7.5.3 Network structures and strategies for government engagement

The results suggested that it was challenging to interact with governments when changes to the (implementation of the) regulatory framework were required for the biowaste-to-resource innovations. Network composition and engagement strategies were identified (Figure 7.5, Section 7.4.2.4). However, the network data were not sufficiently complete to assess associations with specific structural characteristics such as dyadic and triadic connections (Coleman 1988; Burt 1992; Nooteboom and Gilsing 2004). Clearly there is space for further research efforts on the role of network structures in bottom-up processes during the uptake of industrial symbiosis. Similarly, more research is needed on the ways in which top-down processes could respond to business initiatives in order to prevent blocking industrial symbiosis. This observation adds to the discussion about practical recommendations for iterative and/or balanced strategies to promote resource synergies (Section 7.2.1) (e.g., Costa and Ferrão 2010; Lehtoranta et al. 2011; Koskela et al. 2013), by highlighting areas where bottom-up and top-down processes could be better aligned.
7.5.4 Harmonising bottom-up and top-down processes

In the uptake of industrial symbiosis some companies experienced challenges resulting from poor integration of dynamics within the governmental and economical context. For instance, the waste-oil case demonstrated that landfill reduction targets were not well aligned with other areas of waste regulation. Not only did the new waste-definitions lead to more wasted resources, it also constrained the technologies that could be used to divert waste from landfill in the UK while in other European countries the same technologies were allowed under the same EU directive. Such constraints can have far reaching effects. The case studies suggested that various recycling markets emerged later in the UK than in mainland Europe. For instance, the RDF was imported at first while the biofuels produced from waste oils and fats were initially exported to mainland Europe. Furthermore, in the waste-oil case the usage of the resource was initially impossible within the UK. The UK being a late adopter of these technologies is an issue when companies in other countries can adopt them sooner, reach economies of scales to reduce costs and take significant market share before companies in the UK had a chance to join the market. Other challenges resulting from ill-aligned contextual processes include the increasing bottleneck within the regional governance system to support resource innovations (Velenturf 2016b; Chapter 6) as well as the cease in funding for NISP just when industrial symbiosis was gaining momentum within government and industry (Velenturf and Jensen Forthcoming). As discussed in the preceding paragraph, companies can overcome such challenges by cultivating network relations at multiple governmental levels. For instance, the RDF case overcame the barriers of the underdeveloped market and regulation in the UK by engaging governments and potential RDF-suppliers to construct one part of the solution at a time. Such approach of aligning heterogeneous elements of a system is similar to the co-evolutionary perspective reflected in transition literature, which may offer valuable research pathways for industrial symbiosis (Geels 2004; Laurentis 2015).

7.6 Conclusion

This paper has brought together empirical insights into the macro-, meso- and micro-level dynamics and provided qualitative insights into the linkages between these system levels
that were important during the evolution of industrial symbiosis. The main finding of this research is the importance of harmonising the dynamics that occur at all the system levels in order to realise industrial symbiosis innovations successfully. The results suggest that this harmonisation requires social networks that span across the industrial and governmental context. However, further research into network structures and interaction strategies to harmonise top-down and bottom-up processes is necessary to increase the applied value of these findings. Continued research into understanding how best to promote industrial symbiosis is important given that it is a vital component of the on-going transition to a more sustainable, resource efficient and circular economy.
Chapter 8: Discussion
Discussion

This chapter briefly answers the research questions a-c with the results of Chapter 5-7, before answering the overarching research question: How and why did industrial symbiosis, interpreted as biowaste-to-resource innovation, develop over time? The thesis concludes with a discussion of the main contributions (and limitations) of the study and its and implications for academia and practice.
Chapter 8: Discussion

This study set out to make both academic and practical contributions to promote industrial symbiosis. Two broad knowledge gaps were identified:

1) Understanding how and why social networks developed between resource partners and other organisations (Chapter 2; Velenturf and Jensen 2016)
2) Understanding how top-down and bottom-up processes interacted and might have contributed to the evolution of industrial symbiosis (Chapter 3)

The main research question was: How and why did industrial symbiosis, interpreted as biowaste-to-resource innovation, develop over time? After briefly answering the research sub-questions and listing the most important findings (Section 8.1), which were already discussed in detail in the respective results chapters, the overarching findings will be presented to answer the main research question (Section 8.2). These findings partly confirm but in several ways complement or contradict earlier work on industrial symbiosis (Section 8.3) and draw out areas for further research (Section 8.4). The chapter concludes with the main implications for academia and practice (Section 8.5).

8.1 Answering the research sub-questions

The main research question was divided into three further research questions:

(a) How and why did collaborations between resource partners develop during biowaste-to-resource innovations? (Chapter 5; Velenturf 2016a)

(b) How did the governance of, and policy and regulation implemented by, regional governmental and associated organisations influence biowaste-to-resource innovation? (Chapter 6; Velenturf 2016b)

(c) How did top-down processes, such as developments in markets and governance, and bottom-up processes, such as network development during biowaste-to-resource innovation, mutually influence each other over time? (Chapter 7; Velenturf et al. Forthcoming)

The main findings will be summarized here, before answering the overarching research question in Section 8.2.
The case studies provided a set of primarily inductive findings which showed how resource partnerships between waste suppliers and clients developed. The social processes through which relations between resource partners developed were largely similar. To be explicit, the innovation process was predominantly triggered by changes in the governmental and economic context. Potential resource partners were then identified as well as other actors that had to be involved in the innovation process. An initial business case was then made followed by a longer period of building shared knowledge and understanding, indeed this was the basis for trust in the resource synergy. At this point the collaboration was formally agreed with a contract before being realised. These results and more nuanced findings partly confirmed, complemented and sometimes, notably, countered current industrial symbiosis literature. Although the social processes showed broad similarities, differences were identified in companies’ networking strategies. Some companies had to engage new industries and therefore diversified their resource partners during the innovation process, but strived to limit the number of resource partners once the innovation was realised. Conversely, others expanded activities within their network and hence strengthened existing relations during the innovation, but strived to increase the number of resource partners afterwards to manage risky over-dependencies within their supply network. Furthermore, resource security, economic benefits and policy and regulation were of key importance. Finally, the role of geographic proximity was further detailed (further explored in, (Velenturf Forthcoming)). The case study results were operationalised into recommendations for business and government strategies promoting these innovations (Table 8.1), Biowaste-to-resource innovation tool included in Appendix D a and published online alongside Velenturf 2016a; Chapter 5). Above all, however, the results added to academic understanding on the promotion of biowaste-to-resource innovation i.e. industrial symbiosis (discussed in Section 8.3), suggesting new directions for future research (Section 8.4).

Building on the finding that governmental organisations within the Humber region could influence the biowaste-to-resource innovation processes, the regional governance system was studied. The results revealed increasing gaps in the regional governance for biowaste-to-resource innovation specifically and bio-based developments in general. Since 2012 the availability of resources within the local and regional governmental organisations, in terms
of money, organisations, people and competencies, was perceived to have decreased significantly. These results were somewhat surprising, because the drive for increased resource security and efficiency, circular economy and the waste-based bio-economy was seen to grow within the national and EU governments. Recommendations were discussed to improve the connections within, and the functioning of, the governance system for biowaste-to-resource and bio-based innovations (Table 8.1).

Finally, the relations between context dynamics, industrial symbiosis network evolution, and the developments within companies engaging in the resource synergies were explored. Analysis of top-down processes resulting from economical, governmental and industrial context dynamics were combined with results on bottom-up processes of companies responding to the changing context via the uptake of industrial symbiosis practices within their evolving networks. The results demonstrated the variation in the responses of companies to contextual dynamics, drawing attention to the significance of understanding these micro-perspectives in the evolution of industrial symbiosis. While previous studies implied a level of optionality for companies to adopt resource synergies, this study suggested that that companies adopted symbiotic innovations because they were faced with economically or government induced crises demanding acute solutions. Nevertheless, analyses of the resource synergies from the longer-term perspective of on-going developments within the companies, it was demonstrated that the symbioses and development of associated collaborations were part of longer-term processes of increasing innovation while collaboration and industrial symbiosis were already common practices. In the uptake of industrial symbiosis some companies experienced challenges resulting from poor integration of dynamics within the governmental and economical context, such as contradicting policy and regulation, bottlenecks in the governance to realise the symbiotic innovations, and less advanced development of recycling markets compared to mainland Europe. Companies could overcome such challenges by cultivating network relations at multiple governmental levels. In conclusion it was suggested that harmonising dynamics between the contexts, networks and companies would be important in order to realise industrial symbiosis.
8.2 Synthesis of the results: How and why did industrial symbiosis evolve?

This section will synthesise the results to answer the overarching research question “How and why did industrial symbiosis, interpreted as biowaste-to-resource innovation, develop over time?” by discussing the system processes figure that was developed in Chapter 3 (copied below).

![Figure 8.1: A dynamic system perspective on the evolution of industrial symbiosis networks was developed in Chapter 3. NB Note how resources build up during exploitation (grey arrows) and resources are released during exploration (black arrows).](image)

Dynamics in the economic and governmental context drove the initiation of the biowaste-to-resource innovations (Figure 8.1). The business activities and development strategies seemed to influence how companies responded to these context changes. For instance, three companies already became more innovative in terms of resource and energy usage motivated by economic crises in the 1980s and 1990s. On top of that, companies were given
economic incentives to divert more wastes with the introduction of the Landfill Directive (1999), which led to development of expertise in industrial symbiosis practices. Other companies were actually founded on the business proposition to create value from waste i.e. industrial symbiosis was an integral part of the business model. Depending on the existing business activities and symbioses, and the areas of industrial activity prone to impacts from economic and governmental dynamics, the companies had to adopt further resource synergies.

Similarly, some of the companies had to diversify resource partnerships into new sectors and this was reflected in the diversification of their social and metabolic networks. Other companies already had potential or existing resource partnerships that could be strengthened with further symbioses using the same kinds of resources. Despite these differences in network strategies, all resource partnerships developed through a broadly similar social process (as discussed in Section 8.1).

During the implementation of the resource synergies, the companies experienced governance challenges although these did not completely block the studied biowaste-to-resource innovations (this may have been associated with the companies’ necessity to innovate). Despite the growing commitment at the EU and national governance level towards the development of a waste-based bio-economy and a more resource efficient circular economy, since 2012 austerity measures increasingly created bottlenecks for biowaste-to-resource innovations at the regional governance level. The results suggested a decreasing capacity within the regional governance system to process applications for the new or adapted environmental and/or planning permits required for the biowaste-to-resource innovations, let alone to specifically promote these innovations in addition to more general innovation and economic development activities. Furthermore, some companies experienced constraints resulting from dissonance within contextual dynamics during the implementation of the biowaste-to-resource innovations, such as poor alignment of climate change and energy policies with waste regulation as well as delayed adaptation of regulation for the emergence of recycling markets. Hence some companies attempted to influence their regulatory framework (for instance, as seen in the company that adopted RDF). This seemed to require network connections at multiple levels of government which
not all companies had cultivated beforehand and thus not all companies were as successful in their government engagements.

Finally, once the biowaste-to-resource innovation was realised, companies did (strive to) replicate the synergies with other resource partners while some companies also continued to search for further symbiotic innovations for the same resource. Taking into account the long-term business processes of the companies’ journeys towards more innovation, which included collaborations with a variety of actors, and the history of preceding industrial symbioses, it could not be concluded that collaboration and industrial symbiosis became common practices within the companies let alone within their region or wider network as a result of the studied innovative synergies.

8.3 Reflecting upon industrial symbiosis literature

This section reflects upon some of the main overarching findings.

8.3.1 Improved understanding of variation in processes and factors

The evolution of industrial symbiosis showed more variation in processes and factors as well as responses to contextual dynamics than previously reported. By exploring industrial symbiosis in more detail with a qualitative approach, variation was identified and partly explained whilst raising questions for further research (Section 8.4). This section will discuss some of the most important areas where variation added to understanding the development of industrial symbiosis.

Geographic proximity was seen to vary considerably due to trade-offs between economic benefits and resource security. This finding challenges the dominant position in existing literature which holds that industrial symbiosis develops between companies in geographic proximity (e.g., Chertow 2009; Simboli et al. 2012). Furthermore, it suggests that seemingly opposing views on the relation between ‘profit’ margins and resource transport distances could be reconciled when considering the role of resource security (Chertow et al. 2008; Jensen et al. 2011a).
More variation was also identified regarding the role of social and cognitive proximity in the development of resource partnerships. While earlier studies suggested that companies had to trust each other and develop social proximity, such as in the form of professional acquaintance or informal interactions, before the innovation process (e.g., Sterr and Ott 2004; Hewes and Lyons 2008; Chertow 2009; Ashton and Bain 2012), this study showed that not all companies involved in the synergies had such social connections with each other and thus suggested that this was not a prerequisite (see also, Jensen et al. 2011a). Furthermore, the development of shared knowledge and understanding on the subjects of economic benefits, resource security, competencies, and reliability of technology (Table 5.5) were identified as the basis of trust in the collaboration and innovation, adding more tangible insights into the role of cognitive proximity than suggested in earlier publications (Sterr and Ott 2004; Chertow and Ashton 2009; Ashton and Bain 2012).

Finally, variation in business activities, strategies and collaborations were observed, which seemed to influence how companies reacted to contextual changes in terms of the kinds of resource synergies and the resource partnerships that were developed. For example, the increasing energy costs seemed to impact mostly on the energy intensive industries while changes in animal by-product regulation directly impacted on waste oils and fats recycling (also suggested by, Hoffman 2003), in that sense the development of individual resource synergies within the region was not ‘random’ (Baas and Boons 2004; Domenech and Davies 2011a; Chertow and Ehrenfeld 2012). Context dynamics and the particular areas within the companies that they affected also forged the selection of network strategies (further discussed in the next paragraph). For instance, the energy intensive company in Case 2 was affected by rising energy costs and energy insecurity and hence had to act to secure affordable energy for their long-term business survival, they decided to adopt technologies (and resources) for on-site power generation that were new for them and hence they had to adopt a network diversification strategy. The development of resource synergies also seemed to be affected by earlier resource synergies and the innovation and collaboration strategies of companies, which may have put them in a position to adopt the studied resource synergies which they could not have adopted before. This observation seems to be in line with Short et al. (2014) observation of a company adopting larger and perhaps more
risky resource synergies over time. It was indeed suggested earlier that understanding such micro-perspective is important (Andrews 2000), and this study adds further insights into the relations between processes within companies, networks and contexts. This is similar to the observation that top-down and bottom-up dynamics need to fit together when promoting industrial symbiosis or, in less hierarchical terms, that bottom-up dynamics need to be combined with contextual processes (Ehrenfeld and Gertler 1997; Desrochers 2004; Gibbs and Deutz 2005, 2007; Mayer 2008; Park et al. 2008; Laybourn and Morrissey 2009; Costa and Ferrão 2010; Shi et al. 2010; Jensen et al. 2011c; Mathews and Tan 2011; Behera et al. 2012; Christensen 2012; Paquin and Howard-Grenville 2012). This suggests that harmonisation of processes across system levels (such as sketched out in Chapter 3) could benefit the development of industrial symbiosis. The results added to earlier findings on the governance of industrial symbiosis, providing practical insights into the ways in which such harmonisation across system levels could be accomplished (e.g., Kincaid and Overcash 2001; Zilahy and Milton 2008; Bulkeley and Askins 2009; Laybourn and Morrissey 2009; Costa and Ferrão 2010; Paquin and Howard-Grenville 2012).

8.3.2 Identifying network strategies and dynamics

Given the variations discussed in 8.3.1, it is hardly surprising that network strategies and dynamics were seen to vary considerably also. Industrial ecologists suggested that both network density and diversity would increase during the evolution of industrial symbiosis networks (Korhonen 2001a; Nielsen 2007; Mayer 2008; Doménech and Davies 2011a; Paquin and Howard-Grenville 2012). Exploration-exploitation literature suggested a longer-term dynamic perspective of alternating periods of increasing network density and diversity followed by decreasing density and diversity (Coleman 1988; Burt 1992; Nooteboom and Gilson 2004). This research, however, suggests that network diversification is sometimes associated with decreasing density (similar to, Hardy and Graedel 2002; Walter and Scholz 2006). Additionally, the durations of resource partnerships were also seen to vary, while some were short-lived (similar to, Paquin et al. 2014) others seemed more durable (similar to, Doménech and Davies 2011b). The variation in duration of resource partnerships may be linked to companies’ network diversification or strengthening strategies. In line with Paquin et al. (2014) observation that increasing diversity of companies was associated with
decreasing likelihood for initiating and completing resource synergies, this study suggest
that it was more challenging to keep partnerships going in previously unconnected sectors
due to issues with resource security. However, in this study the exploration of new sectors
was not a choice for the innovating companies; they had to diversify in these ways due to
economic or regulatory crises. Perhaps because of this necessity to change, the absence of
knowledge and relations in new sectors did not stop the innovation processes converse to
earlier suggestions in the literature (Ehrenfeld and Gertler 1997; Ashton 2008) and neither
did it require the involvement of a facilitator (Mirata 2004; Paquin et al. 2014).

8.3.3 Understanding the role of network structures in innovation and changing
norms

Building on the preceding section, the role of networks and particular network structures in
connecting system levels could be questioned. Companies may change by means of two
mechanisms: through the adaptation to context dynamics or, alternatively, through the
transmission of information within their networks (Borgatti et al. 2009). The results
suggested that the adaptation mechanism was important during the initiation of the
biowaste-to-resource innovations, while transmission was more important during the
realisation of the innovation and for (attempts to) changing contextual conditions. Although
both mechanisms could be recognised in previous publications on industrial symbiosis (e.g.,
Desrochers 2004; Boons 2008; Ashton 2008; Zhang et al. 2013), their separate roles and
relative importance throughout resource innovation processes require further research
(further discussed in Section 8.4).

In addition to questioning the role of networks, the role of network structures could also be
questioned. Network theories that prescribed particular roles to network structures in
promoting innovation or the emergence of norms were neither supported nor rejected with
the results of this study. Amalgamating these theories into a dynamic understanding of
industrial life cycles, it could be suggested that companies go through an exploration phase
in which their networks increase in density and diversity while new practices are
investigated and implemented, before stabilising and moving into exploitation at which
point the new practices become the norm; and during exploitation diversity and density
start to decrease again to optimise efficiencies and eventually move back into exploration (Coleman 1988; Burt 1992; Nooteboom and Gilsing 2004). However, varying network strategies that did not necessarily correspond with the proposed exploration-exploitation cycle were observed during the symbiotic innovations, suggesting that a less stringent interpretation of the network theories might be appropriate. It was challenging to discuss associations between network dynamics and changes in common practices, because in most cases the practices regarding collaboration and industrial symbiosis did not change as a result if the biowaste-to-resource innovation process. Hence this research supports Zhang et al.’s (2013) observation that the effects of actors’ and relations’ characteristics on network characteristics, and vice versa, still requires further research. In addition it suggests that the effects of network characteristics on contextual changes require further investigation (more on this in the next section).

8.4 Limitations and further research

This study focused on the ‘meso-level’, in other words, the inter-organisational networks between actors within and between the various system levels that were identified at the start of this study. However, one of the main findings was that companies responded differently to contextual dynamics and this suggests that, to better understand how industrial symbiosis is implemented and evolves, it is important to develop a better understanding of the ways companies perceive their various relevant contextual conditions such as the economic circumstances, regulatory changes, and resource availability. This ‘micro-level’ focus has been suggested as an important research direction before within the discipline of industrial ecology (Andrews 2000) and this research suggested it is indeed a valuable perspective to gain a better understanding of the evolution of industrial symbiosis as well. This research has brought together case studies that showed the variation in companies adopting resource synergies ranging from relatively incremental innovations up to transformative innovations that involved regulatory changes and development of new markets. Such results were also recently published but in separate studies (Yang et al. 2014; Park and Park 2014; Short et al. 2014). Clearly this is an area that requires further research. Moreover, the growing number of case studies on the evolution of industrial symbiosis from
the perspective of companies could support a comparative analysis to explain the observed variation.

The second point that requires further research is the adaptation mechanism. Actors can change in response to two mechanisms: adaptation to changing contexts or transmission through flows in their networks (Borgatti et al. 2009). This study focused on networks and transmission. However, the adaptation mechanism seemed important during the initiation of industrial symbiosis. Conversely, during the realising, and perhaps also the persisting (Paquin et al. 2014), of resource synergies, the transmission mechanism seemed to play a more important role. Studying these mechanisms for change in conjunction with each other could increase the understanding of the dissemination of innovative industrial symbiosis practices. Besides questioning the role of networks as a whole, it is also necessary to further question the role of particular network structures.

The case studies showed a variety of evolving network structures and characteristics resulting from the network strategies adopted by the companies. First, several companies were seen to diversify their networks during industrial symbiosis innovations and this seemed to be associated with decreasing network density. Second, while some companies seemed to prefer to have one or very few resource partnerships, others felt this created over-dependency and tried to divert the risk with multiple resource partnerships for one resource. Third, companies seemed to have limited effects on regulatory changes despite their efforts, but the network analysis suggested that direct linkages at various government levels helped rather than having only local/regional and indirect linkages into national/ EU level government through trade bodies. Finally, norms in the form of common practices generally did not change as a result of the studied innovation processes and hence it was not possible to assess whether emerging norms and innovation were associated with particular network structures such as predominantly open or closed and dyadic or triadic relations. The results about network structures add a different perspective to other observations of industrial symbiosis networks which suggested that network density and diversity would occur simultaneously. Furthermore, they suggest a wider set of network structures could support innovativeness, converse to the specific structures that have been
linked to innovation (and emergence of norms) by long-standing network theories. This is an area that needs further research.

The transferability of the social process through which companies developed the resource partnerships also needs further research. For example, the partnerships might develop differently for innovations to extract higher value chemicals which may involve more intellectual property rights. Also, resource synergies may develop differently in other regions or areas of the world. For example the business collaboration culture in the US may be quite different from that in the UK. Finally, another angle of further research would be the comparison of innovative industrial symbiosis with other types of innovation, since the activities showed high resemblance to normal due diligence for business development, it might be that industrial symbiosis develops, and thus could be promoted, in similar ways to other innovations.

Finally, the results regarding impacts of companies on their contextual conditions were modest. Although the data presented in Chapter 5 and 7 spanned a relatively long period, they were not detailed enough to develop strong ideas about emergent processes. To gain a better understanding of emergent processes, more longitudinal studies that monitor the companies’ practices, norms, and context would be necessary. This also ties into the first recommendation to develop a better understanding of the micro-perspective, and the point about the role of networks and network structure in the emergence of norms.
### Table 8.1: Recommendations for academic research and the promotion of industrial symbiosis.

<table>
<thead>
<tr>
<th>Academic</th>
<th>Practical</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Study the uptake of industrial symbiosis from the companies’ micro-perspective:</strong></td>
<td><strong>Governmental organisations can use their central network position to promote industrial symbiosis.</strong></td>
</tr>
<tr>
<td>- Explore the evolution of industrial symbiosis networks from the micro-perspective to understand better how and why companies act upon contextual changes.</td>
<td>Particularly the Environment Agency is in a key position to analyse waste resource movements and that information could be used to:</td>
</tr>
<tr>
<td>- Study the adaptation and transmission mechanisms for change together, to get a better understanding of the dissemination of innovative industrial symbiosis practices into individual companies.</td>
<td>- Identify larger waste streams and target sectors for waste-to-resource innovations.</td>
</tr>
<tr>
<td><strong>Further research on the development of relations during the implementation of industrial symbiosis:</strong></td>
<td>- Engage companies in target supply chains and sectors to explore technical possibilities for industrial symbiosis, emphasise potential economic benefits, and discuss legislative solutions.</td>
</tr>
<tr>
<td>- Qualitative exploration of the development of relations between companies and governmental organisations, technology providers, and network brokers.</td>
<td>- Offer information about resource availability to help companies build confidence in the synergy.</td>
</tr>
<tr>
<td>- Repeat the exploration of the development of resource partnerships at other locations and other types of industrial symbiosis (such as utility sharing and waste-to-resource innovations higher up the waste hierarchy) to assess transferability of the results.</td>
<td>- Help companies writing health, safety and environmental policies and provide training to enable companies to monitor their performance in these areas.</td>
</tr>
<tr>
<td>- Test the relations between geographic proximity, economic benefits and resource security.</td>
<td>- Act as credible information source on the performance of companies for potential resource partners.</td>
</tr>
<tr>
<td><strong>Research the effects of network evolution on innovation performance and other emergent properties:</strong></td>
<td><strong>Governmental organisations could support companies to develop track-records, including:</strong></td>
</tr>
<tr>
<td>- Combine qualitative and quantitative network analysis of companies’ ego-networks to research the associations between network structures and innovativeness and the emergence of norms.</td>
<td>- Help companies writing health, safety and environmental policies and provide training to enable companies to monitor their performance in these areas.</td>
</tr>
<tr>
<td>- Analyse the effects of companies’ network strategies on regional networks and innovation performance.</td>
<td>- Act as credible information source on the performance of companies for potential resource partners.</td>
</tr>
<tr>
<td>- Analyse network density and diversity during the exploration and exploitation of business activities.</td>
<td><strong>Governmental organisations could strive for a flexible attitude in the implementation and development of regulation by:</strong></td>
</tr>
<tr>
<td>- Longitudinal study to monitor the companies’ practices, norms, and context to gain a better understanding of emergent processes during the evolution of industrial symbiosis.</td>
<td>- Staying up-to-date with the technologies to use wastes as resources/ Provide the necessary resources for (regional) officers to acquire and maintain their knowledge and skills.</td>
</tr>
<tr>
<td><strong>Further research on the governance of industrial symbiosis:</strong></td>
<td>- Generating evidence for regulation, collaborating with companies to trial new technologies and resources.</td>
</tr>
<tr>
<td>- Explore the variation in innovation intensities (e.g. incremental, radical, system) of industrial symbiosis innovations, followed by a comparative analysis explaining the variation in innovation processes of companies to gain a better understanding of differences in required promotion strategies and activities.</td>
<td>- Formulate shared development-vision of industry and leave space for industry to determine how to realise the vision within agreed health, safety and environment frameworks, i.e. instead of detailing for industry how to achieve the shared vision, leave space for innovation.</td>
</tr>
<tr>
<td>- Compare innovative industrial symbiosis with other types of innovation to better understand their particularities and differences in support they need for their promotion.</td>
<td>- Engaging companies early in the innovation processes to address regulatory issues pro-actively and co-produce solutions with companies to increase commitment to deliver in both government and industry.</td>
</tr>
<tr>
<td>- Compare the role of network governance to the role of other forms of governance in the promotion of industrial symbiosis.</td>
<td>- Establish regional cross-governance working groups, a) to solve cross-regulatory issues which are regularly encountered in biowaste-to-resource innovation and b) to provide a link between national and regional governance levels to implement strategies and plans for/ associated with the circular and bio-economy.</td>
</tr>
<tr>
<td>- Compare the role that different kinds of governance play within the different contexts of countries where the 3-6 models of promoting industrial symbiosis (self-organised, facilitated, planned) were used.</td>
<td><strong>Companies that are getting involved into biowaste-to-resource innovations, or similar kinds of industrial symbiosis, can check their activities and strategies with the tool included in Appendix D.</strong></td>
</tr>
</tbody>
</table>

Appendix D.
8.5 Implications of the findings: Contributions to academia and practice

This study set out to make both academic and practical contributions to promote industrial symbiosis. This study has contributed to academia by opening up the ‘debate’ about promoting industrial symbiosis: It has added to understanding of the variation in factors and processes associated with the realisation of industrial symbiosis through companies’ activities, strategies, and collaborations; and the relations between context dynamics, evolution of industrial symbiosis networks, and on-going business developments. The level of detail revealed in this qualitative, inductive and empirical research was particularly useful for the identification of further research directions (Section 8.4, Overview in Table 8.1). Moreover, this applied study also supported practical recommendations.

Practical contributions were made in a number of ways. The development of industrial symbiosis was directly discussed with the research participants. Indeed, data collection and dissemination of initial results were mutual learning experiences. Furthermore, recommendations for the promotion of industrial symbiosis were formulated in the results chapters and shared with stakeholders (Overview in Table 8.1). Recommendations pertained to the activities and strategic considerations, such as during the social process identified in Chapter 5 (also see Appendix D), that companies could take on board when engaging in industrial symbiosis. Recommendations for government covered the development of a governance system harmonising industries’ demand for support, investment in research, national political commitments, and the regional governance system. Finally, the detailed recommendations for the formulation of strategies to promote industrial symbiosis could be abstracted into one last main message.

This research has reasoned that there is more variety in the ingredients that may lead to the successful promotion of industrial symbiosis than previously thought, that these ingredients need to fit together, and that it is important to understand how they need to be brought together. It has suggested that the success of industrial symbiosis strategies not only depends on the particular context within a country, region, or industry, but also on the on-going development of the companies that are active within these layers of contexts that stretch along spaces and networks. With such a vastly varying perspective in mind,
searching for a common theory for the promotion of industrial symbiosis might render little practical value indeed. Instead, this diversity in the evolution of industrial symbiosis should be used as an advantage. It provides a living repository of ways to support industrial symbiosis, which should be monitored, researched and communicated within the community of applied academics and specialist practitioners, continuously engaging with governmental organisations and companies, to provide the flexible and adaptive support that is suitable in the evolution of industrial symbiosis.
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Appendix A: Interview schedule case studies


- The interview with the case study participants focused on the development of the relation with the resource partner while it also covered broader subjects relevant to the innovation process.
- Questions followed a pattern from open to more structured questions to ensure all relevant subjects were covered while minimising leading the interviewee in their answers.
- Questions presented here in extremely short format, in interview formulated in longer sentences.
- This interview schedule was flexible to allow movement between questions without disturbing the conversation.
- Some questions were not posed directly because interviewees already answered them spontaneously.

1. How did innovation develop and which organisations were involved?
   1a. Who involved?
   1b. Why?
   1c. Location?
   1d. When?
   1e. From which organisation identified innovation?
   1f. Process start and end?
   1g. Sector of collaborator material exchange?

2. Why innovate? Main drivers?
   2a. Motivation to search innovation?
   2b. Motivation to choose innovation?
   2c. Role of policies?
   2d. Role of markets?

3. How did relation with collaborator material exchange develop over time?
   3a. How met? (already knew, introduced, cold call)
   3b. Prior know outside work?
   3c. Prior economic or financial dependency?
   3d. Symmetrical or hierarchical?

4. Proximities, role in decision to collaborate? Influence collaboration? Benefits and downsides?
   4a. Prior dependencies
   4b. Prior knew outside work?
   4c. Sector?
   4d. Spatial distance?
   4e. Local authority planning strategy?
   4f. Cultural differences North-South Humber?

5. How assess if collaboration would work?
   On what grounds feel certain enough?
   5a. Felt certain right away or developed during process?
   5b. How important to feel certain?

6. How strong perceive relation?
   6a. In which respects strong?

7. Role of formal control?
   7a. How control process?
   7b. How important was control?
   7c. For which decisions or actions?

8. Role of trust?
   8a. Trust in what?
   8b. How important was trust?
   8c. For which decisions or actions?

9. What type of knowledge?
   Tacit or codified?
   9a. How influence coordination?
   9b. How influence interaction?

10. To what extent innovation success?
    10a. In which respects?
    10b. Why?
    10c. Most important success factors?
    10d. Affected costs per unit product? Positive or negative?
    10e. Affected long term survival?
    10f. How important were those two factors when deciding to adopt this innovation?
    10g. Environmental effects?
    10h. How important were environmental effects when deciding to adopt this innovation?

11. To what extent changed institutions?
    11a. New business activity or improved existing activity?
    11b. Change production routines?
    11c. Change in attitude/ behaviour in company?
    11d. Environmental management?
    11e. Waste handling?
    11f. Collaboration?
    11g. How likely collaborative process if free choice?
    11h. Changed government policies or regulation?
Appendix B: Interview protocol governmental organisations

- Abbreviated interview schedule for the interviews with governmental and associated organisations
- Questions used as guideline during interviews which required a high degree of improvisation to tie the questions into the interviewees perspectives and knowledge on the subjects biowaste-to-resource innovation and bio-based development

<table>
<thead>
<tr>
<th>Bio-based economy</th>
<th>Public-private networks</th>
<th>Innovation + collaboration</th>
</tr>
</thead>
<tbody>
<tr>
<td>- What’s going well?</td>
<td>- How did it develop?</td>
<td>- Why?</td>
</tr>
<tr>
<td>- What could be better?</td>
<td>- Why interact this way?</td>
<td>- For innovation?</td>
</tr>
<tr>
<td>3. Which policies and regulation consider useful for these developments?</td>
<td>- What’s important for good interaction?</td>
<td>11. Role different cultures Yorkshire – Lincolnshire in collaboration between companies?</td>
</tr>
<tr>
<td>- How improved?</td>
<td>7. Communicate policies and regulation that may support BWTR-BBE to companies?</td>
<td>- Companies – GO’s?</td>
</tr>
<tr>
<td>- Need new ones?</td>
<td>- Your role?</td>
<td>- Role your GO in across Humber collaboration? How?</td>
</tr>
<tr>
<td>4. Focusing on [a strategy produced by the organisation/team of interviewee], which parts consider useful for BWTR-BBE?</td>
<td>- How communicate?</td>
<td>8. Influence from companies on your work regarding BWTR-BBE?</td>
</tr>
<tr>
<td>- How improved?</td>
<td>- If not, how do companies find out?</td>
<td>12. From your personal point of view, what does the Humber region need in order to support BWTR-BBE?</td>
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<tr>
<td>5. What knowledge or expertise, currently unavailable, could support BWTR-BBE?</td>
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Appendix C: Flexible networked interview protocol tool

This tool was developed for the Evolution and Resilience of Industrial Ecosystems project toolkit.

Motivation

A ‘traditional’ interview protocol is likely to be a list of questions or subjects. During interviews you may experience some problems when using such protocol, including:

- You might lose track of where you are in the interview, particularly when the list of questions or subjects is long.
- When you are simply following the list of questions, you might ask questions that the interviewee already answered.
- You might feel restricted by the interview protocol, particularly when an interviewee brings forward a subject that you do want to ask about but which happens to be further down your list, so you may feel like you cannot prompt and probe on it yet.

To solve these problems, a flexible networked interview protocol was developed.

The flexible networked interview protocol looks like a network diagram. It makes intelligent use of predictions regarding the course of the interview. Considering the questions, you may have expectations regarding the kind of answers the interviewee may give and/or directions in which the interview might logically develop. In the networked interview protocol, the questions and subjects that may follow from a preceding question are linked. This enables a more natural flow of the interview, which could also improve the data quality as it improves the interview experience for the participants. Moreover, it can limit the risk of leading the interviewee which again should contribute to better data quality.

Moreover, the convenient arrangement of the interview protocol in one figure also enables the interviewer to cross off questions and subjects that have already been covered sufficiently. This prevents asking unnecessary and repetitive questions which improves both interview efficiency and the experience of participants.
1. Prepare your interview protocol by listing all the questions and/or subjects you will need to cover in the interview.

   - How did the innovation develop and which organisations were involved during the process?
     - a. How did you hear about the innovation?
     - b. When did the process start? When was it finished?
     - c. Who were involved in the innovation process? Which organisations? May I know the persons involved?
     - d. Where were they located?
     - e. Why were they involved?
     - f. What is your communication habit?

2. Go over the interview and consider in which direction the interviewee might take the conversation. Link each question to the potential follow-up questions. It is even better if you can trial your interview and get some real input into this process.

3. Abbreviate the questions so that they can all fit into text-boxes on one page. Copy the questions into textboxes and link the textboxes according to your considerations in step 2.
4. Alternatively, you can use NodeXL to prepare your networked interview schedule. NodeXL is open source software that works within MS Excel, you can download it here [http://nodexl.codeplex.com/](http://nodexl.codeplex.com/). In that case, copy the questions into the NodeXL file as Vertices, and enter the links between questions as Edges. Note that this does not work for very lengthy interview protocols, because then the abbreviated questions cannot be read anymore from the figure.

Figure made with NodeXL.
Appendix D: Guidance for waste-to-resource innovation tool

Figure reproduced from: Velenturf, A.P.M. (2015) Promoting industrial symbiosis: Empirical observations of low-carbon innovations in the Humber region, UK. Journal of Cleaner Production, SF on New approaches for transitions to low fossil carbon societies: promoting opportunities for effective development, diffusion and implementation of technologies, policies and strategies. (in print)

Motivation

Resource efficiency and reducing carbon emissions are increasingly important for companies and various other actors. Waste-to-resource innovation has been identified as a strategy to achieve both whilst also promoting business growth. However, understanding how these innovations can be promoted is still limited. Velenturf (2015) studied how companies developed relations with resource partners during waste-to-resource innovations in the emerging bioenergy sector in the Humber region, UK. The study revealed the processes, operational activities and strategic considerations of companies during the innovation processes. To support future waste-to-resource innovations, the results of this study were used in the development of this tool.
Manual

1. Examine the social process and associated operational activities and strategic considerations presented in the figure below.

2. Assess which parts of the figure might be important for innovation processes which you are leading/participating in.

3. Integrate the relevant process steps, including associated operational activities and strategic considerations, into your existing processes and procedures for innovation.

Figure: Activities and strategic considerations throughout the social process through which the biowaste-to-resource innovations were implemented. This figure has been presented online at http://dx.doi.org/10.1016/j.jclepro.2015.06.027.
Appendix E: Overview of results policy analysis

The table below lists the government reports, policies and regulations identified through a structured policy evaluation (Schiller, unpublished ERIE data) and during the collection, analysis and reporting of the case study results.

Table: Industrial symbiosis and (bio)waste-to-resource innovation have been influenced by many and often volatile government outputs in various subject areas.

<table>
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<tr>
<td>EU Thematic Strategy on the Sustainable Use of Natural Resources (2003)</td>
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<tr>
<td>The Roadmap to a Resource Efficient Europe (2011)</td>
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<tr>
<td>Resource Security Action Plan: Making the most of valuable materials (2012)</td>
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<tr>
<td>Government report Building a high value bioeconomy: Opportunities from waste (2015)</td>
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<tr>
<td>Revised EU Circular Economy Strategy (2015)</td>
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<tr>
<td>Environmental Protection Act (1990, amended)</td>
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<tr>
<td>Landfill Tax (1996)</td>
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<td>Landfill Tax Credit Scheme (1996, revised in 2002)</td>
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<tr>
<td>Landfill Tax Escalator (since 1999)</td>
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<tr>
<td>Waste Strategy England and Wales (2000, revised in 2007 and then England only)</td>
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<td>Landfill Allowance Trading Scheme (since 2004)</td>
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<td>National Industrial Symbiosis Programme</td>
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<td>Waste and Resources Action Programme</td>
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<td>Business Resource Efficiency and Waste Programme</td>
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<td>UK Waste Management regulations (England and Wales) 2006</td>
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<td>Duty of Care regulation</td>
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<td>Carriers and Brokers regimes and regulations</td>
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<td>Environmental Permitting regulations (2007, new version 2010)</td>
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<tr>
<td>Quality Protocols project (since 2009) with end-of-waste procedures, regulatory position statements, and option to apply for exemption if material not listed in protocol.</td>
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<tr>
<td>EU Animal By-products regulation (2009)</td>
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<tr>
<td>EU Implementing regulation (on animal by-products) (2011)</td>
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<td>Climate Change Programme (2000, revised in 2006)</td>
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<tr>
<td>Climate Change Levy (2001)</td>
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<tr>
<td>Renewables Obligation (RO) Certificates (2002, reformed in 2007)</td>
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<tr>
<td>Aggregates Levy (2002)</td>
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<tr>
<td>EU Emissions Trading Scheme (ETC) (2005)</td>
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<tr>
<td>National Allocation Plan, part of EU ETC phase 2 (2007)</td>
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<tr>
<td>Climate Change Agreement (CCA) (2005, extended until 2023)</td>
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<td>Renewable Transport Fuel Obligation (2007)</td>
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<td>Climate Change Act (2008)</td>
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Waste and recycling

Climate change and carbon emissions
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<th>Other</th>
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<tr>
<td>Carbon Price Floor (2011)</td>
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<td>Renewable Heat Incentive (2011, reviewed in 2014)</td>
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<td>Feed-In-Tariffs (2010)</td>
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<tr>
<td>Carbon Reduction Commitment Energy Efficiency Scheme (2010) – parallel to EU ETC and CCA</td>
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<tr>
<td>Contract for Difference (2015) (partly replaced RO)</td>
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<tr>
<td>International transport regulation</td>
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Appendix F: Outline of forthcoming article “Emergent and immergent processes during the evolution of the National Industrial Symbiosis Programme”

Anne P.M. Velenturf and Paul D. Jensen

Summary of the research idea
This research will analyse the combination of contextual conditions and initiator’s actions which have led to the emergence of the National Industrial Symbiosis Programme (NISP) in the UK. NISP initiators and facilitators arguably promoted the uptake of industrial symbiosis within governmental organisations, both within the UK and also internationally, resulting in the inclusion of industrial symbiosis in the EC circular economy package which generates immergent pressures for the further promotion of industrial symbiosis within the UK. Finally, bearing in mind the contextual changes which have occurred in the past 15 years, this article will argue whether the role of a facilitator such as NISP has changed since it first emerged.

Introduction
Velenturf et al. (Forthcoming) showed that contextual conditions, business strategies and activities, and inter-organisational networks were all evolving at the same time and that, for industrial symbiosis to be realised successfully, these dynamics had to be harmonised i.e. they had to be aligned or otherwise the evolution of industrial symbiosis practices might be hampered. This idea will be applied to analyse the emergence of NISP with the aim to eventually suggest whether and how a ‘NISP 2.0’ could emerge in the UK in the future.
It has often been suggested that the strategies to promote industrial symbiosis need to fit to the context within which they are employed. Strategies need to connect the relevant top-down and bottom-up processes. However, understanding on how to achieve this in practice needs further research. NISP has managed to do this successfully and it is important to analyse the lessons learned.
Data and empirical evidence

Data availability:

- Documents: Peer-reviewed articles, Professional articles, NISP reports, and EC and UK government reports
- Transcripts of interviews with (former) NISP practitioners and Environment Agency
- Direct experiences from former NISP practitioner and, potentially, further feedback from the NISP initiators

In the preparation of Velenturf et al. 2015 (Chapter 7 of this thesis) an analysis of the emergence of NISP was already partly written but, in an effort to consolidate and focus Chapter 7, it was excluded from the publication at a later stage. The prepared text can be converted for the purpose of this article:

The Humber and National Industrial Symbiosis Programme

One important change within the regional governance system was the cease of funding for the National Industrial Symbiosis Programme (NISP) and consequently its delivery in the Humber region. NISP was a business initiative inspired by the ‘By-Product Synergy’ programme in the Gulf of Mexico and brought to the UK via a multinational petrochemical company and the Business Council for Sustainable Development (BSCD) in 1999 (Bailey et al. 2008). These organisations also had connections in the Humber region, and hence this became one of the pilot areas for NISP in 2000. Various efforts were made to launch the Humber Industrial Symbiosis Programme (HISP) but industry participation was initially low (Mirata 2004). In 2002 an industrial partner funded the development of NISP including part-funding two regional symbiosis programmes, one of which was HISP and encompassed an expanded Yorkshire and Humber wide remit which enabled offering services for free at point of delivery (Bailey et al. 2008). Additional funding was acquired from the Regional Development Agency and the Landfill Tax Fund (Gibbs 2000; Mirata 2004). HISP gained momentum as it engaged more companies. The success of the regional symbiosis
programmes in meeting and exceeding their funding targets created the groundswell needed for the creation of a national programme (Laybourn and Clark 2004). As it gained momentum, NISP applied for funding from DEFRA through the Business Resource Efficiency and Waste (BREW) programme and was officially launched in 2005 (Bailey et al. 2008; CIWM 2015). Despite continuously exceeding their assigned targets (Laybourn and Morrissey 2009), NISP were subject to a series of government driven funding changes and reductions since 2008 eventually leading to the complete stop of public funding, for most UK regions, in 2012.

Due to its success in the UK, NISP also influenced similar developments in other countries. Since 2005, International Synergies Ltd (ISL), the architects and deliverers of NISP within the UK, widely communicated NISP as a tool to develop the circular economy. As a result, the NISP philosophy and method for resource innovation has been applied in various other countries within the EU and other continents (CIWM 2015). Based in part on the empirical and tested success of the likes of NISP, industrial symbiosis has been included in various strategic documents such as the Resource Security Action Plan (DEFRA and BIS 2012), the Roadmap to a Resource Efficient Europe (EC 2011b), and, perhaps, also in the forthcoming EU circular economy package in 2015.

Finally, looking at society as a whole, it could certainly be said that industrial symbiosis became broadly recognised as a strategy through the efforts and success of NISP. NISP was a business initiative, i.e. a bottom-up or emerging process. As discussed in the context analysis, NISP evidently has had a direct effect on the development of EU level governance which will probably eventually feed back into the UK. As such, it could be said that NISP is an example of an emergent process, leading to context changes in the UK, which then continued to influence other countries government-contexts followed by the whole EU, which then might feed back through UK governance to the companies of which some may have contributed to the original emerging process in the first place i.e. closing the loop of emergent and immergent processes.

Success factors, which may have turned into new challenges, included:
- NISP was built on a network of regional practitioners who had in-depth knowledge of the industries within their region as well as the collaborative skills to engage companies.

- NISP was free at point of delivery to the companies; it started to gain momentum when it had the funding to offer the services for free, it lost momentum when it lost public support and switched to a paid membership model. Arguably, part of the reason why NISP lost public support was because it was too successful. If it was such a valuable service then surely companies would be willing to pay for it? And, although some companies can and are indeed willing to pay for NISP’s services, the argument as to why others do not and hence why a publicly funded facilitation model would still be preferred within the UK needs to be explored. Furthermore, this argument may also be transferable to other countries.

- NISP emerged with the introduction of the Landfill Tax and Animal by-product regulations, at a moment when the waste management sector in the UK was relatively underdeveloped compared to the waste challenges the new regulations created i.e. there was a gap in the market which NISP could fill. During the time that NISP lost public support, the waste management sector experienced strong growth (evidenced by EA data). Hence the market context within which a ‘NISP 2.0’ would be launched has changed compared to 10-15 years ago and this poses challenges as to what would be a reasonable, ethical positioning of a publicly supported commercial waste management programme and their effects of and role in the current waste management sector.

- The reasoning above already shows how NISP successfully tapped into the changing government context to fund its on-going emergence 10-15 years ago. Now, with NISP and other organisations successfully communicating and promoting industrial symbiosis and similar approaches to governments, and climate change and resource security having risen on the political agenda, the government context for on-going support for programmes like NISP has changed as well.

Further success factors and challenges may emerge from the further analysis of the data.
Appendix G: Economic structure of the Humber region

Figure: The economic and industrial structure of the Humber region expressed by the proportion of enterprises in each sector in the four local councils in the Humber region in 2014 (NOMIS 2015).
Appendix H: Article “Initiating resource partnerships for industrial symbiosis”

This article has been submitted to Regional Studies, Regional Science.

Abstract

Industrial symbiosis is a strategy to limit carbon emissions whilst promoting resource efficiency and business development. This study interprets industrial symbiosis as waste-to-resource innovation. Understanding how these innovations are actually realised, and hence how they can be promoted by public and private partners, is still limited. Particularly initiating resource partnerships for waste-to-resource innovations in the absence of a government-funded facilitator, such as previously the National Industrial Symbiosis Programme in the UK, has remained underexplored. This article explores how companies identify potential resource partners in terms of a) network and b) geographic distances. Based on case studies of waste-to-resource innovation in the Humber region, UK, the article concludes that a) companies can identify resource partners among/through their direct contacts that are involved in resource production/management themselves and b) that ca. 73% of these connections are located within a 75 miles radius. Furthermore, various new ‘facilitators’ were identified, demonstrating the need for a refined government approach to facilitate industrial symbiosis as part of the wider transition towards the circular economy.

Keywords: Self-organised industrial symbiosis; Networks; Geographic proximity; Waste-to-resource innovation; Circular bio-economy; Business strategies

Industrial symbiosis research on initiating resource partnerships

Industrial symbiosis is a recognised strategy to limit carbon emissions whilst promoting resource efficiency and business development (Laybourn and Morrissey 2009). Industrial symbiosis can be interpreted as the innovative process in which the waste from one company is used as a resource by another company i.e. waste-to-resource innovation (Frosch and Gallopoulos 1989; Jensen et al. 2011). In addition to these resource partners, the realisation of industrial symbiosis can also involve other actors such as governments and technology providers. Actors involved might exchange information, materials and/or energy (Chertow 2000; Korhonen et al. 2004). Hence, it could be said that industrial symbiosis
involves network development. Although the industrial ecology community has indeed seen some research on industrial symbiosis networks (e.g., Ashton 2008; Doménech and Davies 2009; Paquin and Howard-Grenville 2012), open qualitative empirical explorations are rare (Romano et al. 2012; Velenturf and Jensen 2016). Consequently, understanding how industrial symbiosis actually develops, and hence how it can be promoted by public and private partners, is still limited.

Three broad models have been distinguished for the development of industrial symbiosis, ranging from government-planned to facilitated and self-organised approaches (Paquin and Howard-Grenville 2012). When the government plans or facilitates the development of industrial symbiosis, then resource partners are identified for companies by the government or through publicly funded programmes such as previously by the National Industrial Symbiosis Programme (NISP) in the UK. The government or facilitator acts as network broker, which can be understood as a coordinator that initiates and manages connections between resource partners (Provan and Milward 2001; Paquin and Howard-Grenville 2012). Conversely, in the case of self-organised industrial symbiosis, which is the prevailing model in the UK since public funding for NISP stopped in 2012, companies need to initiate resource partnerships themselves without government support. Despite various studies on self-organised industrial symbiosis, particularly the initiation process of resource partnerships has remained largely unexplored.

Rather than exploring the actual process through which industrial symbiosis is realised, research has tended to list barriers and success factors (Madsen et al. 2015; Velenturf and Jensen 2016). The importance of a limited number of factors, such as social and geographic proximity between resource partners, has been emphasised (e.g., Chertow 2000) though rarely empirically questioned. In the case of geographic proximity, research on waste resource flows suggests that distances between resource partners can vary considerably (Lyons 2007; Jensen et al. 2011). Jensen et al. (2011) observed that waste resource movements facilitated by NISP varied from 0.1 to 269 miles, while 90% of all movements between resource partners were within 75 miles from each other. Lyons (2007) recorded waste resource movements varying from local to (inter)national scale. Converse to these studies on *metabolic* networks comprising of material and energy flows, geographic
distances in social networks (including information flows) associated with industrial symbiosis have not been questioned yet (Romano et al. 2012; Velenturf and Jensen 2016).

In sum, there are significant knowledge gaps pertaining to the process through which self-organised industrial symbiosis develops, the ways in which resource partnerships are initiated, and the role of geographic distances between the actors involved. Consequently, it has been challenging to translate research outcomes into practical recommendations for the promotion of industrial symbiosis. This article aims to add to the practical understanding of realising industrial symbiosis and to complement research on the development of resource partnerships after they were initiated (Velenturf 2016a). The objective of this article is to explore how companies identified potential resource partners in the first instance, answering the question: Where did companies find potential resource partners in terms of a) network and b) geographic distances?

**Researching industrial symbiosis in the Humber region, UK**

Research was carried out in the Humber region (Figure 1). Located in the northeast of England, the Humber region hosts one of the busiest port complexes in the UK combined with a predominantly agricultural hinterland. It is one of England’s most diverse and mature industrial systems (Jensen 2016). Five qualitative exploratory case studies were conducted with companies adopting industrial symbiosis in the form of a waste-to-resource innovation (Frosch and Gallopoulos 1989):

1. ‘Fuel producer’ searching customers for waste oil
2. Energy intensive company searching suppliers for anaerobic digestion plant feedstock
3. Energy intensive company searching suppliers of Refuse Derived Fuel
4. Steam producer searching for waste-wood suppliers, and customers for steam
5. Specialist recycler and fuel producer growing their partnership for biofuel manufacturing

As part of a larger research project (also see, Velenturf 2016a; Velenturf et al. Submitted), the case studies were designed to explore how and why these waste-to-resource innovations developed. Key individuals closely involved with the innovation at hand were interviewed. Interviews were transcribed before analysis and complemented with documents such as permit applications and news articles to get a thorough understanding.
of the development of relations with resource partners and others involved in the innovation processes.

![Figure 1: The Humber region is located on the coast in the northeast of England with ports facing Europe (Map source: Bondholders scheme Ltd.).](image)

Data were processed with conceptual and open coding. Codes included (but were not limited to) network actors and relations, absolute and relative proximity (Boschma 2005), self-organised and facilitated relations (Paquin and Howard-Grenville 2012), and order of events during the innovation process. Data were further interpreted in several steps: The role of each code was analysed in isolation and in relation to other codes. Then, a holistic understanding of the innovation processes was developed in case study reports. The interpretation was completed with a cross-case comparison.
Figure 2a-e: Resource partnerships were formed between case study participants’ plants within the Humber region, and in some cases their business groups, and their waste resource suppliers/clients. In most cases the relationship was brokered by a shared contact i.e. ‘network broker’. Distances between resource partners as well as brokers varied from less than 10 miles up to over 75 miles for (inter)national connections.
Analysing patterns in initiating resource partnerships

Network development

The network development for each waste-to-resource innovation has been analysed in detail (Figure 2a-e). The case study participants generally identified potential resource partners through a shared contact that functioned as a ‘network broker’:

- In Case 1 ‘Waste oil’ the participant identified a suitable resource broker, which was a company specialising in facilitating by-product exchanges that was already contracted by another production site of the same parent company. In turn, the resource broker identified a company that could use the waste oil (Figure 2a).
- In Case 3 ‘Refuse Derived Fuel’ (RDF) the case study participant identified a new technology, and company that had already adopted it, from a sector-journal. After contacting the energy intensive company that had adopted the technology using RDF, they facilitated the contact between their RDF-supplier and the case study participant (Figure 2c).
- Case 4 ‘Waste-wood fuel’ showed a complex sequence of brokered interactions between parent- and daughter companies. The studied innovation consists of two symbioses, one of which stemming from a facilitated connection between two of the parent companies that were using the same storage facility. The symbiosis between the steam and wood-fuel producer was a continuation of a long-term collaboration between the two business groups (Figure 2d).

In two cases the resource partners already knew each other:

- While the resource partners in Case 2 ‘agricultural feedstock’ already knew each other, the studied resource partnership for the anaerobic digester was suggested first by a shared contact (Figure 2b).
- In Case 5 ‘Waste oils and fats’ the connection between the two resource partners was originally facilitated by NISP i.e. a classic example of facilitated industrial symbiosis. The partnership then evolved over time into a closer collaboration involving the treatment of increasing quantities of various waste oils and fats, which could be interpreted as a self-organised continuation of the facilitated symbiosis (Figure 2e).

The analysis indicates that the resource partners either already had direct contact or were connected by a shared contact that functioned as a network broker. The results revealed more variation in actors that can function as network brokers than currently visible in the
industrial symbiosis literature. These included members of the company group/ production sites within the same company, specialised by-product management companies (showing much resemblance to government-funded facilitators such as NISP), landlords/site-owners, and companies authored in industry journals. Except for the latter, all network brokers were involved themselves in producing and/or managing resource flows.

**Geographic proximity**

Locations of resource partners and network brokers span across the Humber, UK and Europe, ranging in distances of less than one mile up to over 600 miles (Figure 2). However, most connections were between actors within 75 miles range of each other.

Geographic proximity was considered important in all relations in Case 2 ‘agricultural feedstock’ and in some relations in Case 4 ‘waste-wood fuel’ between the storage facility, steam producer and fuel producer. In these relations the social contacts were inherently tied to a shared location and were considered crucial in the forming of the connections. In the other relations, geographic proximity was considered less important during the initiation. In Case 1 ‘waste oils’ and Case 3 ‘Refuse Derived Fuel’ the long overseas connections were a necessity, caused by an unfavourable regulatory context in the UK and the introduction of a new technology and resource to the British market respectively. In Case 5 ‘waste oils and fats’ the distances were relatively short but generally this was not considered important, the participants perceived that the resource partners could have been over 150 miles apart. However, the continued self-organised growth of the partnership was fostered by shared management of the two sites which was backed by close geographic proximity.

Finally, the analysed geographic distances during the initiation should not be considered typical for the studied symbioses. All participants considered resource partners at shorter and longer distances as the partnerships developed for reasons related to economic value and/or resource security (Velenturf 2016a).
Reflecting on industrial symbiosis literature

The results revealed that potential resource partners were already direct contacts of each other or that they had a shared contact that could introduce them/ suggest symbiotic collaboration. This organic growth of the industrial symbiosis network seems to be in line with earlier suggestions that the one symbiotic relation leads to further resource innovations (e.g. by, Jensen et al. 2012; Short et al. 2014).

The role of shared contacts functioning as network brokers or coordinators adds a nuance to understanding the difference between facilitated and self-organised industrial symbiosis. While ‘facilitated’ tends to mean coordinated by governments/ publicly funded programmes such as NISP (Paquin and Howard-Grenville 2012), the case studies were also facilitated albeit by the private sector themselves. The results suggest that the distinction between spontaneous and facilitated industrial symbiosis is not as sharp since a broader range of actors acted as network brokers or facilitators than identified before. Case 5 ‘waste oils and fats’ adds further nuance by showing how facilitated synergies can lead to self-organised industrial symbiosis.

Turning to geographic proximity, distances varied similar to earlier observations of metabolic networks (e.g., Lyons 2007; Jensen et al. 2011). For the social connections, geographic distances were only considered important in the minority of relations, converse to earlier argumentations on proximity (see Velenturf and Jensen 2016 for an in-depth literature review). Adding to Jensen et al. (2011) analysis of metabolic flows in the case of facilitated industrial symbioses, the majority of social connections analysed in this study on self-organised industrial symbioses were within 75 miles range. There were, however, relatively many social connections, and associated metabolic flows, at distances over 75 miles (ca. 27% compared to 10% observed by Jensen et al.).

Perhaps longer distances between resource partners in self-organised symbioses could be anticipated when compared to facilitated industrial symbiosis. First, as argued above, composition of the existing networks clearly influences the emergence of new resource partnerships. Hence, if a company has a geographically wide-ranging network, then chances
are that potential resource partners are also situated further afield. Second, while companies may have good knowledge of sector(s) they already engage, they are unlikely to have as in-depth knowledge of sectors that are new to them as e.g. regional NISP-practitioners who could draw upon a database of thousands of companies and synergies. However, considerable further research is necessary to explore these ideas further.

Finally, the transferability of the findings to other regions needs further research. Industrial diversity has been linked to the presence of industrial symbiosis (Jensen 2016). Given the high industrial diversity of the Humber region, companies in less diverse areas may have to search a wider area to identify resource partners.

Implications for practice, policy, and academia

This article presented a first exploration of the ways in which companies identified resource partners in terms of network and geographic proximity. The conclusions can be summarised in three points:

(1) The results showed that companies can identify resource partners either among or through their direct contacts that are involved in the production or management of resources themselves and that are predominantly located within a 75 miles radius.

(2) The results also revealed how companies initiated resource partnerships supported by a variety of network brokers. Further research is necessary to better understand the range of actors functioning as network brokers for industrial symbiosis, their commercial interests in resource synergies, the strategic implications for broader economic transitions that private sector brokers could realise compared to publicly funded facilitators, and the role that a government funded facilitator should play in promoting industrial symbiosis. Such insights need to be included in the development of government strategy for industrial symbiosis, as part of promoting the wider transition towards the circular economy.

(3) While this article presented practical implications for the promotion of industrial symbiosis and opened new perspectives on network brokerage, it also identified various research gaps. In addition to the policy relevant research on network brokerage for
industrial symbiosis, further research needs to be carried out on the effects of existing networks, industrial diversity, and companies’ and facilitators’ sectoral knowledge on geographic proximity between companies during the initiating of resource partnerships.
Appendix I: Alternative storylines

This thesis was based on rich qualitative data that offered various angles for analysis and the presented arguments. Whilst the presented chapters form a coherent story answering the research questions in a way that is beneficial for all involved stakeholders (from academic colleagues to industry and government partners), it was not the only story that could have been told.

1. Part A could have included the literature review that was carried out to compare the concept of proximity, which was new to industrial ecology, and embeddedness, which is commonly used. An article containing such comparison, which could have the title “Network Analysis of Industrial Ecosystems: Proximity and Embeddedness”, was suggested during the review process of Chapter 2 (Velenturf and Jensen 2016).

2. In Part B, a chapter could have been included on “Identifying Shared Academic and Professional Knowledge Gaps”. Fellow academics regularly ask for this experiences and hence it may be a well-publishable article too.

3. Deciding the storyline for Chapter 7 was the most challenging of all chapters. For a long time this chapter was going to be about “Multi-level Network Dynamics driven by Resource Innovation”, to explore the relations between network density, diversity and system boundaries. While such chapter would significantly add to understanding system-dynamics within industrial ecology, it did not enable answering research question c in a meaningful way.

4. Similar to publishing the story on network initiation that preceded the case study data published in Velenturf 2016a (Chapter 5), as suggested in Appendix H “Initiating Resource Partnerships”, the network initiation for the public-private interactions analysed in Chapter 6 (Velenturf 2016b) would also have been a valuable addition to the storyline.