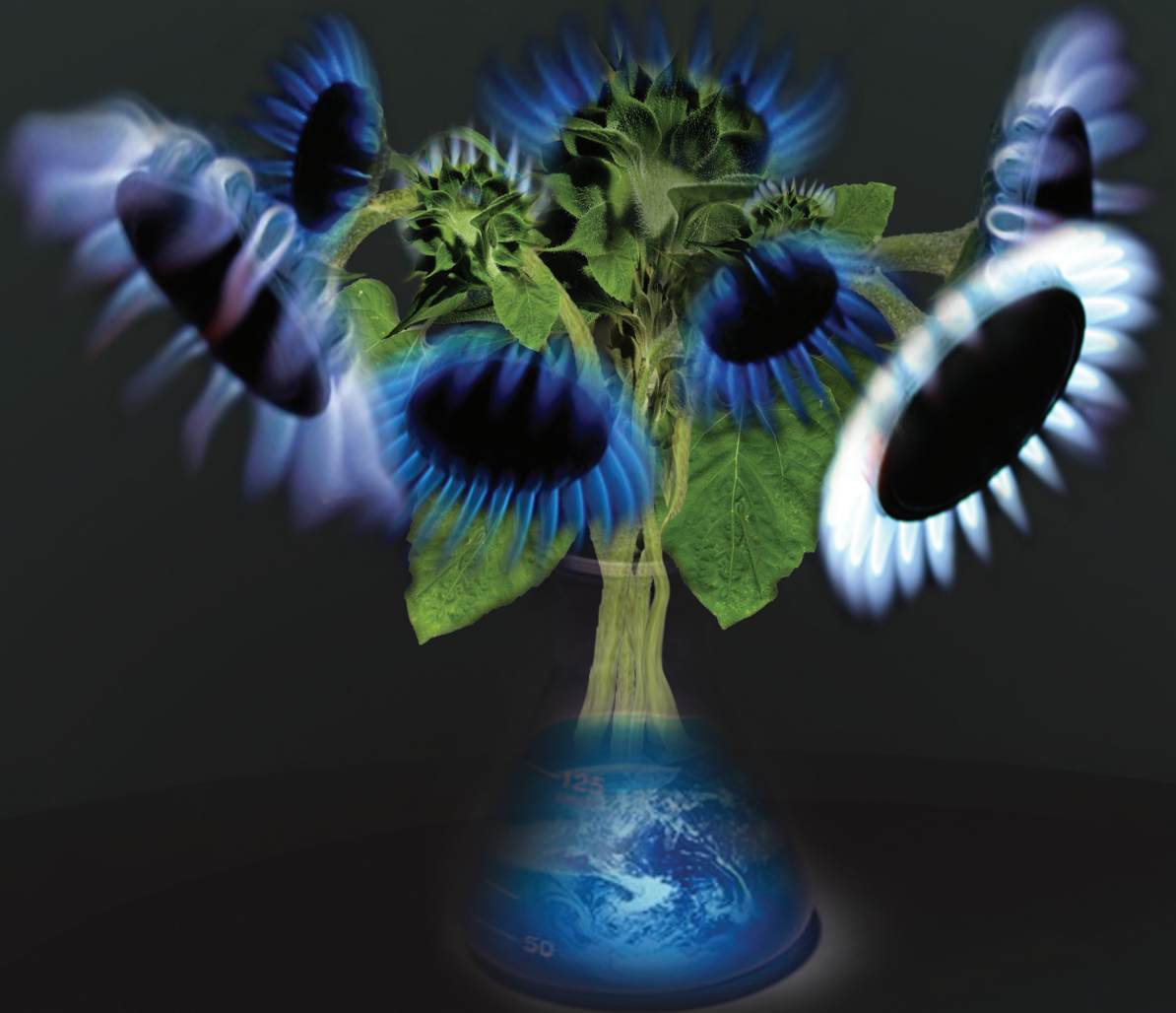


Anastasia Tsvetkova

Designing Sustainable Industrial Ecosystems: The Case of a Biogas-for-traffic Solution





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DESIGNING SUSTAINABLE
INDUSTRIAL ECOSYSTEMS:
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SOLUTION

Doctoral dissertation

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Tampere, October 2014
Anastasia Tsvetkova

ABSTRACT

This thesis focuses on the development of sustainable industrial architectures for bioenergy based on the metaphors of industrial symbiosis and industrial ecosystems, which imply exchange of material and energy side-flows of various industries in order to improve sustainability of those industries on a system level. The studies on industrial symbiosis have been criticised for staying at the level of incremental changes by striving for cycling waste and by-flows of the industries 'as is' and leaving the underlying industry structures intact. Moreover, there has been articulated the need for interdisciplinary research on industrial ecosystems as well as the need to extend the management and business perspectives on industrial ecology. This thesis addresses this call by applying a business ecosystem and business model perspective on industrial symbiosis in order to produce knowledge on how industrial ecosystems can be developed that are sustainable environmentally and economically.

A case of biogas business is explored and described in four research papers and an extended summary that form this thesis. Since the aim of the research was to produce a normative model for developing sustainable industrial ecosystems, the methodology applied in this research can be characterised as constructive and collaborative. A constructive research mode was required in order to expand the historical knowledge on industrial symbiosis development and business ecosystem development into the knowledge of what should be done, which is crucial for sustainability and the social change it requires. A collaborative research mode was employed through participating in a series of projects devoted to the development of a biogas-for-traffic industrial ecosystem.

The results of the study showed that the development of material flow interconnections within industrial symbiosis is inseparable from larger business ecosystem restructuring. This included a shift in the logic of the biogas and traffic fuel industry and a subsequent development of a business ecosystem that would entail the principles of industrial symbiosis and localised energy production and consumption. Since a company perspective has been taken in this thesis, the role of an ecosystem integrator appeared as a crucial means to achieve the required industry restructuring. This, in turn, required the development of a modular and boundary-spanning business model that had a strong focus on establishing collaboration among ecosystem stakeholders and development of multiple local industrial ecosystems as part of business growth. As a result, the designed business model of the ecosystem integrator acquired the necessary flexibility in order to adjust to local conditions, which is crucial for establishing industrial symbiosis.

This thesis presents a normative model for the development of a business model required for creating sustainable industrial ecosystems, which contrib-

utes to approaches at the policy-makers' level, proposed earlier. Therefore, this study addresses the call for more research on the business level of industrial ecosystem formation and the implications for the business models of the involved actors. Moreover, the thesis increases the understanding of system innovation and innovation in business ecosystems by explicating how business model innovation can be the trigger for achieving more sustainable industry structures, such as those relying on industrial symbiosis.

Keywords: industrial symbiosis, economies of repetition, distributed production, business ecosystem, business model.

REFERAT

Denna avhandling undersöker utvecklingen av hållbar industriarkitektur för bioenergi med hjälp av metaforerna 'industriell symbios' och 'industriella ekosystem', vilka inbegriper olika industriers utbyte av sidoflöden av materiel och energi för att förbättra dessa industriers hållbarhet på systemnivå. Studier av industriell symbios har kritiserats för att beakta endast den stegvisa förändring som uppnås genom återvinning av industriers avfall och biflöden, medan de underliggande industriella strukturerna har förblivit oförändrade. Därtill har uttryckts ett behov av tvärvetenskaplig forskning om industriella ekosystem samt ett behov av att utvidga de förvaltnings- och företagsmässiga perspektiven på industriell ekologi. Denna avhandling bemöter detta behov genom att tillämpa ett på affärsekosystem och affärsmodeller baserat perspektiv på industriell symbios för att producera kunskap om hur industriella ekosystem som är både ekologiskt och ekonomiskt hållbara kan utvecklas.

I avhandlingen, som består av fyra forskningsartiklar samt ett längre sammandrag, undersöks och beskrivs ett företag inom biogasindustrin. Emedan målsättningen för forskningsprojektet var att skapa en normativ modell för utvecklandet av hållbara industriella ekosystem, så kan projektets metodologi beskrivas som konstruktiv och kollaborerande. En konstruktiv forskningsmetod krävdes för att utvidga den historiska kunskapen om utvecklingen av industriell symbios och affärsekosystem till att omfatta kunskap om vad som bör göras, vilket är avgörande för hållbarheten och den samhällseliga förändring som krävs. En kollaborerande forskningsmetod tillämpades genom deltagande i en serie projekt inriktade på att utveckla ett affärsekosystem för biodrivmedel.

Resultaten av studien visade att sammanlänkningen av materialflöden inom industriell symbios bör utvecklas i nära anslutning till större omstruktureringar inom affärsekosystem. Detta inkluderade ett logikskifte inom biogas- och drivmedelsindustrin samt en påföljande utveckling av ett affärsekosystem som skulle vara förenligt med principerna för industriell symbios och lokalt inriktad energiproduktion och -konsumtion. Eftersom den här avhandlingen är skriven utgående från ett företagsperspektiv, framträdde rollen som 'integratör av ekosystem' som ett betydelsefullt redskap för att uppnå den nödvändiga industriella omstruktureringen. Detta i sin tur nödvändiggjorde utvecklingen av en modulbaserad och gränsöverskridande affärsmodell med starkt fokus på etablering av samarbete mellan olika intressenter inom ekosystemen samt utveckling av en mångfald lokala industriella ekosystem som en del av tillväxten. Som ett resultat av detta uppnådde den av integratören utformade affärsmodellen nödvändig flexibilitet för att anpassas till lokala förhållanden, vilket är avgörande för etablerande av industriell symbios.

Avhandlingen lägger fram en normativ modell för utvecklandet av en affärsmodell som är nödvändig för att skapa hållbara industriella ekosystem, och som stöder dylika ansatser på politisk beslutsfattarnivå. Således uppmärksammar studien behovet av utökad forskning på företagsnivå för att utveckla industriella ekosystem samt deras betydelse för de involverade aktörernas affärsmodeller. Därutöver ökar avhandlingen förståelsen av systeminnovationer och innovationer inom affärsekosystem genom att redogöra för hur innovationer av affärsmodeller kan utgöra en utlösande faktor för att skapa mera hållbara företagsstrukturer, såsom de som bygger på industriell symbios.

Nyckelord: industriell symbios, cykliska ekonomier, distribuerad produktion, affärsekosystem, affärsmodell.

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- I. Tsvetkova A. and Gustafsson M., 2012. Business Models for Industrial Ecosystems: A Modular Approach. *Journal of Cleaner Production* 29-30, pp. 246-254. DOI: 10.1016/j.jclepro.2012.01.017.
- II. Hellström M., Tsvetkova A., Gustafsson M., Wikström K. Collaboration mechanisms for business models in distributed energy ecosystems. Submitted to the *Journal of Cleaner Production* (1st review round).
- III. Tsvetkova A., Gustafsson M., Wikström K., 2014. Business model innovation for eco-innovation: developing a boundary-spanning business model of an ecosystem integrator. In Azevedo, S., Brandenburg, M., Carvalho, H., Cruz-Machado, V. (Eds.), *Eco-innovation and the Development of Business Models: Lessons from Experience and New Frontiers in Theory and Practice*. Greening of Industry Networks Studies, Vol. II, pp. 221-241. Springer Verlag.
- IV. Tsvetkova A., Hellström M., Gustafsson M., Sjöblom J., 2014. Replication of industrial ecosystems: the case of a sustainable biogas-for-traffic solution. *Journal of Cleaner Production*, in press. DOI: 10.1016/j.jclepro.2014.08.089.

CONTRIBUTION OF THE AUTHOR

The author is responsible for papers I, III and IV as regards data collection, analysis, development of conclusions and larger part of writing. The analysis and conclusions have been developed and discussed together with the respective co-authors. The author is responsible for data collection and analysis of two cases devoted to biogas business in Paper II, whereas the third case in the paper has been elaborated by the lead author of the paper Dr. Magnus Hellström. The development of cross-case analysis and conclusions has been done together with other co-authors of Paper II. The author participated in empirical work and analysis of the data as follows:

Paper I. The empirical work and conceptualisation of results have been carried out with the help of Dr. Magnus Gustafsson.

Paper II. The empirical work for case 1, which is out of the focus of this thesis, had been carried out by Dr. Magnus Hellström and Dr. Magnus Gustafsson. For empirical work for cases 2 and 3, which are in the focus of this thesis, see Paper III. The data set for the two cases in Paper II and Paper III are the same.

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Paper IV. The data collection was supported by M.Sc. Joakim Sjöblom. Dr. Mika Tuomola provided insights during the development of the first version of the paper.

ABBREVIATIONS

ANT	Actor-network Theory
CBG	Compressed biogas
DSR	Design science research
FSSD	Framework for Strategic Sustainable Development
IS	Industrial symbiosis
LBG	Liquefied biogas
LNG	Liquefied natural gas
PBI	PBI Research Institute (PBI stands for 'Project based industry')
TNS	The Natural Step

GLOSSARY

Biogas	a mixture of gases produced in the process of anaerobic digestion. In this thesis, the term ‘biogas’ also refers to the upgraded product, which mostly consists of biomethane (CH ₄) and can be used as traffic fuel
Business ecosystem	an economic community supported by a foundation of interacting organisations and individuals, which produces goods and services of value to customers, who are themselves members of the ecosystem. Over time, they coevolve their capabilities and roles, and tend to align themselves with the directions set by one or more central companies (Moore, 1996)
Business model	a conceptual device which captures the manner by which the enterprise delivers value to customers, entices customers to pay for value, and converts those payments to profit (Teece, 2010)
Industrial ecosystem	a network of industrial actors, in which the consumption of energy and materials is optimised, waste generation is minimised and the effluents of one process serve as the raw material for another process (Frosch and Gallopoulos, 1989), i.e. a system of actors that employs industrial symbiosis
Industrial symbiosis (IS)	an activity that engages diverse organisations in a network to foster eco-innovation and long-term culture change. Creating and sharing knowledge through the network yields mutually profitable transactions for novel sourcing of required inputs, value-added destinations for non-profit outputs, and improved business and technical processes (Lombardi and Laybourn, 2012)

Modularisation	the process of decomposing complex systems based on commonalities between various elements into building blocks or modules with specified interfaces
Replication	the process of delivering 'repeatable solutions' by partly standardising and exploiting the technical and business knowledge
Sustainable development	the development of human society, which allows meeting the needs of current generations without compromising the ability of future generations to meet their own needs (WCED, 1987). The solutions that contribute to sustainable development can be referred to as 'sustainable'

I PART I
EXTENDED
SUMMARY

1 ● INTRODUCTION

This thesis focuses on the development of sustainable industrial architectures for bioenergy. The aim of this study was to develop the knowledge that can drive such renewal, utilising a case of biogas business. A planned local biogas-for-traffic solution, therefore, served both as the main data collection site and as the arena for applying and testing knowledge produced during the research. Although a number of successful similar solutions based on biogas use as traffic fuel exist, for example, in Sweden, the descriptive knowledge of their development was not sufficient to enable the focal business. The problem resided in the lack of an appropriate business ecosystem that could convert a local symbiosis effort into a sustainable business. Thus, the main research question of this study was how industrial ecosystems can be developed that are sustainable environmentally and economically.

1.1. Background

The growing concerns about climate change, depletion of resources, and limitations for economic growth have led to the articulation of the need to change to sustainable development (WCED, 1987). The fossil fuel-based economy has proved to be one of the major reasons for reaching the current unsustainable situation, in which the quest to meet the needs of our generation is significantly undermining the potential of future generations to meet their needs (Korhonen et al., 2004). Now, when environmental challenges and resource limitations are directly affecting the quality of life, economic and social development, the future development of society can be compared to an attempt to get into a resource funnel. The walls of this funnel are narrowing down as society's needs are constantly increasing and resources are constantly decreasing (see Figure 1). Continuing a straightforward movement without adjustments will lead to 'hitting the wall'. Sustainability can be achieved by broadening the walls of the funnel, i.e. ensuring that the supply and demand of resources and ecosystem services, such as clean water, air and land, will correspond over the long term. It is therefore crucial to ensure that the funnel will not close and to design sustainable solutions that will fit into this funnel.

Renewable energy and bioenergy in particular, are seen as solutions that enable continuous fulfilment of society's energy needs and as a pathway towards sustainability. The field of bioenergy includes production of energy from various biomasses that are renewable within a relevantly short timeframe (European

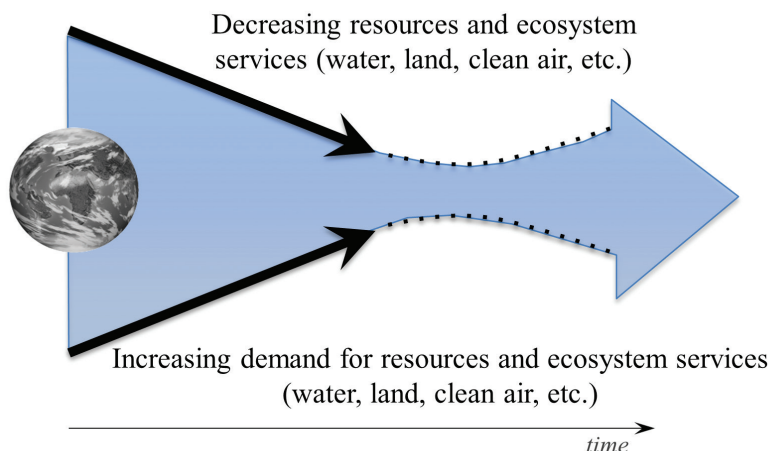


Figure 1. TNS funnel metaphor.¹

Commission, 2013). The technologies for producing fuel and energy from bioresources are constantly developing and many of them are widely commercially available: biogas, bioethanol, biodiesel and wood-based syngas but to name a few. A common shortcoming in implementing these technologies is blueprinting fossil fuel-based economy logics and industry structures. As a result, it is difficult for bioenergy solutions to become feasible and thereby compete with fossil fuels. New business concepts are required for bioenergy so as to create sustainable solutions that would not only help to avoid ‘hitting the wall’ but will also be economically sustainable. These concepts need to be based on both the characteristics of existing infrastructures and those of bioenergy and biomass.

A major difference in the properties of biomass and fossil fuels is in their availability and energy density. Since biomass has lower energy content, and a higher prevalence and variability of sources compared to fossil fuel resources, shorter distribution distances are more appropriate for its transportation (Gustafsson et al., 2011; Mirata et al., 2005). The difference in properties is demonstrated in Figure 2. To fulfil society’s growing energy needs, it is realistic to organise fossil fuel production as a mass-production industry. In this way, an economy of scale and thereby higher efficiency in energy production and supply could be achieved (Johansson et al., 2005). However, since biomass is available almost ubiquitously, but in smaller quantities, production of biofuels at large-scale refineries incurs high transportation costs, both in monetary and environmental terms. Attempts to reduce financial costs often leads to shifting the environmental and social burden onto something else (Mirata et al., 2005), such as in the case where biomass is grown in developing countries in an unsustainable manner, and is refined into biofuel to be used in developed

¹Adapted from The Natural Step (2013)

countries. Such solutions are prone to create new social and environmental problems, to face feasibility challenges, and to inherit the shortcomings of fossil fuel-based economy. Thus, the challenges that the biofuel industry often confronts are not based in the quality of the product – biofuel, but in the incompatibility of the old industry’s structures and logics with the properties of biomass and the aims that bioenergy needs to fulfil.

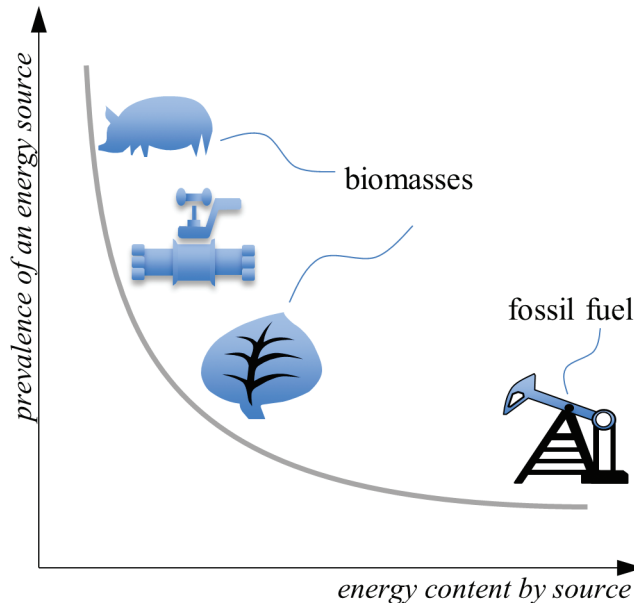


Figure 2. Schematic representation of the differences in prevalence and energy content of biomass and fossil fuels.²

Contrary to mass-production, the distributed way of producing biofuels, and biogas used as a case study in this research, appears to conform much better to the nature of biomass production (Mirata et al., 2005; Ristola and Mirata, 2007). In such an industry structure, production facilities are located close to the biomass source and match its volume, forming a network of fairly independent production units. On a system level, distributed economies are seen as a more flexible and resilient industry structure, which is highly required in the shift from efficiency-driven economy to the economy striving for quality and sustainability (Johansson et al., 2005).

The sustainability of biofuel production can be further improved by inter-connecting material and energy by-flows of various industries as implied by the metaphor of industrial symbiosis (IS) (Allenby and Cooper, 1994; Baldwin et al.,

²Adapted from Gustafsson et al. (2011)

2004; Benyus, 1997; Chertow, 2000; Côté and Cohen-Rosenthal, 1998; Ehrenfeld, 2000; Geng and Côté, 2002; Graedel, 1996; Templet, 2004; Wallner, 1999). For example, various types of biowaste such as sewage sludge, manure or other organic waste can be used as a source for biogas production. This has a positive environmental effect due to the more efficient use of resources, and treatment of waste on a local level, while bringing significant costs savings or even new revenue streams to the biogas producer if biomass has zero or negative value. Stemming from the field of industrial ecology (Graedel and Allenby, 1995), a similar concept of *industrial ecosystems* emphasises the need for reshaping industrial activities into a more cyclic mode as well as the system nature of collaboration required for this production mode (Chertow, 2000). In a seminal article in the field of industrial ecology Frosch and Gallopoulos (1989) wrote:

“...the traditional model of industrial activity in which individual manufacturing processes take in raw materials and generate products to be sold plus waste to be disposed of should be transformed into a more integrated model: an industrial ecosystem. In such a system the consumption of energy and materials is optimized, waste generation is minimized and the effluents of one process ... serve as the raw material for another process.”

Frosch and Gallopoulos, 1989: p. 144

The idea of material flow cycling and higher integration of industrial actors implied by IS has the potential to benefit the needs of establishing small quite independent production and consumption systems implied by distributed economies (Mirata, 2005). In this thesis, a network of local industrial systems where biogas is produced and consumed served as a vision for a sustainable biogas-for-traffic industry. The research interest was, therefore, in how production of biogas and its utilisation as traffic fuel could be organised in order to become a truly sustainable solution.

Production of biofuels within industrial ecosystems is technically sound, although it requires complex material flow engineering and coordination, which ultimately leads to increased costs. The greatest challenge, therefore, lies in the business integration, rethinking the whole value chain of fuel production and re-designing the overall business logic so as to make the business feasible and otherwise sustainable. Current industry structures and the manner in which companies organise their business cannot accommodate the systemic and circular character of production within industrial ecosystems. A systemic and circular character that is not only required for biofuels but for sustainable development in general (Boons et al., 2013). In line with this, Hart and Milstein (1999) argue that ‘transplanting’ models from traditional consumption-focused economies into emerging economies striving for sustainability contradicts the whole idea of building greener industry structures. Moreover, the notion of IS often implies collaboration among traditionally disconnected industries (Chertow, 2000), which makes the business integration task even more challenging.

From an innovation perspective, there is a need not only to develop IS for physical production of biogas, but also to consider the larger socio-technical system around biogas production (Geels, 2002) and ensure the existence of an enabling and suitable business ecosystem (Moore, 1996). Recently, management research has been paying attention to the importance of and the opportunities provided by considering the business ecosystem around products and business models. Amit and Zott (2012) propose that a company can successfully innovate its business model by taking a systemic view, i.e. in the context of the networks and ecosystems it operates within, instead of making isolated choices. In line with this, Gulati et al. (2012) introduced the notion of a meta-organisation in which companies, though not connected through any formal authority, need to perform as one entity, i.e. in a system, in order to succeed.

It is important to note that the ecosystem metaphor has different emphasis in industrial ecology as compared to business and management studies. Thus, in industrial ecology the notion of an industrial ecosystem is used as a prescriptive model that urges the cycling of energy and materials among industries similarly to natural ecosystems, and also stresses the inseparability of these systems (Ehrenfeld, 2001). In management studies, the metaphor has been used to emphasise the interdependency upon each other of the various business actors within and across industries, and the process of their co-evolution (Moore, 1996). Innovation studies pay more attention to the fact that the introduction of new technologies and products requires embedding them into socio-technical systems which already exist, or creating new ones (Geels, 2005). There is, however, a common ground for the use of the metaphor: the eco-*system* idea draws attention to the need for a systemic view on industrial and business activities.

In this thesis, the terms ‘industrial ecosystem’ and ‘ecosystem’ are used as a combination of the above perspectives and to emphasise *system value creation*. This means that together various actors as a part of an industrial ecosystem are able to generate *system benefits*, i.e. benefits inaccessible to separate actors and exceeding the sum of benefits they would receive on their own (Simon, 1962). Whether they are environmental, economic, or even social, these benefits are deeply intertwined in the view of strong sustainability (Ayres et al., 2001). The boundaries of industrial ecosystems, as defined in industrial ecology, need to be widened in order to embrace the actors crucial for such complex value creation even if they are outside the physical material exchanges. Since the context of this research is the development of sustainable biofuel industry structures, a holistic approach is required in order to address both environmental sustainability (through relying on ideas of efficient material flow cycling) and economic sustainability (through focusing on resilience and feasibility of new industry structures). The reason for stressing the business side of ecosystems also lies in the fact that unless industrial ecosystems are economically sustainable they will not be able to replace the current environmentally unsustainable production modes.

Thus, theories from both fields: industrial ecology and management stud-

ies, - are utilised in this study. The ideas of IS and a distributed production mode form the basis for developing a desired way of producing biogas that is environmentally sustainable. The target biogas-for-traffic industry structure can be therefore described as a network of local industrial symbioses. A business ecosystem redesign is required to enable the focal biogas-for-traffic solution so as to reflect and facilitate the envisioned symbiotic and distributed industry architecture. Furthermore, the business model level is chosen as the unit of analysis in order to gain an understanding of what connects businesses and eventually triggers a system change, and the formation of a business ecosystem. This is due to the fact that business models are not only bound by the industry structures, but may also be vehicles in shaping them (Brusoni et al., 2009; Ferraro and Gurses, 2009; Pisano and Teece, 2007). The core of this research is the business model of the company which attempts to establish a sustainable biogas-for-traffic ecosystem through innovating its own business model.

1.2. Research context: the biogas-for-traffic solution

The case that is central to this thesis is a biogas-for-traffic solution planned in a municipality in Finland. Biogas production as a business already existed in the area, however, the fuel was utilised for heat and power production, thereby having quite low value. Sewage sludge supplied by the local wastewater treatment facilities was the main resource for the biogas production. The main revenue stream for the biogas producer was the gate fee for sewage sludge treatment, while biogas brought only marginal value. A gas distribution infrastructure as well as biogas upgrading facilities did not exist in the area thus preventing immediate use of biogas as traffic fuel.

The focal municipality is an urban area with around 200 000 inhabitants. Public transportation and other transportation businesses therefore form an important part of local economy. The benefits of utilising locally produced biogas in public and other local transportation were rather evident: a reduction in greenhouse gas and particle emissions in the area, self-sufficiency in terms of fuel, less dependency on fluctuating prices of fossil fuels, smarter utilisation of biowaste, and creation of local jobs.

Despite the well-articulated advantages of using biogas as traffic fuel and evidence from similar solutions abroad (see e.g. Berglund et al., 2011; Lantz et al., 2007), the implementation of the solution faced a number of challenges. As implied by the notion of IS, the implementation of the solution required the integration of a number of industries that are not traditionally connected to biogas production: transportation, waste management, agriculture, and other relevant businesses. The potential suppliers of biomass in the focal area included a wastewater treatment unit, farms, and waste management companies in addition to the wastewater treatment facility, which already supplied material for biogas production. The potential users of biogas, in turn, constituted a diverse range of companies that had various business logics and interests.

Furthermore, in order to ensure environmental sustainability of the produced biogas and overall solution, the digestate – the by-product of biogas production – needed to be utilised in a reasonable manner, e.g. as a fertiliser in farming. All the named actors operated in considerably diverse industries and it was not clear how their participation in the biogas-for-traffic business would benefit or otherwise affect their operations.

Another critical issue was that most of the potential stakeholders were required to make certain investments, for example, gas-driven vehicles, biogas distribution infrastructures, or equipment for spreading digestate on the farmers' fields. The companies needed to work in a system to create a functioning solution and make these respective investments. This required building an industrial ecosystem that would integrate otherwise disconnected business actors and would ensure system value creation and re-distribution. For the biogas company, that would ultimately become the ecosystem integrator, it was critical to consider the development of a biogas business beyond one location, in order to make the biogas-for-traffic business more resilient and allow competition with fossil fuels. Thus, a distributed production mode and business expansion to new locations was urged in order to support the integrator's ability to create and manage a complex network consisting of a number of local industrial ecosystems.

A research project was started at the PBI Research Institute in order to explore how the biogas-for-traffic solution could be implemented given the above uncertainties. The author's participation as a researcher allowed observation of the processes required, and assistance in shaping the formation of the solution in tight cooperation with the relevant companies and other actors, such as the municipal authorities. The initial design of the target solution started with envisioning the main material flows among the actors as presented in Figure 3. Material flow planning is only a starting point; the following stage, business planning and implementation, proved to be a more challenging task that ultimately affected the industrial ecosystem constellation.

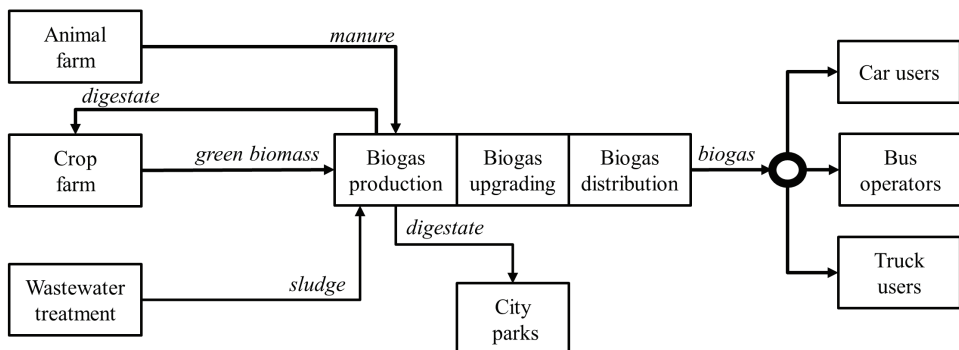


Figure 3. The initial envisioned constellation of a target 'biogas-for-traffic' ecosystem based on material flow design.

1.3. Motivations for the research

The motivations for the research undertaken in this dissertation originated from the research context and theoretical background. First of all, the real-life challenge discussed earlier needed to be solved: in the focal biogas-for-traffic case it was not clear how to implement the solution and integrate the multitude of stakeholders, i.e. how to create a biogas-for-traffic industrial ecosystem that could be characterised as distributed and symbiotic.

As discussed in section 1.1, the new sets of processes that would fulfil the emergent market for biofuels do not align with the currently prevailing market structures, particularly those inherited from the current fossil market. The change towards sustainable industry structures was unlikely to occur naturally, partly because the business actors observed in the focal case showed the following characteristics:

- Lack of entrepreneurial activity to induce new structures and organisations through effectual action.
- Lack of management awareness in existing organisations to facilitate the changes.
- Rigidity within the existing organisations that would make changes risky and costly.

Since the relevant organisations in the focal case did not anticipate nor react sufficiently to the emergent biogas-for-traffic market, new models originating in institutional networks such as educational research and industrial actors had to enable such agency. This was the reason for starting the research project and for the author to engage in the collaborative and constructive research that resulted in this thesis.

Existing research on sustainable industrial organisations within the fields of cleaner production and industrial ecology could not provide the solution to the problem of how to enable such a sustainable biogas business *from a company perspective*. The perspective taken in industrial ecology is often either historical or adopts the policy-maker's point of view in providing prescriptive knowledge (Yu et al., 2013). It is assumed that IS is a free-will collaboration between various industrial actors that occurs spontaneously and is therefore either uncontrollable (Chertow, 2007), or can be triggered by various policy tools (Agarwal, 2011) and is considered traditionally as an altruistic act performed by companies (Lombardi et al., 2012). While a number of examples of successful industrial eco-parks have been researched and described (Baas, 2011; Behera et al., 2012; Côté and Cohen-Rosenthal, 1998; Ehrenfeld and Chertow, 2002; Ehrenfeld and Gertler, 1997; Heeres et al., 2004), it has proven to be difficult to reproduce industrial ecosystems in various locations (Chertow, 2007; Woodard, 2001). Centralised planning (Baas, 2011; Desrochers, 2001; Elabras Veiga and

Magrini, 2009) and a middle-out approach (Agarwal, 2011; Costa and Ferrão, 2010) have been discussed as ways of creating industrial ecosystems, where decisions reside at the policy-maker's level. In addition, the studies on IS have been criticised for staying at the level of incremental changes by striving for cycling waste and by-flows of the industries 'as is' and leaving the underlying industry structures intact (Ristola and Mirata, 2007). In this sense, one of the motivations for this research was to unveil the potential of the concepts of IS and distributed production to guide the development of more sustainable industry structures for biogas production and use in traffic. The need for interdisciplinary research on industrial ecosystems in order to foster the implementation of such industry structures more successfully has been articulated (Posch et al., 2011; Lombardi et al., 2012), together with an acknowledgement of the need to extend the management and business perspectives on industrial ecology (Korhonen et al., 2004). As a result, the way in which business ecosystem research (Gulati et al., 2012; Moore, 1996) could benefit industrial ecology remained to be explored.

This extensive research on business ecosystems and system innovation attempts to explain the phenomenon of how industries are altered due to the actions of individual companies (Echols and Tsai, 2005; Gulati, 1998; Gulati et al., 2012; Jacobides et al., 2006; Normann and Ramírez, 1993; Pisano and Teece, 2010; Sarasvathy and Dew, 2005). Although the need for companies to acquire a system view of their business is acknowledged in eco-innovation (Ceschin, 2013) and technological transition studies (Geels, 2002; 2005), the detailed way in which it could be employed at a company level was still to be researched.

As Lombardi and Laybourn (2012) note, potential members do not invest time and energy in pursuing synergies without a perceived benefit. Given the nature of IS, where actors from traditionally unconnected industries establish material and energy exchanges, the difficulty of establishing collaboration between business ecosystem actors is brought to an even more challenging level. Normal supply chain connections do not yet exist among these companies, and they often target different markets with their main products and services, whereas engagement into IS is achieved through by-flow exchanges. An example of required collaboration between industries that are traditionally unaccustomed to operating within one business sphere is integration of farming into the production of bioenergy. Existing industry structures, common spheres of operation and industrial standards are not directly helpful or effective in the market. As a result, a company, in order to integrate the new biogas-for-traffic ecosystem, needs to develop new ways to establish sustainable interconnections with all the ecosystem actors. This will inevitably be reflected in the industry structure and the business model of such an integrating company. However, existing research on business ecosystem development has not been able to prescribe these means in a highly uncertain market that is still to be created. Instead, a more experimental and creative research approach was expected to serve these needs.

1.4. Research objectives

The aim of this study was to develop the knowledge that can drive the change to the more sustainable industry structures required for biofuel business. The focal biogas-for-traffic case therefore served both as the main data collection site and as the arena for applying, and thereby validating, knowledge produced during the research.

Given the characteristics of the research problem, the ultimate result of this thesis was expected to be a normative model for developing sustainable industrial ecosystems for biofuel industry, using biogas-for-traffic business as an example. This affected the methodology applied in this research as well as the essence of the knowledge produced: prescriptive and actionable. Thus, a constructive research mode was required in order to expand the historical knowledge on IS development and business ecosystem development to the knowledge of what *should be done*, which is crucial for sustainability and the social change it requires.

The main research question in this study is:

- *How to design sustainable industrial ecosystems?*

The aim of the design process is to create artefacts that serve the intended function and can be implemented in the real world. Therefore, in this study, *design* and *development* of industrial ecosystems are treated as inseparable parts of one process and the words are often used interchangeably. Since the actual implementation of design is in the hands of ecosystem actors, the focus of this study is on the design of industrial ecosystems that are sustainable and implementable. Thus, both the target industrial ecosystem structure (the design outcome) and the logics of its development (the design process) were expected to form the actionable knowledge.

In order not to exclude critical elements that might help to answer the research question, the general level of why it is difficult to establish industrial ecosystems was initially considered. This included exploring what are the ecosystem actors and various links between them, e.g. material flows, informational interdependencies, financial flows, interlinked risks, rules and regulations. More concrete research questions arose as the research progressed. This is also true for the theories and concepts used for analysing and conceptualising the generated knowledge – they were used when and for as long as they helped to answer the question of how to create industrial ecosystems that are sustainable. In this way they became instruments for generating practical knowledge (Reason, 2003) instead of imposing dualism on the research problem.

In the process of answering the main research question, new, more focused and rather challenging research questions appeared that included of a multitude of issues (see Figure 4).

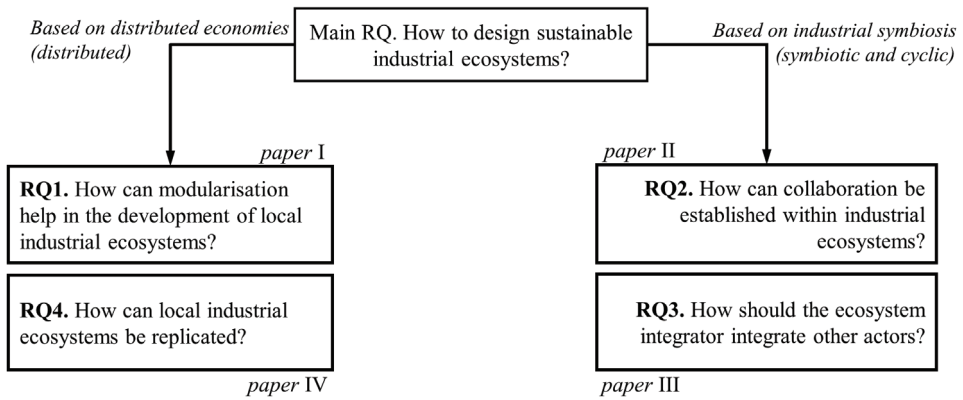


Figure 4. Research questions and the process of their development.

The main ‘how to’ research question and the aim to develop the knowledge on the business side of industrial ecosystems, which is largely unaddressed in the literature on industrial ecosystem formation, guided the research throughout the complex problem-solving. As a result, the latter research questions (RQ 3 and RQ4) addressed the business model of the ecosystem integrator. Taking a company to become the ecosystem integrator as the focal one made it possible to develop knowledge that is actionable in business. Thus, after exploring what needs to be done on a general level in order to create sustainable biogas-for-traffic ecosystems (RQ1 and RQ2), it was considered that the best way to develop the knowledge that can be applied in practice was to take the perspective of the *implementer* replacing the earlier ‘helicopter’ view on ecosystem formation, where the market and institutions settle the ecosystems ‘automatically’. RQ3 asked how an ecosystem integrator can integrate various actors into a sustainable industrial ecosystem and RQ4, in turn, asked how business replication of local industrial systems can be done by the integrator.

As the new research questions appeared, new theories surfaced as being the ones that could partly answer the questions and inspire new knowledge creation. This way replication and modularity studies (Davies and Brady, 2000; Langlois, 2002; Miller and Elgård, 1998; Sanchez and Mahoney, 1996; Shilling and Steensma, 2001) helped to analyse how complex systems can be managed and replicated while keeping them feasible. Moreover, business model studies helped in analysing the way new industry logic can be implemented through business model innovation (Amit and Zott, 2012; Linder and Cantrell, 2000; Teece, 2010; Zott and Amit, 2010) and how collaboration can be enhanced by employing more open, boundary-spanning business models (Chesbrough, 2006; 2007; 2010; Wikström et al., 2010; 2011). System innovation (Geels, 2002; 2005) and eco-innovation studies (Ceschin, 2013; Loorbach, 2010) were utilised in order to explain the dynamics of biogas-for-traffic solution implementation and to inspire the way the ecosystem integrator can shape its own envi-

ronment in order to succeed. An overview of the relevant literature is presented in Chapter 2 of the extended summary.

1.5. Structure of the thesis

The thesis is structured as follows:

- I. Extended summary
- II. Papers

The extended summary consists of five chapters:

1. Introduction
2. Literature review
3. Methodology
4. Results
5. Discussion and conclusions

Part I of the thesis summarises the major concepts, definitions, and findings presented in Papers I-IV and further discusses them in order to present a holistic picture of the research and its contribution. Part II includes three research papers and one edited book chapter. They are referred to throughout the thesis as Papers I-IV.

Paper I. Tsvetkova A. and Gustafsson M., 2012. Business Models for Industrial Ecosystems: A Modular Approach. *Journal of Cleaner Production* 29-30, pp. 246-254. DOI: 10.1016/j.jclepro.2012.01.017.

Paper II. Hellström M., Tsvetkova A., Gustafsson M., Wikström K. Collaboration mechanisms for business models in distributed energy ecosystems. Submitted to the *Journal of Cleaner Production* (1st review round).

Paper III. Tsvetkova A., Gustafsson M., Wikström K., 2014. Business model innovation for eco-innovation: developing a boundary-spanning business model of an ecosystem integrator. In Azevedo, S., Brandenburg, M., Carvalho, H., Cruz-Machado, V., *Eco-innovation and the Development of Business Models: Lessons from Experience and New Frontiers in Theory and Practice*. Greening of Industry Networks Studies, Vol. II, pp. 221-241. Springer Verlag.

Paper IV. Tsvetkova A., Hellström M., Gustafsson M., Sjöblom J., 2014. Replication of industrial ecosystems: the case of a sustainable biogas-for-traffic solution. *Journal of Cleaner Production*, in press. DOI: 10.1016/j.jclepro.2014.08.089.

2. LITERATURE REVIEW

This chapter reviews the literature in the scientific fields that are relevant to this research. The first field includes studies on sustainability and industrial ecology. The second field regards innovation in business ecosystems. The third field is management of complex systems. The first two research areas are reviewed and discussed because the thesis aims to contribute to both of them, which is also achieved by bridging the gap between them. The third field – management of complex systems – is discussed because it includes a number of theories and concepts, such as functional modularisation and replication of complex systems, which served as instruments in solving the research problem of this thesis.

2.1. Sustainability and industrial ecology

Sustainability

The question of sustainability is central to this thesis because biofuel production and utilisation are seen as an important part of sustainable development. The focus is therefore not on the product and its technical characteristics as such, but rather on the way energy is produced and consumed, so as to prevent resource depletion. Failing to meet resource needs in the future has drastic implications, including social instability, inequality, wars, starvation, and stagnation of wealth production. When this problem became too great to ignore, the notion of sustainable development was introduced and defined as follows:

“Meeting the needs of the present without compromising the ability of future generations to meet their own needs”

WCED, 1987

The challenge of sustainable development is in the fact that it implies both **conservation** and **change**: thoughtful and reasonable resource expenditure, responsibility for current actions while sustaining technical progress, wealth creation, and high quality of life for people. Another critical principle is that intra-generational equity is as important as inter-generational equity (Anand and Sen, 2000; UNDP, 1994). The three dimensions or pillars of sustainability: economic, environmental, and social (Adams, 2006), reflect the need for complex and systemic understanding of society’s development, which is limited by the fact that human society and economic system are only a sub-system of the

biosphere (Costanza et al., 1991; Daly, 1991). In general, the notion of sustainable development is anthropocentric: the core of it is in ensuring the ability of humankind to maintain and continuously improve the quality of life for current generations and generations to come. Various ethical interpretations of this definition, as well as the choice of a guiding discipline, - economics or ecology, - evoked the discourse about weak and strong sustainability (Hediger, 1999).

In the view of weak sustainability (Hartwick, 1978; Solow, 1974; 1986), it is acceptable *to replace* natural capital (resources and ecosystem services) with man-made capital as long as the aggregate stock of natural and man-made capital grows or at least remains the same for future generations (Neumayer, 2010). Such an approach stresses the economic and social development of society, downgrading the importance of the natural ecosystems to simply being a resource base. When the adverse effects of such economic growth have become apparent, for example, in the form of the climate change, the question of how much the natural capital is actually substitutable was raised. It was recognised by many scientists and policy-makers that weak sustainability is not sufficient for sustainable development, which requires preserving the ecosystem's overall integrity (WCED, 1987).

The opposing notion of strong sustainability implies that man-made and natural capital are complimentary, first of all, because society cannot replace or reproduce certain things provided by the nature (Jain and Jain, 2013; Neumayer, 2010). Resource depletion and undermining of ecosystem services in order to achieve wellbeing of current generation will inevitably limit the opportunities of future generations to fulfil their needs. Strong sustainability implies that the total stock of natural capital needs to remain constant over time (Costanza et al., 1991; Costanza, 1991; Daly, 1991; Pearce et al., 1994), while the provision of basic needs is a prerequisite for economic development (Hediger, 1999). This does not imply preservation of every ecosystem everywhere. Rather, it requires maintaining the integrity and therefore resilience of the natural ecosystem so as it could adapt to changing conditions (WCED, 1987; Hediger, 1999).

Neumayer (2010) notes that since neither paradigm (weak and strong sustainability) is falsifiable, science cannot provide a reliable answer to which view is 'correct', and the choice depends largely on personal beliefs. Hediger (1999) argues that extreme interpretations of weak and strong sustainability are not useful for achieving *development* since limitations either to economic development or natural ecosystem preservation will arise. He proposes a combined framework, which utilises the requirement of *growing total aggregate value of economic activity* from weak sustainability and the requirement of *protecting the natural environment* (ecosystem capital) as our life-support system. Thus, he calls for setting basic ecological and economic conditions, such as ecosystem resilience and basic human needs, while striving to develop beyond these limits.

In this thesis, a refined perspective of strong sustainability similarly to Hediger's (1999) view is preferred over weak sustainability when discussing sustainable industrial ecosystems due to the following reasons:

- The effects of substitution of natural for man-made capital implied by weak sustainability may not be reversible in the long-term (Costanza et al., 1991).
- It is hard to put price on natural capital as implied by weak sustainability (Hediger, 1999).
- Assessment of ‘substitutability’ of natural capital is limited by the current level of human knowledge about the world and by the current values, which may differ from values of future generations (Arias-Maldonado, 2013).

However, admitting the fact that strong sustainability cannot be achieved in its extreme form (Hediger, 1999), it is crucial to have certain guidance in order to identify ‘unacceptably high costs’ as well as solutions that are sustainable, i.e. contribute to sustainable development. In the view of strong sustainability, a **sustainable** alternative implies an improvement of the generalised productive capacity of the economy without degrading the overall quality of the environment (Hediger, 1999). This means that every project has to meet a set of ecological criteria (Costanza, 1991; Daly, 1991). While some approaches propose frameworks for finding trade-offs between the three dimensions of sustainability, others urge for redesigning social systems so as to conform to the goals of sustainable development in the view of strong sustainability.

Since sustainability is hard to define and propose a form for, there are no ideal criteria for which solutions or innovations can help in the pursuit of sustainable development (Arias-Maldonado, 2013; Boons and Leudeke-Freund, 2013). In one of the attempts, sustainability was defined with the help of **underlying principles** (Ny et al., 2006; Robèrt, 2003; Robèrt et al., 2002), which outline system conditions for a sustainable society.

The four principles are part of a larger 5-level Framework for Strategic Sustainable Development (FSSD), which starts from setting the sustainability problem and goes down to the level of concrete actions and tools to assess sustainability of those actions (The Natural Step, 2014). The main challenge is outlined with the help of a resource funnel metaphor (see Figure 1), which implies that society’s sustainable development is threatened due to the constantly increasing demand for resources and ecosystem services and the constantly decreasing amount of those resources and services. At the second level of the framework, four system conditions are outlined as follows:

1. In the sustainable society, Nature is not subject to systematically increasing concentrations of substances from the Earth’s crust
2. In the sustainable society, Nature is not subject to systematically increasing concentrations of substances produced by society
3. In the sustainable society, Nature is not subject to systematically increasing degradation by physical means
4. In the sustainable society, people are not subject to conditions that systematically undermine their capacity to meet their needs.

The idea behind those principles is in the fact that they are based on the ‘flaws of basic design of our societies’ (Robèrt, 2003). Eliminating them, it is possible to revert current development towards sustainable one. An opposite strategy is based on forecasting and reductionism: attempts to solve problems as they arise without understanding their roots. The FSSD switches the focus from “fixing of problems” to strategic re-design (Robèrt, 2003), and is a coherent framework for guiding sustainability as it contains within it the key concepts of equity, needs and limitations (Hediger, 1999). The use of the word ‘systematically’ in formulations of the conditions basically gives the mandate to have a higher rate of natural capital use at some points of time in order to build sustainable platforms and solutions that will drastically and persistently reduce the need for natural capital use in the future (Ny et al., 2006).

While the first three system conditions address preservation of natural capital, the latter condition concerns human and man-made capital. It is important to note that the modern economy has been criticised for measuring aggregate wellbeing in purely monetary terms, which misleadingly emphasises *consumption sustainability* (Jain and Jain, 2013). It was proposed to focus, instead, on *human development that is sustainable*, which allows fulfilling lives, i.e. living without degrading the earth and its capacity to regenerate (Jain and Jain, 2013; Morse, 2003; Neumayer, 2001; Neumayer, 2012). Within such a paradigm, more value is ascribed to increasing human and social capital (freedom, knowledge, education, institutions, life expectancy, etc.) compared to the endless growth of material man-made capital stock.

Since this thesis focuses on *designing* sustainable industrial ecosystems, the first three system conditions defined in the FSSD served as a guideline for the initial design of a biogas-for-traffic ecosystem (see section 1.2) in terms of its environmental sustainability. Fulfilment of the fourth condition is seen as the main focus of this thesis: developing solutions that increase human capital while not undermining the natural ecosystem’s resilience. The discussion of whether the focal biogas production and consumption system complies with the system conditions, i.e. contributes to sustainable development, is presented further in this section together with reviewing the literature on industrial ecology.

Renewable energy, effective use of resources, recycling, and bio-based economies are among the trends that are drawing considerable attention from society as the means for sustaining development while preserving the natural capital.

Already certain efforts have been made by industrial enterprises to bring sustainability into their operations. The most apparent activities employed by companies include: optimisation of their internal operations, energy recovery, waste minimisation, harmful material substitution, etc. The benefits of such activities include cost saving, efficiency increase, and improved reputation. However, even if certain economic benefits arise from these activities, they constitute only a small part of what ‘sustainable entrepreneurship’ could bring to companies (Cohen and Winn, 2007). Moreover, for most of them becoming

‘sustainable’ is still an issue of relationship management, rather than a structural change in the nature and scope of their business (Adams, 2006).

In academic literature, the discussion concerning ‘sustainable’ business models has paid much attention to dematerialisation i.e. the switch from products to services (Halme et al., 2004; Halme et al., 2007; Mont 2002; 2004) and from owning to delivering functionality (Ceschin, 2013). Indeed, new business models, for example, those based on car sharing and energy use optimisation, are able to decrease energy and fuel consumption significantly. However, sustainability visionaries (see e.g.: Ehrenfeld, 2008; Jackson, 2009; Welford, 1998) stress that dematerialisation or reductionism is crucial, but not enough in order to move towards sustainability, and the fundamental roots of unsustainable production and consumption need to be addressed. In line with this, Korhonen et al. (2004) emphasise that although eco-efficiency strategies, i.e. ‘producing more value with less environmental burden’, are primarily employed by companies and promoted by governments, they are not able to produce the required fundamental changes in the current economic paradigms.

It is generally noted that many ‘eco-innovations’ remain at the incremental level (Larson, 2000; Wagner and Llerena, 2011), e.g. striving to optimise one-company production and operations. This leads to ‘sub-optimising’ and completely ignoring the system perspective, which indeed requires a change (Boons, 2009). In order to fulfil sustainability criteria, incremental, isolated innovation is not sufficient; current socio-technical systems are incompatible with the goals of sustainability and therefore they must be redesigned (Ceschin, 2013). Radical innovation that disrupts current systems is the way to bring new greener technologies into operation and to restructure the unsustainable modes of production. This, however, requires a larger system-wide effort (Boons et al., 2013).

Industrial ecology

The field of industrial ecology is able to provide a certain vision for sustainable industrial organisation and structures. One of the main concepts – that of industrial symbiosis (IS) – is seen as a tool of systemic innovation required for green growth (OECD, 2010) and as a useful metaphor to promote sustainable industry restructuring from linear value chains to more cyclical ones. This is because it emphasises system thinking, increased interdependency, and cooperation among business actors (Côté and Cohen-Rosenthal, 1998; Korhonen et al., 2004; Ristola and Mirata, 2007). The metaphors of IS and industrial ecosystems are based on the third level of biomimicry of natural ecosystems, assuming that industry can deal with waste and regeneration in closed-loop life-cycles similarly to natural ecosystems (Allenby and Cooper, 1994; Baldwin *et al.*, 2004; Benyus, 1997; Chertow, 2000; Ehrenfeld, 2000; Geng and Côté, 2002; Templet, 2004; Wallner, 1999). These researchers emphasise the idea of the roundput of material and energy inside systems of enterprises that is beneficial environmentally, economically, and socially. IS has been defined as follows:

Industrial symbiosis engages traditionally separate entities in a collective approach to competitive advantage involving physical exchange of materials, energy, water, and by-products. The keys to industrial symbiosis are collaboration and the synergistic possibilities offered by geographic proximity.

Chertow, 2000: p. 314

As discussed in section 1.1, a distributed way of producing biofuels can benefit from relying on IS. Firstly, the full benefits of bio-based fuel can be better realised in attempting to organise fuel consumption close to its production (Mirata et al., 2005), i.e. within a local industrial ecosystem. Secondly, increased feasibility can be achieved by utilising by-flows in biofuel production, thereby leading to higher competitiveness of biofuel against fossil fuels. Ristola and Mirata (2007) propose that IS has the potential to enhance the technical and economic viability of small-scale production units, which are pertinent to the distributed mode of production, and so can make them competitive with their large-scale, centralised counterparts. Moreover, production and consumption of fuel within a local industrial ecosystem based on efficient material cycling and waste utilisation lead to considerable environmental and economic improvements not only associated with fuel production industry, but also with other involved industries: farming, transportation, and waste management (Johansson et al., 2005; Mirata et al., 2005).

The metaphor of IS provides a systems perspective on environmental issues, extending approaches that concentrate on individual system components (Côté and Hall, 1995; Ehrenfeld, 2000; Ehrenfeld and Gertler, 1997; Graedel and Allenby, 1995; Jelinski et al., 1992; Korhonen, 2004; 2007). Nevertheless, it has been noted that many of the studies focus too much on IS as location-bound waste and energy exchanges (Korhonen et al., 2004; Lombardi and Laybourn, 2012). In this thesis, however, IS is understood in wider and experience-based terms, as explicated by Lombardi and Laybourn (2012), who position IS as a business opportunity and a tool for eco-innovation. The renewed definition has been articulated as follows:

IS engages diverse organizations in a network to foster eco-innovation and long-term culture change. Creating and sharing knowledge through the network yields mutually profitable transactions for novel sourcing of required inputs, value-added destinations for non-profit outputs, and improved business and technical processes.

Lombardi and Laybourn, 2012: pp. 31-32

Another critique of the IS concept is that it often stays at the level of incremental changes, striving for cycling of waste and by-flows of the industries ‘as is’, leaving the underlying industry structures intact. This slows down the development towards sustainable modes of production (Ristola and Mirata, 2007). **Restructuring** of industrial systems in line with IS principles is another task, both more challenging and more beneficial. To pursue this aim, it is necessary

to acknowledge that there is a significant social and economic side to IS in addition to the beauty of the analogy to material and energy cycling in natural ecosystems (Baas, 2011; Boons et al., 2011; Lambert and Boons, 2002). In line with this, Posch et al. (2011) propose that the definition and understanding of IS needs to be improved so as to include economic and business benefits as the necessary criterion for developing and evaluating IS.

Acknowledging the potential benefits of IS and pursuing the idea that such an industrial arrangement needs to become more widely adopted, a research stream within industrial ecology is interested in the way IS can be promoted and implemented. There are three distinct approaches discussed in the literature characterising how IS is or can be established among companies (Baas, 2011; Chertow, 2007; Costa and Ferrão, 2010; Côté and Cohen-Rosenthal, 1998; Desrochers, 2001; Heeres et al., 2004; Korhonen et al., 2004):

- Self-organising approach (or ‘free market evolution’ as defined by Korhonen et al., 2004).
- Planned approach.
- Middle-out approach.

The successful industrial ecosystems, including the IS established in Kalundborg in Denmark and Styria in Austria, were not planned in advance but developed spontaneously (Côté and Cohen-Rosenthal, 1998; Ehrenfeld and Chertow, 2002; Ehrenfeld and Gertler, 1997; Jacobsen, 2006; Woodard, 2001). As noted by many researchers, the development of IS was business-driven rather than an environment-preserving activity (Behera et al., 2012; Chertow, 2007). Moreover, the involved companies did not see this as IS, but instead perceived collaboration as a number of bilateral exchanges or cooperation until the essence of what they were doing was ‘uncovered’ as IS (Chertow, 2007). Nevertheless, the question remains whether the successful experience of industrial ecosystems that have emerged naturally can be reproduced in other locations (Ehrenfeld and Gertler, 1997; Woodard, 2001).

The second approach is based on centralised planning of industrial ecosystems in the form of eco-industrial parks, which can be defined as “a holistic community of businesses that cooperate with each other and with the local community to efficiently share resources (information, materials, energy, infrastructure and natural habitat), leading to economic gains, improvements in environmental quality and equitable enhancement of human resources for business and the local community” (President’s Council on Sustainable Development, 1997). A number of efforts in centralised planning and implementation of eco-industrial parks has been undertaken mainly in the USA, Canada, China, and Europe (Chertow, 2000; Côté and Cohen-Rosenthal, 1998; Geng and Zhao, 2009; Geng et al., 2008; Lowe, 1997; Lowe et al., 1996). Nevertheless, most of them are unlikely to be perceived as successful (Chertow, 2007; Desrochers, 2001; Tudor et al., 2007). Moreover, most of the planned eco-industrial

parks were subsidised, making their actual feasibility questionable. In line with this, Elabras Veiga and Magrini (2009) demonstrated in their study that policies supporting IS turn out as a vulnerability when public and political changes occur. Comparative studies of planned and spontaneous IS revealed that the latter approach leads to the development of more resilient systems (Chertow, 2007; Heers et al., 2004), and that the success of planned efforts depends on the local context (Baas, 2011). The struggle planned IS encounters in order to be implemented successfully may be explained by the fact that real examples of IS, which inspired the whole field of industrial ecology, were self-organising and business-driven (Costa and Ferrão, 2010).

In general, researchers of IS agree upon the fact that the context largely defines the success of industrial ecosystems, leading to a conclusion that instead of centralised planning the proper conditions need to be created for making the natural emergence of IS more likely (Chertow, 2007; Mirata, 2005). Thus, the third approach to development of IS, the middle-out approach (Agarwal, 2011; Costa and Ferrão, 2010), implies the development of policies and local conditions that favour and promote networking of industrial actors in the pursuit of optimising their material and energy streams on a local ecosystem level (Heers et al., 2004; Gibbs and Deutz, 2007). Local authorities, research organisations, policy-makers, and communities become the main drivers of IS in such cases.

At the same time, industrial ecology still remains quite disconnected from business studies and industrial investments (Coelho and Ruth, 2006; Woodard, 2001), leaving the business side of IS largely under-researched. As some researcher note, there is a clear need to consider the business model of the ecosystem members, as being the requirement needed for a fundamental shift towards sustainability, rather than only inputs, outputs, or production processes pertinent to the IS notion (Ehrenfeld, 2007; Hopwood et al., 2005; Lombardi and Laybourn, 2012). Moreover, the extensive normative research on how IS can be fostered and supported by governments and NGOs needs to be enriched with knowledge regarding how industrial actors can effectively create more cyclic and collaborative industrial arrangements with or without such favourable contexts.

Based on the overview of the literature about IS development, this research aims to address the call for utilising the potential of IS to drive industrial renewal towards cyclic and more sustainable structures instead of focusing solely on material and energy flow cycling and individual local endeavours.

The biogas-for-traffic case, central to this thesis (see section 1.2), acts as an example of an industrial arrangement that is based on the metaphor of IS, where the organic matter is recycled between waste management, farming and biogas production industries in order to fulfil transportation needs. Following the first three system conditions defined in the FSSD, the initial design of the solution adheres to the principle of preservation of natural capital as required in the paradigm of strong sustainability and contributes to eliminating the roots of unsustainability as envisioned in the FSSD:

- Replacement of diesel and gasoline with a biofuel in local transportation reduces the need for extracting substances from Earth's crust (the 1st system condition)
- Replacement of fertilisers with a digestate in farming reduces production of substances produced by society (the 2nd system condition)
- Production of biogas from waste materials and hay does not contribute to the physical degradation of nature or natural processes (the 3rd system condition)

Compliance with the fourth principle, which implies meeting the needs of current and future generations, is contained in the fact that such a local industrial ecosystem allows fulfilling certain society needs such as transportation, food production and safe utilisation of organic waste, *if successful*. Drawing special attention to biogas as a product, replacement of fossil fuels with a locally produced biofuel is bound to have positive environmental effects (Lantz et al., 2007). However, in this thesis, the biogas-for-traffic solution is seen as a system that abandons practices that have led to unsustainability, while still fulfilling a number of social and economic needs. Similarly to the idea of functional economy (Ceschin, 2014), such an approach to measuring the economic value declares that the wealth creation and monetary gains are only an intermediary for fulfilling human aspiration for wellbeing, but not the end in itself. The more valuable outcomes of the focal solution include the creation of local jobs, ensuring of public transportation function, mobility, food supply and safe waste management.

However, it is crucial to admit that economic sustainability is a critical part of the fourth system condition. If an environmentally sustainable production mode cannot compete with fossil fuel economy, i.e. cannot persistently fulfil the needs and create the social capital named above, then such a solution cannot be called truly sustainable. Even disregarding the competition with fossil fuel economy, it is preferable that a new system is self-sustaining economically, i.e. profitable. Indeed, sustainable solutions can be financed through, for example, taxes, but the evidence shows that this proves to be a weakness of the solution in turbulent times (Elabras Veiga and Magrini, 2009). The aim of this thesis is to contribute to exploring how sustainable solutions can be designed that are not only strong in the environmental dimensions (Conditions 1-3 of the FSSD), but are also able to *endure* in fulfilling the last, but not the least, system condition.

This is achieved by specifically addressing the feasibility and the business side of industrial ecosystems, strongly embedding *economic* sustainability into the design of industrial ecosystems, as well as by considering business models of the involved actors required for the industry renewal.

2.2. Innovation in business ecosystems

Innovations that require a shift within larger socio-technical systems rather than only the introduction of a new product onto the market can be called 'system innovations' and are widely discussed in the literature on general innovation

(Geels, 2005) and eco-innovation in particular (Loorbach, 2010). The interest in the systems surrounding innovations is based on the understanding that a new technology (a product, a service or a combination of those) needs to be embedded into a complex 'landscape' comprised of social, regulative, economic and infrastructural factors, which are often established for or along with other technologies, creating a 'lock in' in the currently prevailing technological regimes that is difficult to break (Geels, 2002; 2005; Nelson and Winter, 1982; Rip and Kemp, 1998; Sartorius, 2006). Moreover, to reach sustainability certain products or services need to be introduced together with a complex socio-technical system surrounding it, because a product or service cannot be called sustainable as such; it is only sustainable within such a system and context (Gaziulusoy et al., 2013).

The necessity to build or reconfigure the socio-technical system when radical innovations are introduced (Geels, 2002; 2005) goes hand in hand with the need for creating functioning industrial ecosystems when sustainable bio-fuels are produced.

Geels (2005) argues that companies are not able to affect the larger landscape, and the way to move from a niche to establishing a new socio-technical regime is through 'windows of opportunity' that open up when the pressures from the landscape developments affect the currently prevailing socio-technical regimes. This thesis is based on the idea that while certain windows of opportunity, such as rising prices for fossil fuels, are able to foster the use of biogas as traffic fuel, the biogas company also needs to create those windows of opportunity by actively trying to shape the business landscape (Ceschin, 2013). In line with this, the recent research in management and business studies touches upon the same phenomenon of companies' embeddedness in large business ecosystems and discusses the way they need to adapt to and attempt to shape them (Gulati et al., 2012; Iansiti and Levien, 2004; den Ouden, 2012;). Moore (1996) defines a business ecosystem as follows:

An economic community supported by a foundation of interacting organizations and individuals – the organisms of the business world. This economic community produces goods and services of value to customers, who are themselves members of the ecosystem. The member organisms also include suppliers, lead producers, competitors, and other stakeholders. Over time, they coevolve their capabilities and roles, and tend to align themselves with the directions set by one or more central companies. Those companies holding leadership roles may change over time, but the function of ecosystem leader is valued by the community because it enables members to move toward shared visions to align their investments, and to find mutually supportive roles.

Moore, 1996: p. 26

Based on the discussion in the previous section, development of industrial ecosystems for biogas production needs to address not only the material and energy exchanges, but a larger context that defines feasibility and resilience of a business organised using IS principles.

Business model innovation is known for being able to reach the goals of re-designing whole business ecosystems (Chesbrough, 2010; Zott and Amit, 2010) and is discussed in this thesis as the vehicle for creating sustainable industrial ecosystem for biogas-for-traffic industry. Since business models are concerned with the outcome, the implementation, and the tactics of strategies (Casadesus-Masanell and Ricart, 2010), they can serve as a tool for implementing a radical system innovation such as the one required for the focal biogas-for-traffic solution.

Business models are often conceived as devices that describe how companies create and capture value from innovations (Amit and Zott, 2001; Chesbrough and Rosenbloom, 2002). The research on business models has so far focused on the firm as the unit of analysis, although an increasing stream of research has suggested that both innovation and competitive advantage lie in the relationships a firm has (Dyer and Singh, 1998; Powell et al., 1996) and that value is, essentially, co-produced or co-created (Lusch and Vargo, 2006; Prahalad and Ramaswamy, 2004; Ramirez, 1999). It has further been argued that competitive advantage not only resides in a specialised supply base (Dyer, 1996; Jarillo, 1988), but must be understood as a result of the various organisations being embedded in a network of inter- and intra-organisational relationships (Echols and Tsai, 2005; Ghoshal and Bartlett, 1990; Gulati, 1998; Gulati et al., 2000).

The concept of business models is widely used nowadays and a significant number of interpretations have been proposed for business models. In simple terms, these models are “stories that explain how enterprises work” (Magretta, 2002). More concretely, the role of a business model is to define “the manner by which the enterprise delivers value to customers, entices customers to pay for value, and converts those payments to profit” (Teece, 2010: p. 172). Researchers have proposed different frameworks for describing business models, consisting of certain elements, but the two components that appear in most writings in one or another form are value proposition and value capturing or revenue model (Afuah and Tucci, 2001; Chesbrough and Rosenbloom, 2000; Linder and Cantrell, 2000; Teece, 2010; Weill and Vitale, 2001; Wikström et al., 2010). However, these elements of the business model have the power of analysis only in connection with the elements which capture the transactions with external actors, most importantly customers (Zott and Amit, 2008). Capabilities define how companies deliver the promised value to the customer, and a cost structure largely affects the value capturing and profitability of a business (Afuah and Tucci, 2001; Halme et al., 2007; Osterwalder et al., 2005).

The major reason that the business model concept is used in this thesis, is the fact that it depicts the way companies do their business in general (their value proposal, earning logic, and cost structure), the way they innovate, and what differentiates them from their competitors. However, only a limited number of business models elements are used as an analytical framework. The choice is limited to those elements and components that help capture the innovation and change process *within one company* when whole business ecosystems are being restructured.

As discussed earlier, the research on how IS can be implemented lacks the perspective of a company level. The concept of the business model is comprehensive and allows understanding innovation and transition from this perspective. Moreover, business models can be seen as the building blocks of any industry, as the decision-making remains largely on a company level. By addressing the business models of the companies as part of the industrial ecosystem in focus – the biogas-for-traffic solution – it is possible to drive the change towards ecosystem development. What is apparent is that a change in business models is required in order to incorporate the system thinking and symbiotic relationships that are pertinent to IS.

The capability to implement such changes is directly connected to the notion of open or boundary-spanning business models (Chesbrough, 2006; Chesbrough, 2007; Wikström et al., 2011). In order to organise symbiotic relationships among various actors from disconnected industries, it is crucial to understand that these actors are usually already well-established and operating businesses in their own specific sectors with their own business logic and value chains and are unaccustomed to working in a system (Gustafsson et al., 2011; Lambert and Boons, 2002). The enrolment into an industrial ecosystem for biofuel production may be outside the vertical scope of their ordinary value chain if, for example, they are supplying a by-product or waste for biofuel production. The physical proximity of such business actors, i.e. operations within one community or region, makes their cooperation easier to establish due to the possibility of personal networking (Ristola and Mirata, 2007). However, it does not abolish the fact that they lack the capabilities to cooperate within an ecosystem for biofuel production in an industrial sense.

Boundary-spanning business models have been conceptualised by Wikström et al. (2010) as business models which enable participating firms to act as equal partners with different responsibilities in the value chain and with separate strategies and capabilities, while still working for a common investment objective. Boundary-spanning business models take a broader business view and can be interpreted as a strategic aim drawing on the different actors' joint strengths in order to achieve long-term value for the investment. These business models are typically used when there is a high degree of uncertainty stemming from the external environment. Thus, this notion corresponds with the need to align ecosystem actors in order to create system value in the highly uncertain context of IS.

2.3. Development of complex systems

Industrial ecosystems are complex systems that aim at creating benefits, improving efficiency and effectiveness, which goes beyond the pursuit of improvements in individual industrial units (Mirata, 2004; Ristola and Mirata, 2007). That is, they can be perceived as complex systems since they are “made up of a large number of parts that interact in a nonsimple way” (Simon, 1962: p. 468)

and the whole is more than the sum of the elements in a pragmatic sense. In order to address the structure and development of complex systems such as the ecosystems focussed on in this thesis, the relevant literature on management of complex systems was studied.

Returning to the topic of sustainable modes of production and industrial ecology, there is the need to build multiple industrial ecosystems in many locations, integrating local partners. In line with that, Chertow and Ehrenfeld (2012) have acknowledged that the development of a single local material exchange network is only the first stage in the development of IS, while institutionalisation of such industrial organisation requires extending the knowledge across the region. At a higher level, there is a need to ensure integration in the business ecosystem required for a restructured biofuel industry. As a result, the major issues related to the development of complex systems that are relevant for this study include a replication of systems while adjusting to local conditions and integration within those systems. Two scientific domains appeared to be useful for solving these challenges: modularity in complex systems and replication of complex systems. Keeping the focus on the business side of the development of industrial ecosystems, the way in which modularity could aid *business* replication of ecosystems was explored.

2.3.1. Modularity

Modularisation implies decomposition of complex systems into building blocks or modules with specified interfaces. This division into modules can be defined by technical reasons, as has been seen in the case of product modularisation. Another definition of modularity, proposed by Schilling (2000) defines modularity as a general systems concept, which describes “the degree to which a system’s components can be separated and recombined” (Schilling, 2000: p. 312). In this respect modularisation has a strong connection with the idea of mass-customisation (Davis, 1987; Pine, 1993), which is a strategy striving to enable a high, but restricted variety by mixing and compiling a limited number of standardised components or modules (Hellström, 2005).

The drivers behind modularity are the reduction of system complexity, creation of variety and utilisation of similarities, and the need for balancing customisation and standardisation (Hellström, 2005; Lampel and Mintzberg, 1996; Miller and Elgård, 1998). The research on modularity has expanded from product modularisation to explaining its effects on the organisation of businesses, business networks, and whole industries in terms of knowledge management and innovation (Langlois, 2002; Langlois and Robertson, 1992; Sanchez and Mahoney, 1996; Schilling and Steensma, 2001).

As discussed earlier, a certain level of customisation is required for industrial ecosystems to be adjusted to local conditions efficiently. Local variance is a normal problem for distributed systems and is a key challenge in large-scale implementation of distributed systems. In order to achieve local fit and func-

tionality the solution has to be tailored, which increases costs and reduces profitability. Economies of scale achieved through standardisation are one possible solution to control the costs and reduce the need for a system fit. At the same time, complete standardisation would minimise the benefits provided by distributed systems, since potential local opportunities might be overlooked and poor integration of the solution into the local environment could result in its failure. Therefore, it is necessary to balance between customisation and standardisation. In order to address these challenges, Hellström (2005) proposes functional modularisation and mass customisation not just based on physical units, but utilising a more functional perspective.

When such a functional modularisation approach is applied to industrial ecosystems, businesses or companies can be viewed as modules because they are already viable by themselves as established businesses. As in the empirical case of the biogas production system, all the businesses already exist and have required resources to develop an industrial ecosystem together. In line with Simon's (1962) idea that system partitioning into more elementary details depends on the purpose of looking at the system, all the businesses can be defined as modules in a complex ecosystem. It is also recognised that business models and the businesses of the involved actors as such consist of even smaller parts and are complex subsystems in themselves.

Such modules are the elements that form a whole, i.e. an industrial ecosystem, and can be replaced by other modules with the same function. The functions of the modules are the aggregative properties (Simon, 1962) of the businesses that constitute interest in the context of an industrial ecosystem, and which help to describe the interactions among the modules.

Industrial ecosystems are complex systems that are nearly decomposable because the interaction among the subsystems or modules is fairly weak. In nearly decomposable systems "the short-run behaviour of each of the component subsystems is approximately independent of the short-run behaviour of the other components" and "in the long run, the behaviour of any one of the components depends in only an aggregate way on the behaviour of the other components" (Simon, 1962: p. 474). Similarly, business actors within an industrial ecosystem are relatively independent in the short term and can only be influenced if other businesses create changes in their functions in the ecosystem.

A rather weak interdependency among the modules, i.e. businesses, in an industrial ecosystem can have the positive effect of stabilising the system and making it dynamically resilient. Simple subsystems that have stability evolve into hierarchic systems much faster than complex systems that are "assembled" from separate relatively small elements at once (Simon, 1962). Therefore, by combining already established businesses with minor adjustments it is possible to create industrial ecosystems faster and in a more sustainable manner.

The use of modularity for mass customisation is able to reduce the complexity of various systems through creating variety and utilisation of similari-

ties (Hellström, 2005; Lampel and Mintzberg, 1996; Miller and Elgård, 1998). Industrial ecosystems, being complex systems comprised of material flows, businesses, regulations, etc. can likewise benefit from applying this approach. Although the possible composition of an industrial ecosystem for biofuel production varies from location to location, from a functional perspective this variance is limited. For instance, there are a limited number of alternatives for biogas utilisation and for biomass supply. Thus, the functions in such an industrial ecosystem are more or less standard, while different businesses can serve these functions depending on the location.

Another benefit of modularity is that it can provide both flexibility and structure (Hellström and Wikström, 2005; Sanchez and Mahoney, 1996). In businesses that incline to mass customisation rather than mass production, flexibility in the business model can be reached through defining interchangeable modules that can be re-combined in order to fit any particular solution as regards the local conditions. Thus, modularity is seen in this thesis as the prerequisite for replication of industrial ecosystems.

2.3.2. Replication

The success of 20th century industrial activity is undoubtedly at least partly a result of the conscious pursuit of economies of scale (Chandler, 1990). The simple logic that the more you make of something, the cheaper you can make it, or put differently, the more standardised the things we make the cheaper they become, revolutionised industrial production. According to Mirata et al. (2005), this logic has led to the dynamics that undermine sustainability.

Capital goods, in turn, such as raw material process plants, have relied on a logic where characteristics of raw materials are explored and the capacity of the plants is set to meet the expected demand (at a certain point in time). As a result, the outcomes are customised designs and more or less unique projects. This is not a problem for large plants, but for smaller ones it is likely to be a problem as the revenues cannot bear the cost of customisation. For companies delivering small capital goods, such an operating model becomes inefficient (Magnusson et al., 2005). Not everything has to be unique. Lampel and Mintzberg (1996) express the central idea of this standpoint in the following way:

...customization and standardization do not define alternative models of strategic action but, rather, poles of a continuum of real-world strategies.

Lampel and Mintzberg, 1996: p. 21

Capital goods companies, too, strive to standardise their products and reuse their designs. As firms deliver more similar projects they can achieve so-called “economies of repetition” putting in place organisational changes, routines, and learning processes (Davies and Brady, 2000). As capital goods projects include much more than mere products (goods, hardware), a suitable goal would be to be able to deliver entire “repeatable solutions” (Davies and Brady, 2000).

A pursuit of “economies of repetition” opens up an opportunity for replication, a strategy that is often associated with firms such as McDonald’s or IKEA and entails the creation and replication of a business format (Jonsson and Foss, 2011; Winter and Szulanski, 2001). Replication is, however, far more than the standardisation and exploitation of a business model. Winter and Szulanski (2001) argue that it is a specific type of strategy that, in addition to an exploitation regime, also involves a subtle exploration phase of business model development.

While some technically fairly complex technologies, such as semi-conductor manufacturing equipment need to be copied exactly to enable the execution of a replication strategy (MacDonald, 1998), other cases require a more adaptive approach. Jonsson and Foss (2011) found that IKEA’s success in replicating their business format to various international locations partly lies in the flexibility of their approach. The authors stress the organisational support for key elements such as an on-going learning process, frequent modifications, and local adaptation.

As Ruuska and Brady (2011) note, replication literature is scarce on cases in which replication is complex. They illustrate the difficulty of pursuing such a strategy in uncertain and complex investment projects such as the design and construction of renewable diesel refineries, where the underlying technology is still immature causing frequent design modification during the implementation phase. In the special case of complex products and systems (large-scale high-cost capital goods), Brady and Davies (2004) argue that at the core of repeatable solutions lies a base moving, “vanguard” project that triggers a process of project and organisational capability building. In their project capability building model the firm moves from the exploratory project-led exploratory learning to business-led learning where the developed capabilities are exploited in repeated projects.

Lampel and Mintzberg (1996) have identified three areas in industrial production that can be standardised or customised: the product itself, the working processes, and the transactions. Transactions lie at the core of business model design (Zott and Amit, 2007). However, in the case of the biogas industry it is crucial to consider the entire industrial ecosystem around the biogas production facility, rather than design and replication of a single firm’s business model. Indeed, it is vital to consider transactions that span traditional firm boundaries and develop the business models and replication strategies accordingly.

2.4. Theory synthesis

This section synthesises the theoretical perspectives adopted in the thesis, which are discussed in Chapter 2, and their relevance to the research process and outcomes. In general, this research aims to bridge a gap between the fields of industrial ecology and business studies, which has been articulated earlier (Coelho and Ruth, 2006; Lombardi and Laybourn, 2012; Woodard, 2001). As Ehrenfeld (2001: p. 871) put it, in the term ‘industrial ecology’, the ‘industrial’ part of the metaphor is as crucial as ‘ecology’ part.

Further, by striving to produce actionable knowledge on how more sustainable industry structures can be developed, it attempts to bridge another gap – between theory and practice (Harper and Graedel, 2004). The relation of various concepts and theories utilised in this thesis is visualised in Figure 5.

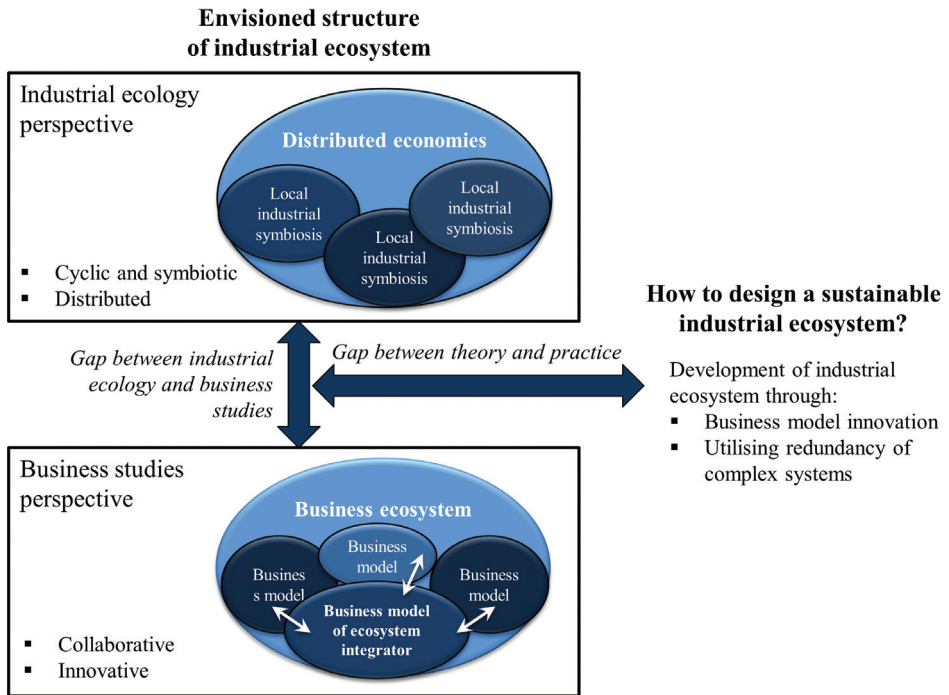


Figure 5. Synthesis of theoretical insights utilised in the thesis.

The first main theoretical domain – studies in industrial ecology – served to inspire and inform the process of answering the main research question. That is, the initial vision of a sustainable biogas-for-traffic ecosystem was created based on the ideas of IS (Chertow, 2000; Korhonen, 2004; Mirata, 2005) and local distributed production (Johansson et al., 2005; Mirata et al., 2005). Further, existing studies helped to identify the challenges industrial ecosystem formation faces and the successful practices that have been applied in order to overcome them. However, existing explanatory knowledge was not sufficient to produce the normative models and prescriptive knowledge for driving the change in the biogas-for-traffic industry towards symbiotic and distributed structure. The reason for this was considered to be the scarce attention given to the business side of the development of industrial ecosystems. Thus, this research was expected to contribute to the research field by generating prescriptive knowledge on how a business ecosystem can be created in order to enable the envisioned biogas-for-traffic industry structure.

The second domain of business studies is represented in the study by adopting a business ecosystem perspective on creating a resilient and sustainable biogas-for-traffic ecosystem. The development of such an ecosystem is studied through addressing multiple ecosystem business models and by especially focusing on the way the business model of an ecosystem integrator can reshape the business ecosystem and establish the links between the business models of other ecosystem actors. The focus on innovation (den Ouden, 2012; Gaziulusoy et al., 2013; Geels, 2005; Jacobides et al., 2006) and particularly business model innovation (Amit and Zott, 2010; Chesbrough, 2010) becomes crucial in developing resilient ecosystems involving traditionally unconnected industries.

Finally, studies on the development of complex systems were examined in order to assist in developing sustainable industrial ecosystems in a reliable and feasible manner. Insights into functional modularisation and replication, which were not previously applied to such complex settings (Ruuska and Brady, 2011), were explored in order to help in developing a feasible replication strategy for developing multiple local industrial ecosystems.

3. METHODOLOGY

This chapter presents the methodology employed in this research. The explanation of the research process and timeline is followed by a deeper description of the main methodological standpoints and approaches utilised in this thesis. The explanations are complemented by real-life examples from the research process. This is followed by a discussion concerning the validity, quality, and relevance of the produced knowledge.

I seek a philosophy that I don't have to leave behind in the study.
Ruth Anna Putnam

3.1. Research approach

In order to answer the research question of how sustainable industrial ecosystems for biogas production and utilisation can be developed there were two options. The first and more obvious one would be post-observation of existing industrial ecosystems, for example, those developed in Sweden, where biogas is widely used as traffic fuel. The second was to become engaged in the development of an ecosystem, which is still to be established in the focal location. The implications of choosing one or other alternatives were quite different: while in the former case it would be possible to see the resultant ecosystem and even assess whether it is successful, in the latter case this would be impossible, in a traditional sense. The nature of research would also be drastically different. In the first alternative, when making post-observation, it would be possible to interview the relevant stakeholders operating in the ecosystem and even those people who took part in its early development. The data collected would include the challenges that appeared during the ecosystem formation and the way they were solved. It would be logical to assume that the analysis of such data would lead to a discovery of the laws that define how ecosystems could be successfully developed in other locations through induction. Such an approach would reflect the ontology and epistemology pertinent to the positivist model of science. This model implies that the world exists a priori as a unified and causally ordered system, which can be logically represented with laws applicable regardless of meanings and values that humans may give to the terms of such laws (Susman and Evered, 1978).

However, since “organisations are artefacts created by human beings to serve their ends” (Susman and Evered, 1978: p. 584), the search for universal laws beyond human cognition and values within organisational science would mean accepting the fact that development of our society is presupposed by nature (Putnam, 1987). This statement fundamentally contradicts the purpose of this study namely to research how more sustainable industrial organisations can transpire: the basic assumption in this thesis is that since people create organisations and industry structures, they are able to shape them into more sustainable modes that would help avoid ‘running into the wall’. Thus, a more participatory research approach is required.

The quality of the knowledge striven for in this research was different compared to the knowledge produced in a positivistic model of science. Based on the motivations for this research discussed in section 1.3, the goal was to create prescriptive knowledge on ecosystem development, which is actionable and holistic. The main reasons for this included the following:

- *Focus on the future*: in the pursuit of creating a more sustainable industrial organisation, research of what exists cannot provide the knowledge about what actions are appropriate for problem-solving in new challenging situations (Mirata, 2005; Putnam, 1987; Susman and Evered, 1978).
- *Complex and ill-defined research problem*: as was mentioned previously, the target ecosystem was not pre-designed, thereby posing not only the question of ‘how to solve the problem?’ but also that of ‘what is the problem?’
- *Need for change*: the purpose of the study was also to trigger change in an industrial organisation towards more sustainable structures by generating knowledge capable of inflicting actions. Moreover, the knowledge on how change is triggered was an expected research outcome.
- *Concrete practical problem*: in the focal location, the introduction of biogas as traffic fuel faced a number of challenges specific to the context: institutional rigidity, market uncertainty, organisational passiveness, and a need for inter-organisational cooperation. The way these challenges could be overcome in order for the organisations to work as one sustainable ecosystem was still to be discovered.

Based on the outlined characteristics, there was a need to employ a research approach that would allow the diagnosing of current problems, envisioning target solutions and developing knowledge on how to turn the current situation into a desired one, which would be actionable for the respective agents. This, in turn, required constructive, experiential, and collaborative research. Returning to the second alternative, i.e. participation in the ecosystem development, direct engagement in creating the solution promised real-time and rich data for creating the prescriptive knowledge. As a result, the author became involved in the projects and on-going research at PBI Research Institute in order to explore ‘from the inside’ how ecosystems are created.

The PBI Research Institute is an organisation that strives to conduct research in close cooperation with industry while retaining an academic perspective on the studied issues (PBI Research Institute, 2014). The methodological approach employed at PBI is not only based on the co-creation of research results with industrial companies and other stakeholders, but is also based on providing a critical outlook on current unsustainable management practices as well as proposing solutions for them. Such methodology, based on involvement of business actors, allows for accessing rich data while producing and constantly validating the relevance of that knowledge. At the same time, focus on the academic side of the research ensures production of knowledge that can be generally applied to solving management problems and improving society beyond the networks of collaborating companies.

By engaging in projects where the industrial companies and other stakeholders were the clients, the author was doing clinical research (Schein, 1995; 2008). Clinical research, being one of the approaches of wider action research tradition (Argyris et al., 1987; Coghlan, 2011; Eden, and Huxham, 1996; Elden and Chisholm, 1993; Lewin, 1946; 1947; Reason, 2003), builds on the idea of engaging in research activities that are based on the needs of organisations and co-create solutions in collaboration with those organisations. It allows not only the accessing of sensitive contexts, but also ensures commitment of the research participants to co-create valid knowledge (Coget, 2009; Schein, 1993). The validity and, what is more important, the relevance and actionability of the produced knowledge are ensured by studying social systems ‘as they react to experimental manipulation’ (Clark, 1980).

While the clinical research paradigm (described in detail below in section 3.3.1) explains the process of engaging in dialogue with practitioners and the motivation to do so, the actual knowledge production process occurs along with the design science research paradigm (in future referred to as DSR). DSR, opposed to explanatory and descriptive modes of research, uses target systems when defining the initial situation and urges people towards thinking *how* the system could be made to work (Romme, 2003). The main outcomes of such research include the design proposition, i.e. the desired outcome and the knowledge on how to achieve it (Romme, 2003) that can be transferrable to other similar contexts. Such actionable knowledge is able to support and motivate practitioners for actions in order to achieve the desired goal. This is in contrast to purely explanatory knowledge, which strives to answer the question ‘how to’ by establishing general cause and effect rules or laws, and extrapolating from them the future. The difference between the three main modes of research and the knowledge produced within them is demonstrated in Table 1. DSR is relevant for solving research problems, where the underlying laws are not discoverable or are irrelevant. The design orientation is not only appropriate when trying to answer the question of *how to* develop complex systems, but is also necessary when attempting to reach more sustainable modes of production.

That is, industrial and business ecosystems need to be *designed* to be sustainable rather than only followed in their evolution (Ehrenfeld, 2008).

The focus on reaching a meaningful design proposition in DSR is closely related to the focus on change in clinical research, as the change is unreasonable without the view of a target solution. Therefore, DSR was employed in order to contribute to the needs of clinical research in developing the solution to clinical and larger sustainability problems and answering the ‘how to’ question. This way the traditional focus of action research approaches on producing *critical* knowledge (Lewin, 1947) is relocated to producing *actionable* knowledge. This is achieved by admitting that the solution or target system cannot be developed merely by addressing current problems, but rather by actively creating them when introducing new artefacts and by eliminating the incompatibilities in the current situation with a vision of the future.

Table 1. Comparison of the three modes of research³

	Science	Humanities	Design
Purpose	Understand phenomena by uncovering causalities, patterns and forces that underlie this phenomena	Describe, understand and critically reflect on the human experience of phenomena	Produce the systems that do not exist yet, i.e. change the existing situations into desired ones
View of knowledge	Representational: - our knowledge represents the world as it is; - nature of thinking is descriptive and analytic	Constructivist and narrative: - all the knowledge arises from what actors think and say about the world; - nature of thinking is critical and reflexive	Pragmatic: - knowledge is in service of action; - nature of thinking is normative and synthetic
Produced knowledge	Explanatory	Descriptive	Prescriptive (actionable)
Examples of scientific domains	Natural science (physics, mathematics, biology)	Humanities (history, hermeneutics, literature)	Design and engineering based upon diagnosis (engineering, medicine, architecture, computer science)
Focus of theory development	Discovery of general causal relationships among variables (expressed in hypothetical statements): Is the hypothesis valid? Conclusions stay within the boundaries of the analysis	Key question is whether a certain (category of) human experience(s) in an organizational setting is “good”, “fair”, etc.	Does an integrated set of design propositions work in a certain ill-defined situation? The design and development of new artefact tends to move outside boundaries of initial definition of the situation
Metaphor	Life understood backwards		Life lived forward

³Based on Romme (2003) and Weick (2003)

3.2. Research background and timeline

In practice, the research was conducted by participating in three consecutive and partly overlapping projects during 2010-2013 (see Figure 6 for timeline). The general aim of these projects was to design a solution for a local industrial ecosystem that would allow the utilisation of biogas as a traffic fuel in the focal municipality, and to plan its implementation together with the key stakeholders that were identified during the research process.

The first project, Project “Pre-design”, was devoted to developing the initial design of the industrial ecosystem required for sustainable production and utilisation of biogas in public traffic within a Finnish municipality. The municipal authority was the client in this project. The practical outcome of the research was the initial design of the target ecosystem, identification of critical actors, the roles and responsibilities of the actors within the ecosystem, and a feasibility assessment of biogas-for-traffic business in the municipality.

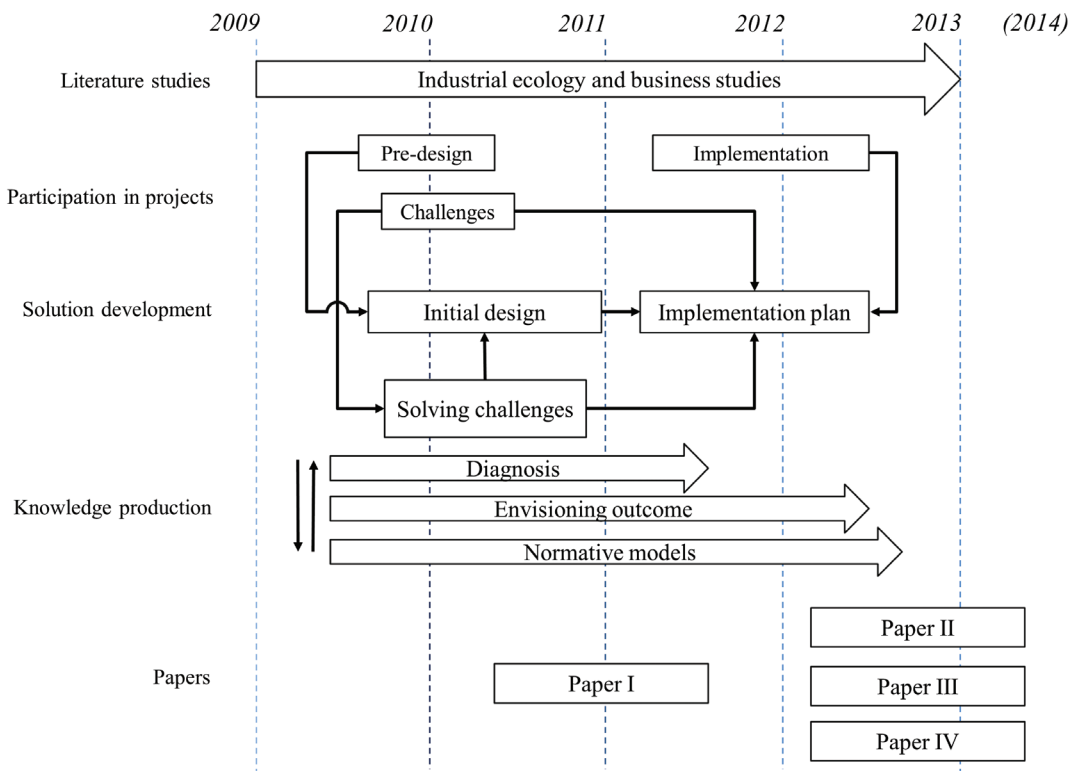


Figure 6. Research timeline.

A few months after the first project, Project “Challenges” was started as a study of the potential for sustainable bio-economic solutions in Finland, where the biogas-for-traffic case from Project “Pre-design” was one of the focal cases.

During this project, general challenges and pre-requisites for building sustainable biofuel industry based on ecosystem thinking were explored. Since both projects were carried out almost in parallel, it was possible to simultaneously take a broader outlook at challenges for developing industrial ecosystem within the country and also specifically focus on the municipality studied in Project “Pre-design” (from now on referred to as *‘focal municipality’*). The choice of participating in these projects was only partly defined by accessibility: the researcher team, as action researchers, actively ‘shaped the problematic context’, thereby influencing the continuation of the research together with the practitioners. Since all three projects were devoted to establishing the focal ecosystem, it allowed a deep and longitudinal involvement to be achieved in the solution development.

During these two projects, contact with a number of stakeholders was established in order to identify the potential stakeholders in the industrial ecosystem, discuss challenges for building such an ecosystem, and obtain the stakeholders’ input into the ecosystem design. In total, around 15 organisations that would form the biogas-for-traffic business ecosystem were involved into an ongoing dialogue. The list of discussions within projects “Pre-design” and “Challenges” specify the positions of the representatives that were contacted, and can be found in Appendices A and B correspondingly. It is important to note, however, that these initial discussions as such were not the only and major source of data for this research. Rather, they served as the way to establish collaboration with relevant actors so as further to continue exchanging information in various ways: through meetings, emails, telephone conversations, etc.

One year after Project “Pre-design” and Project “Challenges” were finalised, Project “Implementation” started. The latter project was devoted to a detailed design and development of an implementation plan for the industrial ecosystem in the focal location and was a logical continuation of Project “Pre-design”. This time, the focal municipal authority was not officially the client, but it participated in the steering group for the project and actively collaborated with the researchers and other stakeholders in order to develop the solution. The focus of this project was on developing the business model of the company that had to be established in order to integrate the ecosystem. The reason for focusing on a certain company and its business model was that after the research completed in Projects “Pre-design” and “Challenges” it appeared that an integrating company would be the key to implementing and operating the biogas ecosystem envisioned earlier. This is an example of how in a clinical inquiry the development of solutions to initial problems creates new research problems to be solved (Coghlan, 2000; Schein, 1995; Schön, 1995), leading to a constantly evolving research problem.

Throughout the three projects, collaboration with potential actors in the target ecosystem was initiated through various modes of communication. The number of actors amounted to almost 60 organisations, which included:

- Biogas producers
- Biogas and natural gas distributors
- Other fuel distributing companies
- Farmers and their representatives
- Waste management companies (including wastewater treatment)
- Suppliers of gas-driven vehicles
- Research organisations (research in farming, transportation, etc.)
- Various departments of focal municipality authorities (environmental, transport, waste management), which represented the citizens
- Relevant state-level governmental and non-governmental authorities
- Funding and investment organisations
- Equipment and facility suppliers (biogas treatment, distribution)
- Fuel users (transportation, delivery, waste management companies)
- Companies and municipalities that consume biogas in Sweden (for benchmarking and experience sharing purposes)

Collaboration with the listed actors was initiated and developed during the research process by holding a number of face-to-face meetings, joint workshops, telephone conversations, and email conversations. Certain organisations were contacted more than once and in each of the three projects due to the iterative and collaborative character of research. Therefore, as the design proposition for the target industrial ecosystem evolved, more discussions with the same stakeholders were required in order to validate, test, and improve the design. The timeline of documented communications with various actors is presented in Appendix C. More communications through phone calls and emails took place during project “Implementation”, which are not reflected in Appendix C.

Since the author participated in the projects together with other team members from PBI, not all the interviews and communication acts were performed by the author. However, proper documentation of interviews and thorough discussion of new critical issues that surfaced during informal communication within the research team allowed the author to be constantly involved in solution design. Thus, the project research results were co-created together with the author’s colleagues from PBI and informed by the stakeholders mentioned earlier. The author’s contribution was in participating in the development of practical solution thereby facilitating the change process along with other researchers. However, scientifically, the contribution was to develop the actionable knowledge and later conceptualise it in the form of four research papers and this thesis.

3.3. Research process

3.3.1. Designing the solution together with practitioners

Clinical research, or clinical inquiry, is associated with the action research tradition and can be seen as one of the approaches in the broader paradigm of experiential action research (Coghlan, 2000). Thus, the general features of action research are also pertinent to clinical inquiry. They include the following (Coghlan, 2000; 2009; 2011; Gummesson, 2000):

- Research is done in cooperation with a client organisation and the knowledge is co-created.
- There are always two research goals: solving a problem for the client and contributing to science.
- The developed knowledge is holistic.
- The research approach is applicable to understanding and planning change in social systems.
- The knowledge developed is contextually embedded.

There are, however, a few reasons why the approach utilised in this research is referred to as clinical. This approach is considered to be more client-driven compared to the older tradition of action research (Schein, 1995). In the latter approach, the aim is to solve problems ‘within organisations’ rather than ‘of organisations’. Action research often adopts a critical outlook on organisations and attempts to incur change towards ‘better’ and ‘more fair’ solutions, thereby keeping the ownership of both the problem and solution in the hands of the researcher (Riordan, 1995). Clinical research, in turn, is driven by client problems, and the researcher helps the client organisations to explore the roots of the problem they face and develop solutions based on practical knowledge and theoretical insights. This difference is crucial for this research because it has a major implication on the research process. That is, by doing *clinical* research it was possible to achieve better access to sensitive data and commitment of key stakeholders in order to co-create a solution that would be realisable and potentially beneficial for all involved actors. By involving the stakeholders in the design of the ecosystem it was possible to empower them through letting them know that they would keep the ‘ownership of data’ (Schein, 1995) and were able to influence the solution to their problem. Since the research involved a multitude of stakeholders, ensuring their commitment to participate and share their insights was crucial and otherwise impossible if a more critical approach would be employed. As discussed in section 3.1, the focus was on designing a working solution rather than criticising and changing current problematic situations.

The interaction between the researchers, including the author, and other research participants (listed in section 1.2) took place regularly, even outside the official project time (e.g. between Project “Pre-design” and “Implementation” in Figure 6). At the early stages of the research process (Project “Pre-design” and

“Challenges”) the usual discussion with such stakeholders included the following agenda:

- Envisioning the target industrial ecosystem.
- Discussion on the challenges and obstacles in its development.
- Discussion on the roles and responsibilities of different actors in this ecosystem (with the focus on the interviewed stakeholder in case of an interview).
- Discussion on the benefits of the ecosystem in general and for its participants in particular.
- Discussion on the implementation of the target ecosystem.
- Brainstorming solutions to identified challenges.
- Discussion on the interviewees’ wishes for ecosystem design.

During such discussions, it was possible to collect the data that would serve as input information for the ecosystem design, whilst also involving the stakeholders in the change process that would ultimately affect them. It was also possible to cross-check certain critical issues by raising the newly raised questions from one stakeholder in the discussions with other stakeholders. This way the development of the target ecosystem was already taking place during the first discussions. Later, during Project “Implementation” the same stakeholders were revisited and new stakeholders were involved. The PBI research team was able to discuss and validate the propositions developed in earlier projects with them. New challenges were constantly arising and a more detailed design was required. An example of how the solution to engaging truck users in the ecosystem was co-created with various stakeholders, is demonstrated in Box 1.

The role of the researcher in clinical research is to understand the problem from inside the context (Schein, 2008) and generate actionable knowledge, so neither the researcher nor the collaborating stakeholders were detached from the actual research object. As a clinical researcher, together with a group of practitioners the author was constructing the meaning and framing the problem, “setting the stage for problem-solving”, which brought new problematic situations into being as the context changed (Schön, 1995). Thus, the aim was to enable the practitioners to explore, diagnose, and act upon the events as they emerged, while generating ‘real-time’ actionable data (Coghlan, 2000: p. 192). This underlines the iterative and reflective research process within the clinical research paradigm, and its proximity to the design in its broadest sense (Schön, 1995) and the DSR as methodology. However, although participants from the industry may have good knowledge of the context, this knowledge is limited. The collaboration with researchers is important when moving to novel situations because the researcher can bring insights from general, fundamental knowledge (Brannick and Coghlan, 2006). In case of this research, the researcher’s role was to embrace the larger ecosystem, which would be impossible for one actor to achieve.

Box 1. Co-creation of knowledge with the practitioners**Designing new business models together: engaging truck operators**

Truck operators such as waste management and delivery companies were seen as the potentially largest consumers of biogas due to a number of reasons. Firstly, they are able to make ‘fleet decisions’, i.e. they may purchase a large number of vehicles at once so as to increase the feasibility of the investment into the technology such as biogas-driven vehicles. Secondly, large trucks consume several times more fuel compared to passenger cars, and therefore truck users are potentially large-volume consumers of traffic fuel. Another advantage of attracting these companies into the focal ecosystem was that they are able to make faster decisions compared to, for example, public transport operators who depend on tendering.

In order to understand what would motivate truck operators to make a switch to biogas and as a pre-requisite for them to acquire gas-driven trucks, discussions were held with the managers in these companies. It was discovered that besides the unknown price for biogas the major challenges were the need to purchase new vehicles, the need to train personnel to operate and maintain them, and insecurity about the operational costs. The concrete fear was that due to the absence of experience with gas vehicles the costs for maintenance and operation might transpire to be higher compared to diesel analogues, even if the price for biogas would be significantly lower. These considerations brought the research group back to the vehicle dealers to discuss how the risks of the potential consumers could be reduced. The traditional business model for vehicle sales was partly able to tackle these issues: a leasing option could reduce the risks of owning new trucks, while maintenance agreements would reduce the need for operators’ personnel training. However, this would transfer the outlined risks to the vehicle dealers since they would bear the risk of owning the vehicles, and a second-hand market for these vehicles is barely existent in the focal country. The larger volume of trucks being sold at once, however, would help to make the deal more appealing for the vehicle dealers: not only through making more profit from sales, but also by making it reasonable to invest in the appropriate maintenance facilities and training for the new technology.

Returning back to the issue of operating costs, it was critical to attain the operators’ confidence in the fact that their operating costs would ultimately be lower for biogas trucks so that their investment in more expensive trucks would pay off. A vehicle dealer was not able to make such a promise, because the major part of these costs – fuel costs – was highly dependent on price and supply security provided by the biogas distributor. After several discussion rounds with the mentioned stakeholders the idea of a joint offering was developed: if biogas trucks could be offered in conjunction with long-term fixed price contracts for fuel, the value of such an investment would become more apparent to the vehicle operators, since they would be spared from the non-core risk of uncertain fuel price. Moreover, by establishing direct collaboration between the biogas distributor and vehicle dealers it would be possible to agree on the acceptable level of fuel quality thereby keeping the maintenance costs to the minimum.

Thus, by iteratively addressing the challenges and uncertainties that concerned the various potential stakeholders of the ecosystem to be established, a new business model was designed that would re-distribute risks and benefits among the companies.

As a clinical researcher, the author needed to be self-aware and self-reflective through constant questioning of own assumptions, biases and filters (Coghlan, 2009). This is not driven by the pursuit for objectivity in positivist sense, but by the need for relevance and *actionability* of the produced knowledge and its validity in pragmatic sense. Therefore, the active participation of other research actors, such as team members and business stakeholders was needed and beneficial for knowledge production.

To summarise, the author's role as of researcher was to facilitate a change process driven by the clinical inquiry that was undertaken within certain PBI projects, and in producing and conceptualising the actionable knowledge. The representation of such knowledge had to be done in such a way that the problem and action strategies would be *transferrable* to new situations being perceived as similar to the original (Schön, 1995). Therefore, this thesis not only describes how the change was achieved, but also proposes generic models, concepts and action plans that can be transferrable and can be used to solve similar problems.

3.3.2. Stabilising the actor-network in order to create a working solution

In order to produce scientifically significant and valid research, it is not sufficient to collect feedback from the stakeholders and design an ecosystem purely based on such information. The development of a working solution appeared to be equally dependent on economic, social, technical, physical, and political features, as well as many other factors. To design a solution, none of these critical issues could be left out, because it would undermine the resilience of the solution as such. Moreover, it was impossible to prescribe the success of developing an industrial ecosystem to one set of factors. Rather, a complex socio-technical system was required to enable such an ecosystem.

Actor-network theory (ANT) is interested in 'how it is that everything hangs on together if it does' (Law, 2009), which is one side of the design science approach, where the question is how to *design a system*, in which everything will 'hang on together'. ANT became known from the writings of Callon (1986) and Latour (1987; 2005) on socio-technical systems and their formation. The distinct feature of ANT is the attempt to dissolve the dualism between actors and structure, micro and macro level, global and local, subject and object, knowledge and belief (Smith, 2012).

ANT allows complex phenomena to be approached, such as socio-technical systems, in all their complexity and networked structure. Industrial ecosystems can be perceived as socio-technical systems since they are made up of a large number of parts of the heterogeneous origin. Therefore, certain concepts and methods based on ANT appeared to be useful for designing the solutions to develop industrial ecosystems. One such method, controversy mapping through sociotechnical diagrams (see Figure 7) was used in order to identify which actors support or oppose the system, i.e. were enrolled in the programme or antiprogramme of an innovation taking place. This mapping helped understand how the opposing actors could be co-opted, and how the supporting actors could be strengthened.

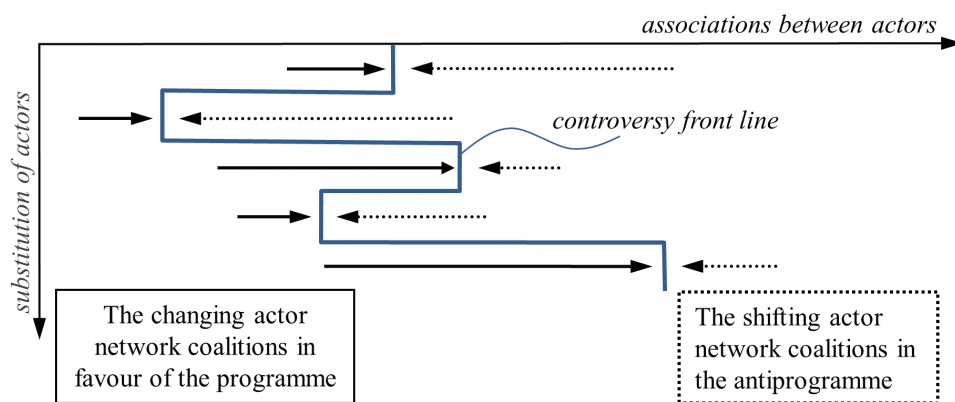


Figure 7. Principle of a sociotechnical diagram.⁴

The approach of controversy mapping was used as a research tool. More specifically, the approach was used for creating the proper mindset when conducting the research and keeping track of the solution development. Since the target industrial ecosystem for production and utilisation of biogas was seen as an actor-network (Callon, 1980; 1986; Latour, 1987; 2005; Law, 1992; 2009), the actors included not only the business actors, but also all the elements ‘that mattered’. For example, the price of biogas was considered as one of the actors. If this was too high, then the price would belong to the antiprogramme, and thereby obstruct the solution implementation. If it was low and competitive, it would add to the programme supporting the solution implementation. Certain actors were clearly in favour or in opposition to the solution, some had to be *strengthened* or *enrolled* into the programme, such as in the example of the biogas price. In this case, enrolment was possible through underlining that a biogas distributor needs to set a price for biogas that would be competitive with other fuels. This example of controversy mapping in order to develop a reasonable solution is presented in detail in Box 2.

Controversy mapping used in this research was particularly useful for analysing and developing the complex system, the boundaries of which are difficult to establish. The method allowed focusing on the crucial actors, mapping the interdependencies between them and utilising this information for changing the designed solutions towards better stability and feasibility. Thus, controversy mapping allowed pursuing the iterative nature of clinical research and DSR through constantly assessing the design proposition stability and attempting to improve the solution.

In the process of designing solutions for the research problems, the interest was in the ‘blackboxes’ (Latour, 1987), meaning that as long as an actor was

⁴Adapted from Markowski (2008)

Box 2. Mapping and addressing controversy**Managing controversy and overcoming resistance: setting the biogas price**

The question of the biogas price was the first and most critical one for many stakeholders when discussing using biogas as traffic fuel. It was also seen as the main output of the feasibility study (in project A), since it would define the commitment of potential consumers to use biogas in their vehicles. However, while it was possible to define the cost of biogas production given the local conditions, the price was seen as an opportunity to balance the stability of the ecosystem to be created. First of all, it was clear that for the public transportation authority it was crucial not to increase the costs of bus operators, so as to keep the ticket fares unchanged. That was the condition for them to promote biogas in the tendering for bus operations. After calculating the acceptable level for the biogas price for public transportation it was discovered that such a price, if offered to all consumers, would make the profit of the biogas distributor insufficient for recouping their investments in the infrastructure. Therefore, it was decided that the price for other consumers can be higher compared to the one offered to public transportation, as long as it is ultimately lower than the prices for competing fuels. After discussions with truck operators, it became apparent that their main fears were the potential interruption of biogas supply and unpredicted price for the fuel that would make their investments in gas-driven trucks risky. In order to address these issues, it was proposed that the biogas distributor would make long-term contracts for a fixed price for large truck operating companies. In this way the truck operators would achieve a stable supply of biogas at a lower price, and the biogas distributor would ensure large volumes of biogas consumption in the long term. The price for small consumers would be set higher in order to compensate the lower price offered to large consumers, but would still be competitive with other fuels.

As a result, the **differentiated pricing model** for biogas was designed in order to enroll potential consumers into the supporting programme by counteracting the arguments against it.

plausible, the manner in which it was constructed was not relevant. ‘Plausible’ does not mean ‘the right’, or ‘the best’, but rather the one that became meaningful to many people for certain reasons. For example, the one that made the most sense when no alternatives exist, other people being enthusiastic about it, or taking the same perspective, or it being close to their identities (Mills et al., 2009; Thurlow and Helms Mills, 2009). The idea of accepted facts or ‘blackboxes’ is central when creating solutions that involve a significant number of stakeholders, each of whom needs to accept those facts. Returning to DSR, the author was interested in how to stabilise the actor-networks and develop ‘blackboxes’, which could be judged by their plausibility, i.e. whether they were accepted by the stakeholders and, taking one step further, were actionable for them. Thus, if designed business models and other means to create the ecosystem were accepted and acted upon by the relevant stakeholders, it could be

concluded that the author had arrived at the results she was striving for: creating actionable knowledge and answering the ‘how to’ question.

By approaching the ecosystem design in this way, it was possible to deal with all the multitude and variety of critical issues that appeared during discussions with the stakeholders and tackle them one by one. This allowed a holistic view to be kept on the problem of ecosystem development without overlooking crucial issues simply because they were outside of the imposed categorisation.

3.3.3. Arriving at a good design proposition

Sustainability was the key characteristic pursued during the design process even though the outcome was not predefined. It included not only environmental sustainability, which was ensured by the local cyclic way of producing biogas and by considering all the input and output material flows, but also the economic and social sustainability, i.e. the acceptance of the key stakeholders and the viability of the ecosystem to be established. Viability, in turn, was based on the feasibility of the business models within the ecosystem and the commitment of key stakeholders to participate, which was achieved step by step during the research. An example of how the quest for designing a sustainable ecosystem led to the enlargement of its boundaries is presented in Box 3.

DSR was combined with clinical research in this study in order to promote a focus on solution development. Another reason for conducting research within the DSR paradigm was its emphasis on a creative leap between knowledge that is generated in exploratory and explanatory science and a design proposition (van Aken and Romme, 2009). The development of a design proposition is therefore not based on the causality discovered in ‘pure’ science (A causes B, therefore do A if you want to reach B), but is rather based on pragmatic ‘reasonableness’ of a solution (C is the problematic context, D is a design proposal based on the vision of an ideal target system O; if D overcomes problems C and leads to O, then it is a good solution). A proper solution to a complex and ill-defined problem cannot be induced from a problem or deduced from theory, but can only be *informed* by problem specification and theory. As James puts it, “theories thus become instruments, not answers to enigmas, in which we can rest” (James, 1907/1981: p. 28). It is in line with the clinical research paradigm, where researchers are not only concerned with ‘diagnosis’ but have the primary focus on ‘treatment’ (Coghlan, 2009).

Enrolment into the programme also concerned the companies participating in the study. In this case it meant achieving their commitment through incentive development and cooperation within the research projects. This process helped achieve both the goals of developing a design proposition and triggering the actual change.

The creation of a solution in this clinical study was not purely based on input and feedback from participating stakeholders. The data informing the design proposition development came from the following major sources:

Box 3. Enlarging system boundaries**Enlarging ecosystem boundaries: organic farming and biogas production**

The initial constellation of the target ecosystem was developed at the very start of this research, based on previous knowledge developed at PBI. However, the system evolved as the research proceeded and the contextual knowledge on the focal location was embedded into what was technologically possible and reasonable. Initially, sewage sludge was seen as the main source of biomass for biogas production. At a later stage when the potential biogas consumption was assessed, based on consumer information from one side, and the required consumption for recouping the investment into distribution infrastructure on the other side, it was discovered that the utilisation of sewage sludge volumes would be insufficient to ensure the biogas supply. Therefore, the idea of utilising green biomass such as grasses or hay emerged in the discussions with the company producing biogas.

First it was assumed that a crop farmer could dedicate part of their fields to growing biomass that would be used for biogas production instead of growing grain. After discussing this idea with the agriculture specialists it transpired that the biogas producer would need to buy green biomass at a price that would cover the 'lost opportunity' for the farmer, i.e. at the level of the price of grain. The following round of calculations showed that this would not be feasible and would significantly increase the price of biogas. Further discussions and literature reviews resulted in the idea of combining biogas production with organic farming that would be based on rotation of food crops and grasses over several years, as well as the utilisation of the digestate generated during biogas production instead of the current use of synthetic fertilisers. In this way not only non-food biomass would be produced for biogas production purposes, but also the farmer could significantly reduce costs associated with acquiring and utilising fertilisers and pesticides.

The business model of a farmer would need to change in order to accommodate these changes: to introduce organic farming new capabilities are needed, but also the ultimate product – organic food – is more valuable. By attempting to plan how costs for acquisition of green biomass can be reduced, the boundaries of the target ecosystem changed: the scope of biomass supply changed from simply buying it from a stakeholder to re-defining the whole business logic of farming in order to integrate it into the solution.

- Insights into the problems and contexts of various sources (secondary data)
- The logic and common sense of the research team members
- Research in context (interviews, discussions with stakeholders)
- Existing explanatory theory (see Chapter 2 for overview)

Since the final outcome of the design process was not pre-defined, it was guided by the pursuit of sustainability in all dimensions, as well as by the ability to act at the same time on the knowledge produced. Thus design propositions evolved as the actor-network was being stabilised in order to create a solution that would lead to the envisioned future and that would commit the stakehold-

ers to its implementation. Through constant validation of the developed solutions and attempts to stabilise the actor-network that lay behind the designed industrial ecosystem, it was possible to generate the sound design proposition along with and as a part of the actionable knowledge, which is discussed further. The process of development of the design proposition is visualised in Figure 8.

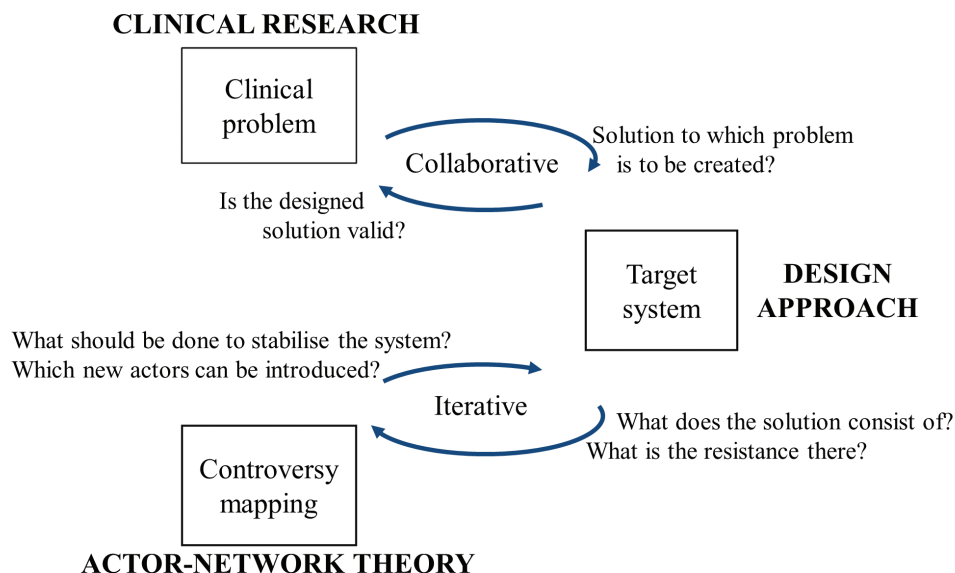


Figure 8. The collaborative and iterative process of design proposition development.

3.3.4. Knowledge production

The knowledge that is produced in this research can be called *practical knowledge* (Reason, 2003), *practical knowing* (Reason and Torbert, 2001), *actionable knowledge* (Coghlan, 2011; Romme, 2003), or *knowledge in action* (Schön, 1995). The main feature of such knowledge is the fact that it can be used for taking action, while the underlying laws of the phenomenon are undiscoverable or even irrelevant (Schön, 1995). It is opposed to the positivistic view of knowledge, which implies that scientific knowledge has to be detached from subjective and abstracted theories relate to one another in recurring patterns (Coghlan, 2009). Such ‘universal’ knowledge cannot be used to predict what is actionable and what is not (Coghlan, 2011), whereas practical knowledge is contextually embedded and useful for practitioners. It is not universal, and this is not the aim of clinical research, however, extrapolation from a local situation to more general situations is possible (Coghlan, 2009).

Actionable knowledge is not only generated as the ultimate outcome of research, but is constantly produced as a solution to diagnosed problems, and then feeds into the action taken by the collaborating organisation, which in turn leads to changes in the context and new problems to be diagnosed, ex-

plored, and taken action (Coghlan, 2000; Schein, 1999; Schön, 1995). It is demonstrated in Box 4 how the knowledge produced during the research was utilised by practitioners, proving the ability to act on this knowledge.

Thus, the outcome of clinical research was both the actual change and the knowledge that can be generalised in a specific manner (Coghlan, 2000; Coghlan, 2009). The generated knowledge can be generalised through framing the problem and strategies of action appropriate to its solution in such a way that both the problem and action strategies can be carried over to new situations being perceived as similar to the first (Schön, 1995: p. 31). For example, although the design of the ecosystem integrator's business model was deeply embedded in the local context, the described models, mechanisms, and strategies of its development can be re-used in similar contexts after certain re-adjustment to specific conditions in the new context.

Box 4. Creating actionable knowledge

Proving that the knowledge is actionable: the integrating company

The idea of a company that would integrate industrial ecosystems for biogas production did not exist at the very start of the research. This idea rather appeared during the later stages when it was revealed that none of the currently operating stakeholders would have the capabilities necessary for integrating the multitude of actors into a working solution. There was a need for a credible business actor that would serve the functions in the ecosystems that were missing, such as upgrading and distribution of biogas. More importantly, this actor would base its business on the understanding and coordinating of the whole ecosystem through a number of collaboration mechanisms.

The need for an ecosystem integrator was also driven by the understanding that in order to develop the desired ecosystem, there had to be a company that would do it. This was true at least in the focal context where there was a spontaneous emergence of IS with companies starting to exchange waste- and by-flows without actually realising that the ecosystem benefit would have a very low chance of transpiring in the biofuel industry. There was a clear need for a leader and a visionary that would *integrate* the ecosystem, instead of waiting for it to form *spontaneously*.

As a result of such thinking, the research was steered into the direction of the integrator's business model, i.e. what would be the business of such an actor, and how would *this actor create the ecosystems around biogas* by integrating the other stakeholders and managing the ecosystem. At this point the focus of the research was narrowed down and the focal point was set.

At the same time, since this idea was generated in the collaborative research process, the idea of the ecosystem integrator did not remain on a purely conceptual level. The discussions about founding the integrating company were started among the key players, and also involved the PBI research team. The knowledge on how to create industrial ecosystems was developed further along with the process of planning the actual implementation.

The outcome of the research was the design of the integrator's business model and the actual change in the form of the readiness of major ecosystem stakeholders to establish such a company. Together these results formed the ultimate and indivisible outcome of any clinical study: actionable knowledge and change.

The ultimate outcome of this study is the design of the focal industrial ecosystem which includes both the design outcome and design process. The produced knowledge is explicated in such a way that it includes the description of problematic context, vision of desired outcome, and means to achieve it. Thus, the models and solutions proposed in this thesis and the four research papers can be reused in similar contexts by following the development logic (rather than simply copying) these elements.

3.4. Validity, quality and relevance of produced knowledge

3.4.1. Ensuring validity

Basically, any scientific facts are more rigorous when they are accepted by more people or peers (Latour, 1987; Putnam, 1987). This fact does not make them biased, since the question of objectivity is not even posed; rather, scientific facts are inseparably intertwined with our beliefs and values (James, 1907/1981; Putnam, 1987). Coming to the design mode of research, it is even harder to say which design is 'right', because it is created for a purpose, and it is good if it serves the purpose (Putnam, 1987; van Aken, 2004). Nature cannot 'settle the controversy' in this case (Latour, 1987) so that it would be possible to say which design is better. Taking a positivistic perspective, for example, certain scientific facts, such as the laws of physics, are considered to be *true* since nature 'stands behind them'. However, due to the limitations of human perception even those facts are driven by values and can be re-invented in the future (James, 1907/1981). For the knowledge created in design, it is impossible to even approach it in such a way, and instead reasonableness and serving the purpose become the ultimate criteria of 'truth'. Taking the example given by Putnam (1987: p. 78), the truth or quality of a knife cannot be based on nature, but is driven by the purpose it is designed for. Therefore, the design of the knife cannot be true or false in a positivistic meaning, but it can certainly be good or bad in a pragmatic sense. According to James (1907/1981: p. 38), truth is a species of good, i.e. something can be called *true* if it is *good* in the way of current belief and good for definite, assignable reasons.

Knowledge produced within clinical research through DSR cannot be judged by positivistic categories of objectivity such as rigor and validity. The latter can be re-defined, however, in the light of pragmatism: it is valid if it serves its purpose or is 'reasonable' (Putnam, 2002). While Cartesian doubt implies the use of doubt as a route to *certain* knowledge by finding those things that could not be doubted, the author adheres to anti-scepticism, fallibilism and pragmatism by saying that scientific knowledge is true if there is *currently* no *reasonable doubt* (James, 1907/1981; Wittgenstein, 1969). This is the reason for focusing on 'blackboxing' facts and testing their validity throughout the research process. By exposing produced research knowledge to practitioners in the search for facts that would contradict them, it was possible to arrive at

the knowledge that withstood reasonable doubt. In the context of management research science, this meant that the practitioners were ready to act upon this knowledge.

James (1907/1981: p. 88) puts the pragmatic idea of truth in the following manner:

“Truth *happens* to an idea. It *becomes* true, is *made* true by events. Its verity *is* in fact an event, a process: the process namely of its verifying itself, its *verifi-cation*. Its validity is the process of its *valid-ation*.”

This way, the knowledge produced while making a clinical inquiry was judged by testing its plausibility with the actors who are to use it for making the change. Plausibility might be a better word to describe what can be seen as ‘truth’ both from a pragmatic and social constructionism point of view. For the knowledge informing a change, plausibility is even more critical, because unless the change agents accept and understand it, they will resist the change. Continuing the idea, the endeavour for letting nature ‘settle down’ the controversies in not only mathematics or physics, but also in social sciences, leads to the assumption that ‘everything social’ is built upon some fundamental laws of nature that presuppose how people act and the world develops (Putnam, 1987). Accepting the complexity of the social world and industrial ecosystems in particular, the design approach helps to answer the question of how a social change can occur without assuming that human actions are completely predictable and rational.

3.4.2. Relevance and quality

Since design is based on pragmatism as the underlying epistemological notion (Romme, 2003), the aim to produce relevant and actionable knowledge was realised through combining clinical research with DSR. Although such knowledge is produced in the context of application (Huff, 2000; Starkey and Madan, 2001; Tranfield and Starkey, 1998), it could be transferrable to similar problems.

Thus the relevance gap between the theory and practice is tackled by being able to produce knowledge through practice rather than seeing practice as a setting for only implementing the knowledge (Schön, 1995). In general, both the clinical research and the DSR paradigms imply that knowledge production should be democratic, i.e. those who know more about the context need also be involved in creating the knowledge. By being able to influence the process, they can produce ***the knowledge that is relevant and capable of driving social change***. In line with this are the discussions about equality and democratic values in scientific research (Brannick and Coghlan, 2006; Coghlan, 2011; Greenwood, 2002; Lessem and Schieffer, 2010; Putnam, 2002; Romme, 2003) which generally leads to the conclusion that practical knowledge should not be underestimated and perceived as low-quality, and that people in a position to know the particular context should be involved in the research. This is seen as the only way of bridging the gap between theory and practice by abandoning the purposeful attempts to separate them.

The quality criteria of a clinical inquiry, as defined by Coghlan (2009), include the following:

- The clinical inquiry/research engages with real-life issues.
- The clinical inquiry/research must be collaborative.
- The clinical inquiry/research must have a reflective process.
- The clinical inquiry/research must have workable outcomes and actionable knowledge.

In line with this, van Aken (2004) defines the quality of DSR as the production of valid knowledge for field-problem solving. This study attempts to fulfil this minimum quality for the research approaches utilised. The knowledge developed during the research appears to be actionable because it greatly informed the real-life preparation for building the target industrial ecosystem. As a result and based on the research a consortium of stakeholders started the discussion to establish the company that would become the industrial ecosystem integrator.

Rigor of practical knowledge falls outside the boundaries of technical rationality (Schön, 1995). The basis for validation in clinical research is “the conscious and deliberate enactment of the action research cycle” (Coghlan, 2011: p. 61), which means that the relevance and validity of knowledge produced in this research was tested throughout the research process by constant exposure of the research results to the practitioners and discovering and further addressing new challenges.

The research results of this study are not expected to be generalisable in a positivistic meaning, but are *transferrable* to similar situations (Schön, 1995). Transferring to new similar contexts occurs through framing the problem and appropriate strategies of action in such a way that both the problem and action strategies can be carried over to new situations. These strategies of action can be tested for validity in the new contexts and reinvented or adjusted if that is required (Schön, 1995). In line with this, the term *transportability* is proposed to better describe how the knowledge, developed during DSR, can be re-used. It can be achieved in the following process: developing knowledge within a specific context, and then decontextualizing and recontextualising it in the next context, and again decontextualising, and so on. This way the design proposition for such complex solutions as industrial ecosystems can be reused in new contexts with certain adjustments.

The limitations of DSR are such that the information about a problem or situation is limited as it is in any mode of research. However, due to the participation of many stakeholders it was possible to reduce the effect of this shortcoming, since the knowledge came from many sources and could be validated by relevant people throughout the research process. The involvement of a multitude of participants in knowledge creation is most likely to benefit the validity, quality, and relevance of this knowledge.

3.4.3. Reaching the research goals

While it was neither possible nor reasonable to identify what the resulting design proposition would be from the start of the research, the design goals were the guiding light for understanding whether the research outcome was reached. Functionality, plausibility, and adherence to the initial criteria of distributed and symbiotic industry structure were the constants, while the actual composition of the focal ecosystem and the actors in the underlying actor-network evolved as the goal of creating a *sustainable* solution was pursued. Sustainability is understood in its full definition, where environmental, economic, and social dimensions are inseparable from each other and the overall ability to *sustain over time*.

Developing actionable knowledge on how to create sustainable industry architecture for biofuel production and utilisation was the ultimate outcome of this research. The process of ecosystem development and models are presented in this dissertation thereby constitute such knowledge. The *actionability* of the knowledge is proved by the fact that major stakeholders in the developed ecosystem were ready to make decisions based on these facts and make the relevant investments.

The goal of developing the *transferrable* actionable knowledge was pursued by explicating the knowledge in such a way that the context, desired outcome, and mechanisms for achieving it are described together. Moreover, the later stage of this research (the second half of Project “Implementation”) was devoted to assessing the potential for creating industrial ecosystems based on the knowledge developed in the focal location. This was done through de-contextualisation and re-contextualisation of this knowledge in new settings.

3.5. Summary of the research design

According to Schön (1995), there are two types of research problems, those that can be compared to high, hard ground and those that are more like swampy lowlands. While the former can be solved with the help of rigorous research-based theory and technique, the latter are so complex and confusing that they are beyond mechanistic and technical solutions per se, but at the same time are generally more relevant for society (Schein, 1993). The research problem in the core of this thesis can be rightfully ascribed to the ‘swampy land’, because it arose from society’s need to achieve sustainable development rather than from the fact that that it is resolvable by applying existing or deductible theories. DSR is an approach to working with ill-defined problems (Romme, 2003) because the ultimate outcome of such research – a design proposition – cannot be deduced or induced from data, but is instead designed evaluatively and analytically and verified by testing (van Aken and Romme, 2009). While in explanatory science the justification of produced knowledge is from question to answer, in DSR it is from answer (the design proposition) to question (the specifications). So testing

the design is the key to the justification, and it has to be supported by an account of the input, i.e. specifications, problem and context analyses, and existing theory (van Aken and Romme, 2010). In line with this, clinical inquiry allows generating ‘practical’ or ‘actionable’ knowledge (Coghlan, 2011) that is verified during the co-creation with the practitioners and iterative revisiting of solutions proposed and even the questions asked. The round of iteration in a clinical inquiry is not in checking whether the problem has been solved, but in asking whether the newly created problems are worthwhile (Schön, 1995). In terms of causality it is reflexive rather than either deductive or purely inductive.

The major consideration when approaching this research problem was that post-observation of the phenomenon is unable to fully reveal the complicated process of the industrial ecosystem formation, which involved considerable resistance and controversies before it is ‘settled down’. Certain tensions and challenges may be forgotten by the respondents after the project is completed, making the data obtained ex-post insufficient for answering the question of how industrial ecosystems can be built. Moreover, the success of one or another ecosystem development might be context-dependent making the generalised knowledge about why it succeeded not easily transferrable to other contexts. Going even further, it appeared that the research of ‘how it was done’ is not always able to inform the answer to the question ‘how it should be done’ due to the difference in the quality of knowledge required for answering these two questions.

Another challenge lies in the fact that the research problem is by nature ill-defined, meaning that due to its complexity and involvement of many stakeholders it can be solved by multiple solutions, and the ‘right’ solution is defined by the values and context rather than by discovering the underlying laws that would automatically lead to a unique and appropriate solution.

The gap between the theory and practice is widely discussed in industrial ecology (e.g. Harper and Graedel, 2004), management, and organisational science (Brannick and Coghlan, 2006; Coghlan, 2011; Hambrick, 2007; Rynes, 2005; Schein, 1993). Weick (2003) draws the distinction between ‘life understood backwards’ and ‘life lived forward’, which are associated with theory and practice correspondingly. Simon (1969/1996) in “The Sciences of the Artificial” also recognises the difference between describing and explaining ‘what is’ and designing and evaluating ‘what can be’ and ‘how it can be’. Since these are different forms of activity, the contribution of the two modes of research is different and cannot be judged in the same way. In the research of how industrial ecosystems can be developed, looking back can only partly inform the problem-solving, whereas the vision of target systems, which are *designed* to be more sustainable compared to current industry structures, does affect the way the research problem can be solved. In management research, it is important not only to be able to learn from the past, but also to embed a strong creative element into the process of change towards better practices. This is especially relevant for the organisation of industrial activities: the research of currently

prevailing industrial management practices, which in many ways has led to undermining sustainability (Mirata et al., 2005), cannot on its own develop a proposal on solving these problems. Rather, the focus on the future and the design of a better solution need to be the starting point for conducting the research on how to reach a sustainable industrial organisation.

In the quest for sustainability, the question of change is crucial: the goal of this research was to make the focal industrial ecosystem work, which could be done by producing relevant and actionable knowledge and by actual involvement of the researchers in the process. Moreover, organisational change is more likely to happen when the change agent does not feel disconfirmed, but is rather involved in a trustful cooperation, knowing that she/he has ‘a say’ in the process (Schein, 2006).

Summarising the outlined concerns, the following are the distinctive features of the research problem, which ultimately defined the choice of the research methodology:

- Orientation on the future instead of orienting on the past
- Complexity and need for a holistic approach
- Search for a solution to an ill-defined problem
- Need for fostering change
- Need for eliminating the gap between theory and practice
- Dependency on context

Clinical research and design science research paradigms, based on pragmatism, allow the defined kind of research problems to be dealt with and therefore formed the methodology adopted when doing this research. Their focus on the future (Coghlan, 2009), creating ‘knowledge in action’ (Schön, 1995), and actually making the change (Coghlan, 2000) allowed the knowledge that has the substance to be prescriptive to be produced. The results of this research are contained in the four research papers, which are a part of this thesis.

Table 2 briefly summarises the content and contribution of the papers, while a more detailed summary of the papers and synthesis of results are presented in Chapter 4.

Table 2. Summary of research papers

Research question	Main contributions of the paper	Contribution to answering the main RQ (creating the normative model)
<p>Paper I: Business models for industrial ecosystems: a modular approach <i>Anastasia Tsvetkova and Magnus Gustafsson, Journal of Cleaner Production, Vol. 29-30, pp. 246-254</i></p> <p>How can modularisation help in development of industrial ecosystems? RQ 1</p>	<ul style="list-style-type: none"> • View of industrial ecosystems as complex nearly decomposable systems • Modularisation of industrial ecosystems and its benefits due to redundancy • Implications on the business model of the integrator 	<ul style="list-style-type: none"> • Industrial ecosystems are complex systems, and they can be developed through modularisation and re-combination from quite stable modules (businesses) • Business model of the integrator becomes flexible due to modularity
<p>Paper II: Collaboration mechanisms for business models in distributed energy ecosystems <i>Magnus Helström, Anastasia Tsvetkova, Magnus Gustafsson, and Kim Wikström, Journal of Cleaner Production (submitted)</i></p> <p>How can collaboration be established within industrial ecosystems? RQ 2</p>	<ul style="list-style-type: none"> • Collaboration mechanisms for establishing collaboration between companies operating in disconnected industries for distributed energy ecosystems • Explication of a number of concrete collaboration mechanisms • Boundary-spanning model creates benefits and risks through increased interdependency 	<ul style="list-style-type: none"> • Collaboration mechanisms can serve as interfaces between modules in industrial ecosystems • They should build on the respective companies' business model and industry • Collaboration mechanisms enable boundary-spanning business models

Research question	Main contributions of the paper	Contribution to answering the main RQ (creating the normative model)
<p>Paper III: Business model innovation for eco-innovation: developing a boundary-spanning business model of an ecosystem integrator <i>Anastasia Tsvetkova, Magnus Gustafsson, and Kim Wikström, In Azevedo et al., Eco-innovation and the Development of Business Models: Lessons from Experience and New Frontiers in Theory and Practice. Greening of Industry Networks Studies, Vol. II, pp. 221-241</i></p>	<p>Paper III: Business model innovation for eco-innovation: developing a boundary-spanning business model of an ecosystem integrator <i>Anastasia Tsvetkova, Magnus Gustafsson, and Kim Wikström, In Azevedo et al., Eco-innovation and the Development of Business Models: Lessons from Experience and New Frontiers in Theory and Practice. Greening of Industry Networks Studies, Vol. II, pp. 221-241</i></p>	<p>Paper III: Business model innovation for eco-innovation: developing a boundary-spanning business model of an ecosystem integrator <i>Anastasia Tsvetkova, Magnus Gustafsson, and Kim Wikström, In Azevedo et al., Eco-innovation and the Development of Business Models: Lessons from Experience and New Frontiers in Theory and Practice. Greening of Industry Networks Studies, Vol. II, pp. 221-241</i></p>
<p>How should the ecosystem integrator integrate other actors? RQ 3</p>	<ul style="list-style-type: none"> • The role of ecosystem integrator and requirements for their business model • The way a boundary-spanning business model can be built • The way a boundary-spanning business model can help in shaping industry structure from a company level 	<ul style="list-style-type: none"> • The business model of an ecosystem integrator needs to be open and flexible • A boundary-spanning business model of an ecosystem integrator can be built by addressing most critical issues in the stakeholders' own business models
<p>How industrial ecosystems can be replicated? RQ 4</p>	<p>Paper IV: Replication of industrial ecosystems for sustainable biogas-for-traffic solutions <i>Anastasia Tsvetkova, Magnus Hellström, Magnus Gustafsson, and Joakim Sjöblom, Journal of Cleaner Production (in press)</i></p> <ul style="list-style-type: none"> • Replication through functional modularisation • Business-driven way of developing industrial ecosystems • Replication of large and complex systems • Effect on restructuring of biogas-for-traffic industry 	<ul style="list-style-type: none"> • Replication framework based on functional modularisation and reusing of interfaces (collaboration mechanisms) • Business model of an integrator needs to be based on replication (not only one-off integration) in order to achieve 'economies of repetition' and shape sustainable and feasible biogas industry

4 ● RESULTS

The main results of this research, which are presented in four research papers, are briefly summarised in this chapter. Further, the results are synthesised in order to create a general picture of the produced knowledge. Finally, there is a discussion of how these results answer the research sub-questions and how this contributes to answering the main research question of this thesis.

4.1. Addressing the research questions

In order to answer the main research question of how sustainable biogas-for-traffic industrial ecosystems can be developed, the structure of such ecosystems and the process of their development were addressed. First, the complexity of industrial ecosystems was explored and discussed in Paper I from the perspective of how modularisation can aid in managing this complexity and developing resilient ecosystems. The main findings of Paper I are summarised in section 4.2. Then, answering the second research question of how collaboration among traditionally disconnected industry players can be established, collaboration mechanisms are discussed in Paper II and section 4.3. The answer to the third research question regarding the business model of an ecosystem integrator largely builds on the findings of Papers I and II, because modularity and collaboration mechanisms serve as key cornerstones of a business model that would allow incorporating the system thinking and thus helping to redefine industry structures to be more cyclic, reciprocal and collaborative. The boundary-spanning business model and the logic of its development are discussed in Paper III and section 4.4. Finally, the way to expand a biogas-for-traffic ecosystem by replicating solutions in many locations is discussed in section 4.5 and Paper IV, which aims to answer the fourth research question of how to replicate industrial ecosystems.

Section 4.6 summarises the findings of the four papers and explicates how they form a normative model for the development of sustainable industrial ecosystems around biogas production and its utilisation in transport.

4.2. Structure of industrial ecosystems and the use of modular approach (Paper I)

RQ1: How can modularisation help in the development of industrial ecosystems?

If a biogas business is based on the principles of IS, it is possible for the stakeholders in the resultant industrial ecosystems to achieve **system benefits**, which are otherwise unavailable for any business actor on their own (Simon, 1962). The term ‘system’ itself indicates that the entity in focus has certain structures, functional connections, and system goals. For a company dependent on the functioning of such an ecosystem, that is a biogas producing and/or distributing company within the scope of this thesis, it is crucial to manage the complexity of the ecosystem surrounding its product, and moreover, take advantage of it. As discussed earlier, another challenge for the biogas business is to expand by establishing multiple industrial ecosystems. Thus, the effort to replicate the production and consumption systems for biogas is to face the challenge of adaptation in every new location. Such systems are a combination of technical, social, business, and other elements (Geels, 2002), and are context-dependent, which in combination makes them extremely difficult to copy.

The complexity of industrial ecosystems makes it challenging to manage the multitude of small ‘elementary particles’ at once. However, it is the property of **nearly decomposable systems** that they can be split into smaller sub-systems that are weakly dependent on each other but, nevertheless, form a whole that is more than the simple sum of the sub-systems or individual elements (Simon, 1962). In nearly decomposable systems “the short-run behaviour of each of the component subsystems is approximately independent of the short-run behaviour of the other components” and “in the long run, the behaviour of any one of the components depends in only an aggregate way on the behaviour of the other components” (Simon, 1962: p. 474).

Industrial ecosystems pursue the properties of complex nearly decomposable systems if individual businesses of the involved stakeholders are seen as modules or sub-systems that serve certain functions within the ecosystem. The major functions with an industrial ecosystem based on biogas include production and supply of biomass, production of biogas, utilisation of digestate, distribution of biogas, utilisation of biogas and various support functions required for other functions to be served. Various businesses can serve these functions, which in the end affects the constellation of the industrial ecosystem.

When approaching ecosystems from such a **functional modularisation** perspective, it can be seen that the interaction among the subsystems or modules is fairly weak because businesses within an industrial ecosystem are quite independent in the short term and can only be influenced if other businesses create changes in their functions in the ecosystem. For example, a biogas producer would not be affected by an internal change in a waste management company unless and until it stopped its biomass supply or changed the way it supplied

organic waste for the biogas production ecosystem. The magnitude of connections within each business is much higher compared to the links among the businesses in an industrial ecosystem. This is due to the fact that modules are already viable in themselves as businesses. It is therefore crucial to establish linkages among the modules, i.e. interfaces, especially taking into account that many actors within such ecosystems are not accustomed to working together.

In order to identify the modules of an industrial ecosystem, various businesses were mapped according to the functions they can serve in the system. Following this logic, businesses that could serve the required functions were identified as the potential modules for a biogas production and consumption system. The recombination of these modules depends on the need to adjust to a certain location and whether a business network exists in the location. In the three hypothetical examples discussed in Paper I three ecosystem constellations were discussed:

- Biogas for transportation
- Biogas for heat and power production
- Liquefied biogas

The comparative analysis of the business model of the company producing biogas in each of the ecosystem constellations showed that the value proposition, capabilities required for delivery, revenue models and customers differed significantly in each case (see Table 3). Thus, if a biogas company wishes to establish business in various contexts it must be adaptable to local conditions through functional modularisation, and allow its own business models to alter as well. Moreover, it can be concluded that the biogas company will acquire modularity, which in turn brings flexibility when adapting to local business networks.

The study presented in Paper I achieves two goals. Firstly, it demonstrates the way functional modularisation can help in developing industrial ecosystems so as to incorporate the business side. That is, by treating industrial ecosystems as nearly decomposable complex systems it is possible to develop them from fairly stable subsystems, i.e. businesses that are already existing and operating. Such an approach is intended to contribute to more rapid development of industrial ecosystems and in a certain way addresses the business planning and integration in industrial ecosystems.

Secondly, the study outlines the implications of such an approach on the business model of a biogas company that attempts to build industrial ecosystems based on biogas in various contexts. The ability to adapt to local conditions lies in the variety of value propositions and revenue models that can be employed according to the local conditions and more specifically business environment. This, however, would require more capabilities from the biogas company respectively. However, the opportunity to establish a biofuel business on a large scale while keeping the benefits of customised local distributed solutions (as discussed e.g. by Mirata et al., 2005) is attractive from economic, environmental and social perspectives.

Table 3. Differences in the business model of a biogas producer throughout configurations of the industrial ecosystem

Elements of the business model	Configuration 1. <i>Biogas for transportation</i>	Configuration 2. <i>Biogas for heat and power production</i>	Configuration 3. <i>Liquefied biogas</i>
Value proposition	1. Waste management 2. Transport fuel 3. Organic fertiliser	1. Heat and power 2. Organic food	1. Liquid fuel for various purposes 2. Waste management
Revenue model	1. Gate fees for waste treatment 2. Sales of biogas 3. Sales of organic fertiliser	1. Sales of heat and power 2. Sales of organically grown food	1. Sales of liquefied biogas 2. Gate fees for waste treatment
Customer	1. Municipality 2. Transportation companies, individuals, municipal units 3. Farmers	1. Local communities and industrial enterprises 2. Individuals and companies	1. Various consumers: ship operating companies, energy producers, etc. 2. Municipality
Capabilities	1. Ability to process waste 2. Ability to produce biogas of proper quality to be utilised as vehicle fuel 3. Ability to produce organic fertiliser of acceptable quality	1. Ability to provide energy according to the contract with the customer 2. Ability to produce organic fertiliser of acceptable quality	1. Ability to produce liquefied biogas of proper quality 2. Ability to process waste

Biofuel business, in particular, has been quite unsuccessful in enforcing the same production and consumption patterns regardless of the local conditions. Many biofuel companies remain small-scale because they are unable to expand. By introducing modularity into the business model a company would need to diversify its capabilities and invest accordingly. On the other hand, it would be able to achieve the economies of repetition (Davies and Brady, 2000) and make the efficient development of ecosystems and adaptation to local conditions its competitive advantage. Seeing businesses, rather than the technical units, as functional modules of industrial ecosystem is proposed as a starting point for creating ecosystems that are not only technically feasible, but are also viable in business terms.

4.3. Collaboration mechanisms for developing industrial ecosystems (Paper II)

RQ2: How can collaboration be established within industrial ecosystems?

There are a number of challenges related to the establishment of collaboration among various stakeholders in industrial ecosystems for biogas production and consumption. Firstly, as implied by the notion of IS, the actors involved in industrial ecosystems are normally unaccustomed to working together and are not operating within the same value chain (Chertow, 2000). Secondly, although the benefits of cooperation might be attractive, there is a high uncertainty related to the investments certain actors need to make in order to make the ecosystem function. Thus, apart from the need to establish win-win situations within the developing ecosystem (den Ouden, 2012: p. 164), there is a need to **mitigate the risks and uncertainties**.

Following the idea of functional modularisation proposed in Paper I, collaboration among the business actors, i.e. the modules of industrial ecosystems, can be seen as interfaces that integrate these modules. Paper II demonstrates the logic behind the establishment of a number of interfaces in the focal biogas-for-traffic ecosystem through analysing and explicating two examples of **collaboration mechanisms** employed in its development.

The first example is devoted to the collaboration required for establishing the demand for biogas. Companies that operate heavy trucks, such as waste management and delivery companies, were explored as the potential consumers due to a number of reasons. In addition to the generally higher fuel consumption levels of trucks compared to passenger cars, truck operators are also normally able to make fleet decisions, that is, purchase a large number of vehicles at once. Thus, if a trucking company switches at least part of its fleet to biogas-driven vehicles, the biogas distributor can expect high and predictable demand for the biofuel, which in turn is able to ensure the payback of the investments into the gas distribution infrastructure.

The benefits of committing truck operators to become part of the industrial ecosystem based on biogas are apparent when the perspective of the biogas distributor is taken. However, the challenge is then to define and explicate the benefits that the operators would achieve. Moreover, taking a more proactive approach, the distributor needs **to create** the win-win situation, i.e. find the mechanisms that would commit the potential consumers to establish a long-term interdependency with them.

For the trucking companies, switching to new gas-driven equipment carries an investment cost and risk. However, connecting biogas price and the contract to the investment cost makes the overall lifecycle cost competitive. A stable and comparatively low price for biogas is possible since locally produced fuel is only weakly connected to the fluctuating oil price. Thus a long-term fuel agreement

at a price that is ultimately lower compared to diesel price can be offered in order to reduce the fuel risk and associated operating and capital costs for the trucking company. Further, in the new set-up a gas truck is sold together with a long-term contract for biogas, and the leasing opportunity decreases the end user's ownership risk connected to the second-hand value of the trucks. Thus the risks of the biogas consumer are re-distributed to the suppliers, i.e. biogas and vehicle suppliers. Not only are the quality, price, and steady supply of biogas guaranteed over time, but also the different sides of the new technology are better coordinated through such cooperation if fuel quality and maintenance costs become part of one offering to the truck operators.

The other example of collaboration required in the ecosystem was the aligning of biogas production with the farming businesses so as to expand and guarantee biomass supply, additional to organic waste. At the same time, an increase in the biogas production volume created the need for ensuring that the by-product, i.e. digestate, was disposed of in a safe and feasible manner. The farms were therefore another business actor that needed to be integrated in the biogas business, since they can provide green biomass to be used for biogas production, such as hay, and can take digestate to be used as organic fertiliser on their fields.

Following the traditional farming business model, the biogas producer needs to buy green biomass at a price that is at least equal to the price of currently grown crops, so that the farmer's revenue is not decreased. However, there is a way to reduce the price for hay through introducing ley farming. Ley farming is a method where certain fields stay fallow, i.e. unused for growing food crops, for a year, and then are taken back into use, for example, for grain. This way the soil restores its fertility in a natural way. If the farmer practices ley farming and also uses digestate provided by the biogas production as organic fertiliser, then it is possible to eliminate or significantly reduce the use of synthetic fertilisers that constantly increase in price, as well as of pesticides and herbicides. If the fields are managed in this way, the overall yield from all the fields and the revenue generated by the farmer are likely to increase. For the biogas producer this means that by extending the collaboration with the farmer they can reduce the cost for purchasing the hay. At the same time, the problem with disposing the digestate (or rather returning nutrients to the soil in a sustainable manner) can be solved in a feasible manner.

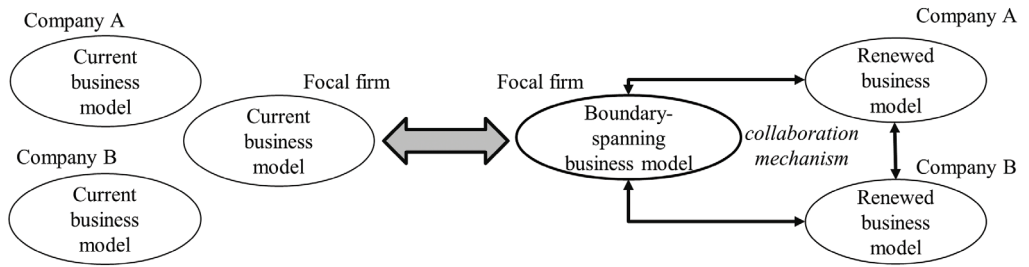
The collaboration mechanisms applied in these two examples were analysed and summarised through CIMO-logic (Context-Intervention-Mechanism-Outcome) (Denyer et al., 2008; see Paper II for a detailed description of CIMO-logic), so as to demonstrate what their role is and how they actually work (see Table 4).

The key element in the collaboration mechanisms presented lies in the ecosystem integrator's ability to identify the fundamental drivers and business model of the relevant stakeholders' risks, uncertainties, operational and capital costs, and business models in general. By harnessing these drivers the companies can be incentivised to participate and cooperate in the ecosystem. In the

Table 4. Explanation of collaboration mechanisms through CIMO-logic

	Biogas as traffic fuel	Biogas and farming
Context	Transportation company fear to invest in gas driven fleet due to uncertainty in gas supply and vehicle reliability.	Current business models make hay an expensive source for biogas production.
Intervention	Joint offering for end user based on stable fuel price, leasing, and a long-term maintenance contract.	Biogas production is deeply integrated with biomass production (joint production planning), leading to the possibility of nutrient cycling and organic farming.
Mechanism	Biogas consumption and steady supply are ensured from the start of the system operation in order to facilitate the simultaneous investment into the new vehicles and distribution system. This is achieved by mitigating transportation company's uncertainties about biogas technology (transaction efficiency) with a joint offering. Both biogas company and vehicle dealer are able to increase the sales volume of their products and services.	Both farmer and biogas company achieve efficiency improvements in production and increased value of their offerings to customers.
Outcome	'Chicken and egg' problem is solved. Investments can be made simultaneously. Initial ecosystem for biogas to be used as traffic fuel is created. Potential for increased total value creation through an innovation ecosystem.	New business model that builds on the low price for hay and the ensured disposal of digestate. Potential for increased total value creation through an industrial ecosystem.

case of the truck operators, *joint offering* by the biogas distributor and vehicle suppliers allows for increasing and explicating the value of the total life-cycle of investment made by the operators. In the farming case, *joint production planning* serves as a mechanism for delivering system benefits to the biogas producer and farmers. In both examples the innovative collaborative mechanisms are required to align industries that are not connected traditionally, but which need to become quite dependent on each other in the long term in order to form a functioning and resilient ecosystem. As a result, the business models of the involved companies need to undergo minor (in the case of vehicle dealers) or major (in the case of farmers) changes. The framework for the business model innovation through the development of collaboration mechanisms is depicted in Figure 9.

**Ecosystem transition need:**

- Investment uncertainty
- Lack of business capability
- Need for cost optimization
- Low value of offering

Design of collaboration mechanisms based on:

- Incompatibilities of old business models and new ecosystem functions and goals
- Need for filling new roles in the target business ecosystem

Establishment of target business ecosystem:

- New roles of companies
- Renewed business models
- Increased collaboration and interdependency
- Generation and capturing of system value

Figure 9. Framework for business model innovation in ecosystem transition context.

The collaboration mechanisms discussed in Paper II form only a few examples of collaboration that is required in the biogas-for-traffic ecosystem. However, the process and logic of their development is the key to establishing and operating *boundary-spanning business models*, which are required for building ecosystems. The business model of the ecosystem integrator that builds on collaboration mechanisms is further discussed in section 4.4 and Paper III.

4.4. The boundary-spanning business model of the ecosystem integrator (Paper III)

RQ3: How should the ecosystem integrator integrate other actors?

As discussed in section 4.2 (Paper I), modularity gives flexibility to the business model of the company that will integrate the ecosystems required for biogas business. The need for collaboration with various ecosystem participants was also addressed in section 4.3 (Paper II), where it was discussed that the collaboration mechanisms serve as interfaces and also form an important part of a boundary-spanning business model of a company that will integrate the ecosystem. In Paper III, the business model of the ecosystem integrator is analysed in greater detail in order to identify the way systems thinking and IS could be incorporated into it.

Based on the differences in the business models of the stakeholders which the ecosystem integrator needs to involve in the ecosystem, the overall business model of the focal ecosystem integrator can be divided into five sub-systems as envisioned in Figure 10. Depending on the business logic of various stakeholders, the ecosystem integrator needs to develop various ways to establish reliable and mutually beneficial collaboration with them.

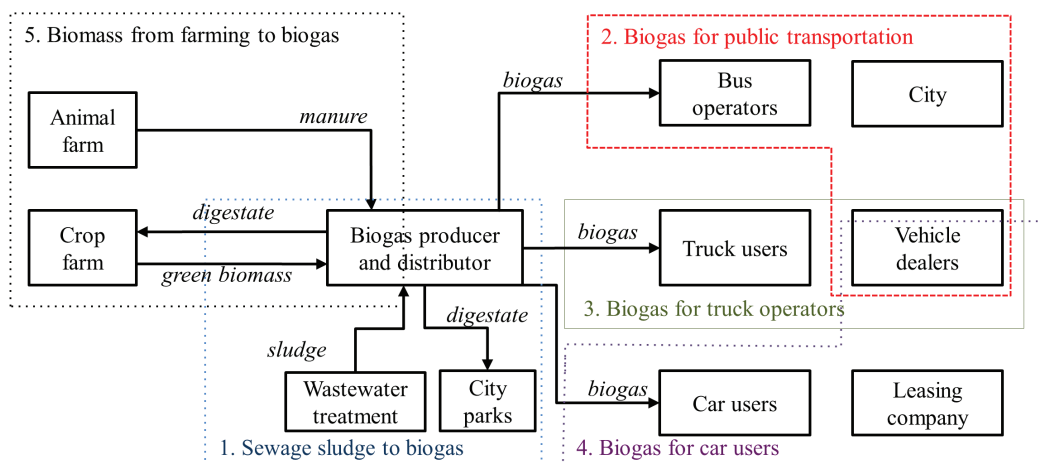


Figure 10. Sub-systems in the target ecosystem.

Table 5 summarises how, through understanding and addressing current business models of the relevant stakeholders, and the challenges they faced in regard to joining the resultant biogas-for-traffic ecosystem, the ecosystem integrator was able to adjust its own business model so as to establish collaboration.

Integration is achieved by considering the stakeholders' revenues, operational and capital cost structures, as well as their industry logics, and business models. After this phase, the connections between the stakeholders are established by various commercial, social, or technical mechanisms. Certain mechanisms allow interlocking with the stakeholders' business models while also recognising that they belong to a different value chain. Other mechanisms, however, result in drastic changes in the stakeholders' business models in order for them to fit better into the target ecosystem. For example, production planning together with the crop farms requires a drastic change in the business model of the farmers: from growing the same crops every year using fertilisers, to crop rotation and utilisation of digestate on the fields. Another mechanism is the mitigation of uncertainty regarding investments. This can be done, for example, by cooperating with the leasing or vehicle sales companies that would bear the risk of owning a vehicle. Finally, joint offering by the biogas distributor, i.e. the ecosystem integrator in this case, and vehicle dealers can make the core products of both actors more valuable when sold in combination.

As a result of developing the multitude of collaboration mechanisms (Table 5), the business model of the ecosystem integrator includes the following elements:

- Offering:
 - Differentiated pricing for different customer groups based on the biogas volumes they can consume

- Fixed-price and long-term contracts for high volume consumers
- Joint offerings with vehicle dealers
- Cost structure:
 - Different production costs depending on biomass utilised
 - Production planning with crop farms
- Cooperation:
 - Higher involvement of non-business actors, such as the city authorities
- Expansion:
 - Gradual investment into infrastructure enlargement

The five analysed sub-systems are the basis for making the ecosystem function. Three of them ensure biogas consumption (sub-systems 2, 3, and 4), and two ensure biomass supply (sub-systems 1 and 5). The business model of an ecosystem integrator acquires a certain level of modularity because these sub-systems can be treated as quasi-independent. This is not only useful for dealing with the multitude of stakeholders in the ecosystem, but also enables a strategy of gradual ‘construction’ for the ecosystem to be followed. The order of numbering the sub-systems (see Figure 10) is in line with the plan of how the ecosystem was to be built in the focal case. It started with securing the sewage sludge supply and the commitment of the large consumers, and then the integrator needs to make the first investment into the distribution infrastructure. Sales to smaller consumers, such as car users, as well as the construction of the relevant infrastructure starts later as a certain stability within the system is reached. This, in turn, requires securing additional sources of biomass and re-definition of the farmers’ business model in order to make the collaboration a win-win situation.

As a result of the differentiation in the ecosystem integrator’s offering, cost structure and revenue model, the business model acquires the *flexibility* necessary in order to integrate a complex system of actors that are traditionally outside of the renewable fuel production value chain. This appears to be crucial for establishing IS in general and the biofuel systems relying on it, since they require increased interdependency among stakeholders so as to be able to function as a whole. The collaboration mechanisms, i.e. joint production planning, joint offering and re-distribution of investment risk serve as tools to make the benefits of such increased dependency apparent and ensure commitment of ecosystem stakeholders. Together they connect various actors into a functioning business ecosystem as depicted in Figure 11.

The essence of the *boundary-spanning business model* that the ecosystem integrator builds is in abandoning the idea of a ‘one size fits all’ business model and attempting to align it with the business models and logics of other ecosystem participants. Taking a proactive role in shaping the ecosystem, the integrator in many cases might also need to shape the business models of others through various collaboration mechanisms. The reason for this is the need to

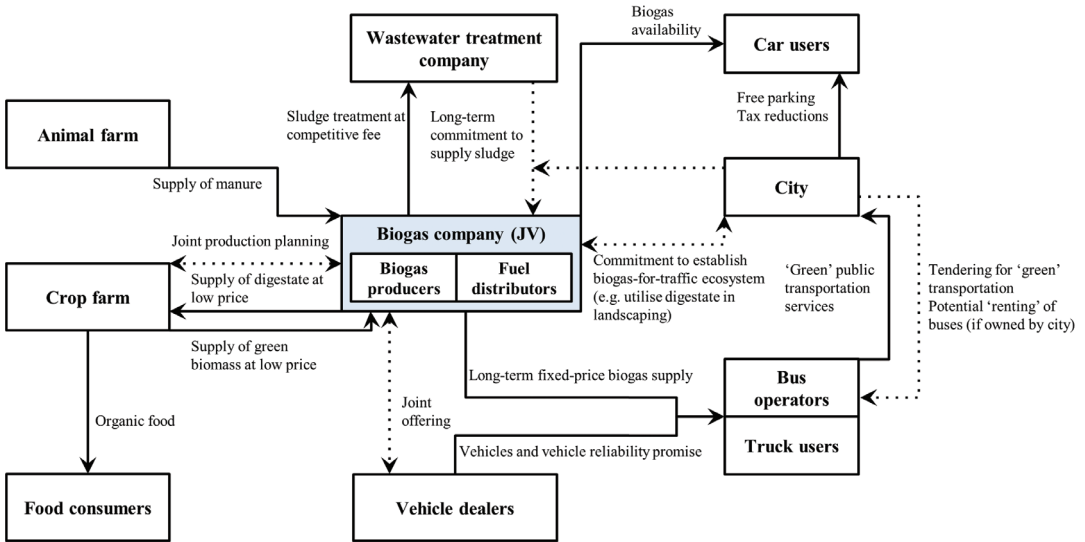


Figure 11. Representation of target business ecosystem through collaboration mechanisms among ecosystem actors.

reach system goals, which are often unachievable if current industry structures remain intact. Thus, through the boundary-spanning business model the ecosystem integrator attempts not only to shape the biogas-for-traffic industry, but also other industries that might need to be integrated into the ecosystem.

Though the business model of the ecosystem integrator becomes relatively complex due to diversification, it forms a good starting point for replicating the ecosystem elsewhere, since the range of capabilities is broad enough to adjust to other locations and business networks. Moreover, these same cooperation mechanisms and logic in establishing ecosystems can be re-applied in new locations. This is further discussed in section 4.5 and Paper IV.

4.5. Replication of industrial ecosystems (Paper IV)

RQ4: How industrial ecosystems can be replicated?

In answering the question of how industrial ecosystems for biogas-for-traffic solutions can be developed an important question is how they can be developed **on a regular basis**. The reason for this is the need to change industry structures to the ones based on circular economy on a wider scale. That is, in this research the aim was not only to develop knowledge on how to create a concrete industrial ecosystem in the focal location, but rather it was necessary to gain knowledge of how such industrial organisation can drive the whole biogas-for-traffic industry. In more practical terms, a biogas-for-traffic system, in order to be resilient and competitive, cannot be limited to one geographical location; vehicles generally drive between locations and a wide distribution network is required to expand biogas use as a fuel. Due to the reasons discussed in Chapter

Table 5. Characteristics and the development of sub-systems

Actor	Current business logic	Risks and uncertainties related to joining ecosystem	Change in the business model
Sub-system 1			
WWT company	Disposal of sludge by giving it to digestion as currently most feasible option	Other ways of sludge disposal might become more feasible in the future	Long-term commitment to supply sewage sludge
City			Commitment to use digestate in city parks for landscaping; influence WWT company's commitment to supply sewage sludge for biogas production
Integrator	Waste treatment business based on gate fees	Uncertainty about sewage sludge supply	Competitive gate fees for waste treatment Collaboration with the city to set favourable policy
Sub-system 5			
Biomass from farming to biogas			
Crop farm	Growing grasses to be used for biogas production is only feasible if the price is comparable to the price of currently grown crops Prices for fertilisers constantly increase	Need to align food growing with biogas production	Sustainable farming through crop rotation and digestate use Regular supply of biomass for biogas production
Animal farm	Manure is either used as fertiliser or is disposed of when critical limits are reached		Supply of manure for biogas production as a side-business at competitive price
Integrator	Green biomass is too expensive as a source for biogas production	If demand for biogas increases, there is a need to utilise materials other than sewage sludge The price for green biomass is too high to keep production costs feasible	Purchase of grass at relatively low price and/or collection at own costs Provision of digestate to the farmers

Actor	Current business logic	Risks and uncertainties related to joining ecosystem	Change in the business model
Sub-system 2	Biogas for public transportation		
Bus operators	Dependency on city tenders Fuel is a significant operational cost Drive locally and in predictable manner	Investment into gas-driven buses is larger than into diesel buses Uncertainty about biogas technology: maintenance costs and reliability Uncertainty about fuel: price and availability of biogas Second-hand risk of owning gas buses	Switch of fleet to gas-driven buses completely or partly Possible: only operation of buses without owning them (the city owns them in this case)
City	Subsidies to unprofitable bus operators Political pressure for 'greening' public transportation	Uncertainty about reliability of transportation based on biogas Uncertainty about transportation price (biogas price and maintenance costs are unclear)	Tendering for 'green' transportation Higher support for local biogas ecosystem Possible: ownership of buses and tendering only for their operation
Bus dealers	Gas-driven buses are not sold in the focal municipality due to the absence of fuel	Investment into gas bus maintenance infrastructure is feasible only if large number of buses is serviced, i.e. is sold in the first place	Sales of buses together with maintenance agreement, leasing option and long-term fuel guarantee from the biogas distributor
Integrator		Investment into distribution infrastructure will not be recouped if high enough consumption volumes are not ensured	Long-term contracts for biogas supply at fixed price
Sub-system 3	Biogas for truck operators		
Truck operators	Fuel is a significant operational cost Green image is important Drive locally but can transfer vehicles to other cities where they operate	Investment into gas-driven trucks is larger than into diesel trucks Uncertainty about biogas technology: maintenance costs and reliability Uncertainty about fuel: price and availability of biogas Second-hand risk of owning gas trucks Limitations of operating buses to the locations where gas is available	Switch of fleet to gas-driven trucks completely or partly Possible: charging more for the 'green service'

Actor	Current business logic	Risks and uncertainties related to joining ecosystem	Change in the business model
Truck dealers	Gas-driven trucks are not sold in the focal municipality due to the absence of fuel	Investment into gas truck maintenance infrastructure is feasible only if large number of trucks is serviced, i.e. is sold in the first place	Sales of trucks together with maintenance agreement, leasing option and long-term fuel guarantee from the biogas distributor
Integrator		Investment into distribution infrastructure will not be recouped if high enough consumption volumes are not ensured	Long-term contracts for biogas supply at fixed price Green fuel as part of the offering
Sub-system 4 <i>Biogas for car users</i>			
Car users	Low volumes of fuel is consumed as compared to bus and truck operators Developed refuelling infrastructure is needed	Slightly higher price for gas-driven cars as compared to diesel and gasoline Uncertainty about wide availability of gas, also in other cities	
City	When public transportation is utilising biogas, promotion of biogas can reduce fuel price	Resilience of the overall biogas industry which affects public transportation and other industries	Free parking, tax reductions in order to promote biogas usage in cars
Integrator		Larger distribution infrastructure needed to attract car users is expensive	Offering: competitive price for fuel, wider availability of fuel Collaboration with the city to set favourable policy Higher price for non-volume users

1, centralised mass-production of biogas and distribution similar to fossil fuels is not sustainable in all three dimensions. Thus, the establishment of many local industrial ecosystems was seen as the way to achieve economies of repetition (Davies and Brady, 2000), making biogas-for-traffic business feasible and competitive. That is, such organisation was seen as a sustainable option for overall business growth of a company producing and distributing biogas.

Since the physical and business environment in every new location is variable, it is not possible to have a universal solution that can be copied completely. However, utilising a modular approach and knowledge of how ecosystems can be integrated, it is possible to replicate industrial ecosystems and at the same time achieve economies of repetition. Such replication does not exclusively concern the technical part of the ecosystems, but is rather based on business replication so as to ensure business viability of the ecosystems to be developed.

Paper IV presents a replication framework based on this approach and demonstrates the logic of its application through assessing the potential of building biogas-for-traffic ecosystems in new locations by re-applying the knowledge developed in the original case, as discussed earlier. The latter includes the knowledge concerning the structure of ecosystems (Paper I), the collaboration mechanisms (Paper II), and the business model of an ecosystem integrator (Paper III). The original industrial ecosystem (Figure 10) serves as a vanguard case (Brady and Davies, 2004), i.e. as a model for replication.

The knowledge generated during the development of the vanguard case was applied in six other locations (named A-F) in order to identify how modules, interfaces, and sub-systems developed earlier can be reused, which adjustments are required, and how the business model of the integrating company changes. One of the new locations chosen was an urban location of a size comparable to the location in the vanguard case (city A), but situated at a considerable distance from it. The other locations (towns B-F) were smaller municipalities, which are fairly close to the original location.

In order to replicate the solution, it was necessary to create an analytical model explaining which elements can actually be reused or copied in the new location, and which new elements need to be introduced. Thus, the knowledge developed in the vanguard case was turned into a so-called *meta-ecosystem* (see Figure 12). The knowledge regarding more elementary 'building blocks' (as demonstrated in Paper I) and the interfaces between them (i.e. collaboration mechanisms discussed in Paper II and Paper III) evolved into a set of predefined sub-systems, which can serve as larger and distinct 'building blocks' for establishing a biogas-for-traffic system. Each of the sub-systems serves a specific function: biomass production, biogas distribution or biogas consumption. However, the logic of collaboration within these sub-systems has major differences in organisation and implications. For instance, utilisation of waste biomass for biogas production requires no changes to the business model of the 'supplier' and brings income to the biogas producer. In turn, utilisation of more valuable material such as hay requires a drastic change in the business model

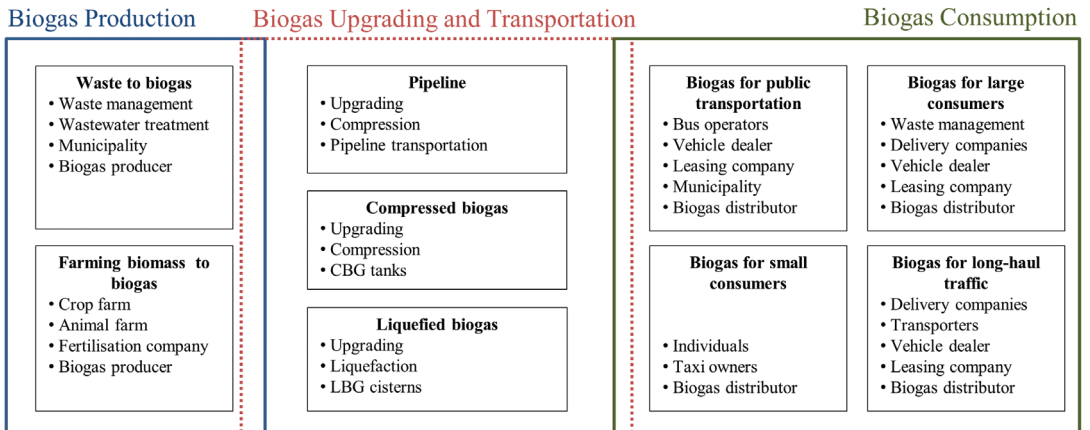


Figure 12. The structure of the meta-ecosystem.

of the supplier, i.e. the farm, and incurs costs to the biogas producer. Incentives for cooperation are, logically, different in various sub-systems. The collaboration logic within each of the sub-systems is described in detail in Table 6. The grouping into three functions also highlights the fact that the production value chain needs to be aligned by the ecosystem integrator, i.e. biogas production and consumption levels, as well as the distribution means, need to correspond.

The development of a meta-ecosystem helped achieve another important goal in replicating the *knowledge* regarding the vanguard case. The assessment whether a biogas-for-traffic solution would be a feasible business in the vanguard case required substantial calculations that addressed certain limitations, such as energy content and availability of various biomasses, biogas distribution distance, capacity of biogas upgrading, compression, liquefaction, and transportation equipment, etc. By enriching the meta-ecosystem with such knowledge, it was possible to define *feasibility criteria* for each sub-system, which could be used when planning a biogas-for-traffic system in a new location. For example, biogas production from sewage sludge has several measures for success that need to be taken into account. It is not only important to ensure that there is enough biomass, but also that the digestate can be utilised in a reasonable manner, and that there is enough dedicated space for its allocation. In the case of consumption sub-systems, it was crucial to ensure that the total net present value of an investment into a gas-fuelled vehicle would be high enough for the biogas consumers to switch to the biogas technology. This directly depends on the price of biogas offered, the number of vehicles in the fleet, the length of routes, and even the distance between a vehicle depot and a fuelling station. Consequently, the rich knowledge on how each sub-system functions allowed not only planning potential biomass sources and biogas consumers in a new location, but also assessing the viability of one or another model for cooperating with biomass suppliers or for reaching biogas consumers.

Table 6. Characteristics of the major sub-systems in the meta-ecosystem and the interfaces within them

Sub-system	Characteristics of the sub-system	Interfaces integrating the modules within the sub-systems
Waste to biogas	Biomass energy potential: low Biomass price: negative Value of the digestate: low Number of decision-makers: small	The biogas producer has to make a long-term contract for sewage sludge treatment in order to secure the biomass supply in the long term. Commitment by the city to utilise digestate for landscaping in city parks is crucial in order to utilise the low-value by-product.
Farming biomass to biogas	Biomass energy potential: high Biomass price: positive Value of the digestate: high Number of decision-makers: large	Establishment of efficient nutrient cycling by using a crop rotation technique to produce hay to be used for biogas production - along with utilising biogas digestate as organic fertiliser. The biogas producer is able to reduce cost associated with hay acquisition.
Pipeline	Biogas flow: constant Biogas volume: large Transportation distance: short Investments in infrastructure: high Operating costs: low	The feasibility of pipeline distribution is defined by the distance between the biogas production plant and the filling stations, construction costs, and returns from biogas sales. The integrator defines whether the volumes of sold biogas are large enough and constant enough in order to recoup investment into pipeline distribution.
Compressed biogas	Biogas flow: irregular Biogas volume: medium Transportation distance: medium Investments in infrastructure: low Operating costs: medium	Transportation of biogas as CBG is a feasible option if long-term contracts cannot be made with biogas consumers, and the biogas flow is small or difficult to predict. CBG is also an option for longer transportation distances.
Liquefied biogas	Biogas flow: irregular Biogas volume: large Transportation distance: long Investments in infrastructure: medium Operating costs: high	Transportation of biogas in the form of LBG can be feasible for the integrator if large enough volumes of biogas can be sold over long distances.
Biogas for public transportation	Consumption per vehicle: high Number of decision-makers: small Type of decision-making: public Required distribution network: small	The city government is involved in the environmental criteria as regards the tendering of public transportation so that biogas technology is preferred. A joint offering made by a vehicle dealer, a leasing company, and the biogas distributor which includes gas vehicles, fuel, and leasing would reduce the end user's uncertainty. The biogas distributor offers reduced prices and long-term contracts for bus operators as they are large consumers. Distribution is done through a larger depot.
Biogas for large local consumers	Consumption per vehicle: high Number of decision-makers: small Type of decision-making: private Required distribution network: small	Joint offering by the vehicle dealer, leasing company and biogas distributor, including gas vehicles, guaranteed fuel and leasing in order to reduce the end user's uncertainty. Biogas distributor offers reduced prices and long-term contracts for truck operators as large users. Only a limited distribution infrastructure is needed within the city.

Sub-system	Characteristics of the sub-system	Interfaces integrating the modules within the sub-systems
Biogas for small consumers	Consumption per vehicle: low Number of decision-makers: large Type of decision-making: private Required distribution network: large	The city offers free parking and other incentives for clean vehicle users. The integrator agrees with existing fuel distributors that they operate biogas distribution at their filling stations and makes invests in upgrading them.
Biogas for long-haul traffic	Consumption per vehicle: high Number of decision-makers: small Type of decision-making: private Required distribution network: large	The integrator can offer a joint offering together with vehicle dealers and leasing companies - such as in the case of large local consumers. However, there is a need to develop a larger distribution network. Focus on such consumers is a solution for locations where there is no potential for a local consumption which is large enough, but where the potential for biogas production is high.

Following the described logic, the locations A-F were assessed as potential areas for expanding the biogas-for-traffic business planned in the vanguard case. Location A appeared quite similar to the vanguard location in terms of large predictable consumption volumes as well as availability of both waste and farming biomass. Thus, most sub-systems could be copied business-wise without many adjustments. In other location, however, a different set of sub-systems appeared to be feasible. For example, in location D, where demand for biogas was difficult to predict, it was unreasonable to aim at local consumers with pipeline distribution of biogas. Instead, transportation in CBG tanks was more feasible due to a number of reasons: operation could be stopped if there was low or no demand for biogas, consumers in a neighbouring large town could be reached, and there was an opportunity to sell the vehicles for CBG transportation in case the local ecosystem fails.

The feasibility analysis of different biogas production, distribution and consumption sub-systems in the six locations showed that certain modules or even sub-systems could be copied completely, thereby reducing the adaptation costs. For example, long-term collaboration with vehicle dealers and leasing companies that operate not just locally but countrywide eliminates the respective costs and efforts, since potential biogas consumers can be approached with the same offering once it has been established. Similar collaboration can be initiated with existing fuel distributors and fertilisation companies. Other elements, such as new collaboration mechanisms, need to be created if old models cannot be used.

Two replication strategies were identified based on how much the vanguard case differed from a feasible solution in new location. It can be concluded that the original solution could be copied in location A, while locations B-F could serve as *satellite locations*, which were not feasible on their own, but only within the total biogas business. This is due to the fact that adequate biogas consumption volumes could be expected from the traffic passing *through* the loca-

tions, which in turn depended on establishing the network of biogas-for-traffic ecosystems in the country.

This leads to the conclusion that a larger business ecosystem (Gulati et al., 2012; Moore, 1996), which unlike industrial ecosystems is not bound to locations, has to be established. The integrator cannot serve all the functions in the ecosystems, but the support of relevant partners is crucial for the success of a biogas-for-traffic business. Consequently, the main capability of such a company is not the physical production or distribution of biofuel, but rather the ability to integrate the required stakeholders and adapt to local conditions by means of a flexible business model. Reuse of previous knowledge and constant learning are key to building such a business model. The process of the replication of biogas-for-traffic industrial ecosystems is visualised in Figure 13.

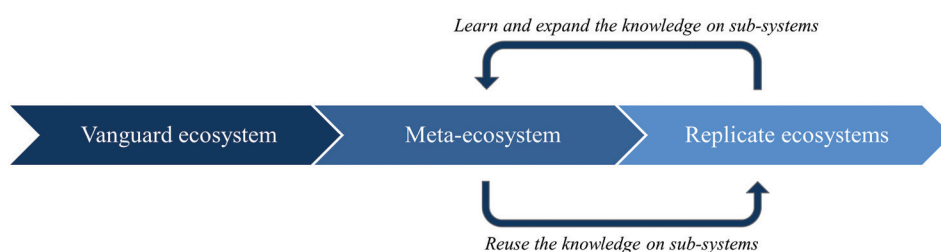


Figure 13. The process of ecosystem replication and knowledge reuse.

Such a replication approach was developed for a company that wants to develop biogas-for-traffic solution on a larger scale. Therefore, the vanguard ecosystem plays a crucial role: all the knowledge developed during its design and implementation can be structured into the knowledge about its elements, interconnections among them, and rules of recombination. Such a structural outlook should simultaneously embed business planning, and allow the creation of a sustainable business based on a number of distributed production and consumption units. The learning process, when new modules, interfaces, etc. are developed, is important in enhancing the replication capability of an ecosystem integrator.

4.6. Summary of research results

In solving the ill-defined research problem of how sustainable industrial ecosystems can be designed, the research questions evolved throughout the research process (as discussed in section 1.4). The answer to the sub-question of what the challenges in developing industrial ecosystems are was expected to inform the solution development as well as the questions asked. As a result, the following key issues were identified, which ultimately affected the way the main research question were to be answered:

- It was difficult for biogas as traffic fuel to compete with fossil fuels in the industry structure and business logic intended for fossil fuels.
- The development of an industrial ecosystem for biogas production and utilisation in transport required connecting traditionally separate industries (this is both a part of the definition and an implication of IS).
- Development of a biogas-for-traffic ecosystem required investments into infrastructure and vehicles, which inferred high uncertainty for the relevant ‘investing’ actors.
- Innovations in terms of industry structure, where business models of various actors need to undergo changes, normally face a resistance. However, such innovations also bring opportunities.

Given these challenges, the development of industrial ecosystems proved to be inseparable from larger business ecosystem restructuring. Thus, the first step in answering the main research question of how biogas-for-traffic *industrial ecosystems* can be designed was to realise that the *business logic* of biogas-for-traffic industry needs to correspond to the nature and goals of utilising the sustainable fuel. Therefore, the need to create a *business ecosystem* that entails the principles of IS and distributed energy production, as the basis for production, was identified. Taking the perspective of the implementer, business model innovation by the company that would develop such a business ecosystem – the ecosystem integrator – was seen as a means to achieve the required industry restructuring. This, in turn, required a strong focus on establishing collaboration among ecosystem stakeholders and development of multiple local industrial ecosystems as part of business growth.

As a result, the research problem was divided into two research foci – integration and replication – that ultimately merged within the topic of an *ecosystem integrator’s business model*. To summarise, the answers to the main research question of this study include the following:

- Proposition of a *business-driven approach* to developing industrial ecosystems, i.e. through business model innovation and consequent business ecosystem restructuring
- Articulation of the critical features of the *ecosystem integrator’s business model* and the logic of its development

Figure 14 depicts the process and results of answering the research questions.

To recap the main results developed in the four research papers, Paper I proposes considering businesses, rather than the technical units, as functional modules of the industrial ecosystem in order to address the business ecosystem level of their formation. Paper IV builds on this approach and develops it further by explicating the replication strategy, where more complex functional sub-systems act as building blocks for industrial ecosystems. Further, Paper IV dwells on the business model of the ecosystem integrator, which becomes

diversified and modular. Paper II explicates a number of collaboration mechanisms that are designed to establish collaboration between formerly unconnected industries. Paper III further discusses how the development of such collaboration mechanisms enables the boundary-spanning business model of the ecosystem integrator required for integrating a sustainable business ecosystem. The implications of these results are further discussed in Chapter 5.

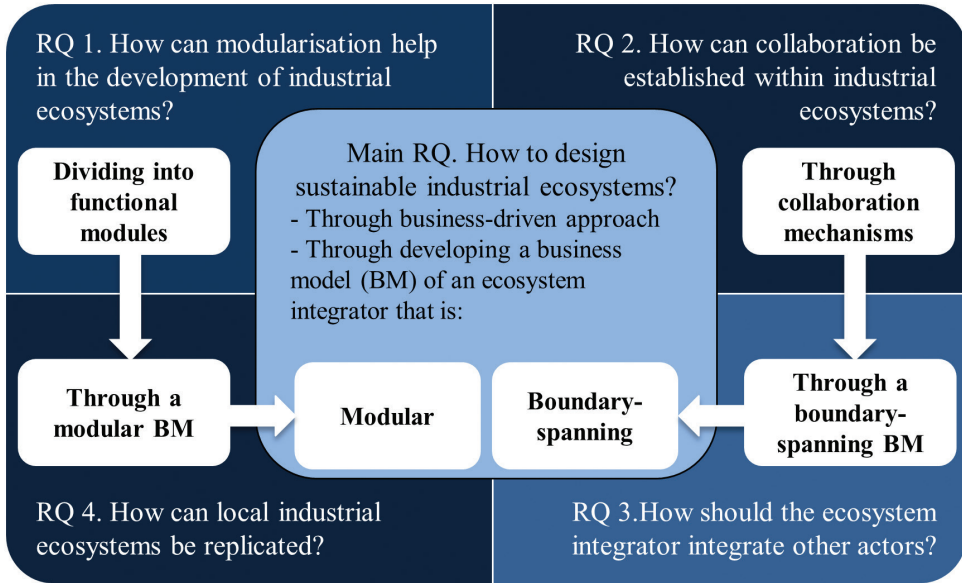


Figure 14. Answering the research questions.

5. DISCUSSION AND CONCLUSIONS

The purpose of this chapter is to synthesise and discuss the key findings of the four research papers. Then, theoretical, methodological, and managerial implications are explicated. Finally, the limitations of the research are discussed and topics for further research are proposed.

5.1. Key findings

The aim of this research was to study how to design sustainable industrial ecosystems, taking biogas-for-traffic industry as an example. The research was done within the paradigms of clinical research and DSR in order to generate actionable knowledge that is prescriptive and capable of driving change. The key findings of this research include the following:

1. The business-driven approach to designing industrial ecosystems, which is characterised by shaping business ecosystems through business model innovation, is based on:
 - o the need for a system integrator
 - o the characteristics of the target ecosystem which inform the change process
2. The characteristics and the process of developing the respective business model of the ecosystem integrator is built on:
 - o collaboration mechanisms in order to build a boundary-spanning business model
 - o functional modularisation and replication in order to base the business on a multitude of local production and consumption systems

As regards the first finding, it brings together the knowledge concerning business model innovation, and particularly open innovation (Amit and Zott, 2010; Chesbrough, 2003; 2006; Wikström et al., 2010), as well as industry reshaping through innovative business models (Brusoni et al., 2009; Jacobides et al., 2006, Normann and Ramírez, 1993)⁵ and industrial ecology (Chertow, 2000; Frosch

⁵ Similar to the notions of market effectuation (Sarasvathy and Dew, 2005) and ‘blue ocean strategy’ (Kim and Mauborgne, 2005)

and Gallopoulos 1989; Graedel and Allenby, 1995) in order to facilitate the development of the business dimension in industrial ecology. The business side of industrial ecosystems is known to be under-researched (Coelho and Ruth, 2006; Woodard, 2000). This fact was a prerequisite of this research, which was set to address this shortcoming by proposing how to make IS not only environmentally sound but also feasible. Business models are known as a vehicle for innovation (Amit and Zott, 2012; Casadesus-Masanell and Ricart, 2010; Magretta, 2002) and the role of business ecosystems in the success of any kind of innovation has been articulated (den Ouden, 2012; Geels, 2002; Gulati et al., 2012). However, these two perspectives have not been merged in order to prescribe how business model innovation should drive the ecosystem restructuring required for industrial renewal. The existing studies depicting how certain companies achieved this (Gulati et al., 2012) take a more observational and historical position. In contrast, the development of sustainable industry structures, such as those relying on IS, requires a forward-looking and creative approach.

At the same time, a number of studies in industrial ecology articulate the need for a wider outlook on industrial ecosystems, that is, not only focusing on the material energy exchanges, but also on the corresponding value exchanges and changes in the business models of the respective actors (Lombardi and Laybourn, 2012). Following this research agenda, in the business-driven approach proposed in this study industrial ecosystems as traditionally understood become only a structural element in a new biogas-for-traffic business ecosystem. Consequently, the development of industrial ecosystems is not seen as an end in itself, but more as an inspiration in the restructuring of the biogas-for-traffic industry towards a structure that is sustainable in all dimensions. This standpoint is the main reason, in this research, for focusing on the business model level and its effect on the target business ecosystem.

At this point, it is crucial to discuss whether the solution designed within this research is indeed sustainable. As argued in section 2.1, the initial design of the biogas-for-traffic industrial ecosystem adheres to the first three system conditions that address environmental sustainability. The essence of producing biogas from local organic waste and non-food biomass solution does not contribute to currently prevailing unsustainable practices. Moreover, considering the whole industrial ecosystem in focus, a larger contribution to preserving the natural capital can be recognised (see Table 7).

The fourth system condition, which regards the ability of society to meet their needs, is partly fulfilled by the fact that the basic needs of food production, transportation and safe waste management are fulfilled by this solution. Biogas production from non-food crops and waste does not undermine local food production capacity and, instead, contributes to more sustainable farming. Moreover, the fact that biogas production corresponds to a part of the local demand helps avoid the negative effects of biofuel mass-production. Thus, it can be concluded that the focal solution is environmentally and socially sustainable

Table 7. Compliance of the focal biogas-for-traffic solution with the first three system conditions of the FSSD⁶

	System condition 1	System condition 2	System condition 3
Content	In the sustainable society, Nature is not subject to systematically increasing concentrations of substances from the Earth's crust	In the sustainable society, Nature is not subject to systematically increasing concentrations of substances produced by society	In the sustainable society, Nature is not subject to systematically increasing degradation by physical means
Meaning	Society needs to eliminate the contributions to increasing concentrations of substances extracted from the Earth's crust	Society needs to stop increasing the concentrations of substances produced by society	Society needs to eliminate the contributions to the systematic physical degradation of nature and natural processes
Examples of unsustainable practices	Mining of heavy metals and fossil fuels	Increasing concentrations of plastics, dioxins, PCBs and DDT	Overharvesting forests, destroying habitat and overfishing
Compliance of the focal biogas-for-traffic solution with the condition	<ul style="list-style-type: none"> • Fossil fuel (diesel) is replaced with renewable fuel (biogas) in public transportation • The need for mining phosphorous to be used as a fertiliser is eliminated 	<ul style="list-style-type: none"> • Switch to ley farming allows eliminating the use of synthetic fertilisers, which otherwise cause nutrient runoff • Smart crop rotation can eliminate the need for pesticides and herbicides • Organic waste is 'recycled' and returned back to nature instead of degrading in a landfill 	<ul style="list-style-type: none"> • Ley farming and the use of digestate as a fertiliser allows the farmland to be restored in a natural way, eliminating the need to expand the farmland due to the erosion of old fields

by design. It is important to note, however, that following the FSSD framework, envisioning a sustainable future is only a starting point, while concrete *actions* and the assessment of their *impact* on sustainable development need to conclude the implementation of such a solution (Robèrt et al., 2002; The Natural Step, 2014). Thus, this 5-level framework is specifically useful for guiding changes in individual businesses. In the case central to this thesis, a whole industrial ecosystem is developed, which comprises a number of businesses. The focus is, therefore, not on altering operations of one company, but on building a

⁶ Based on Robèrt et al. (2002) and The Natural Step (2014)

business ecosystem that will fulfil transportation, waste management and food production needs within a new production mode based on industrial symbiosis, which proves to comply with the goals of sustainable development. Thus, the main *action* in regards to achieving the envisioned sustainable solution is to actually implement it.

At this stage, the economic sustainability of the solution, which is another part of the fourth system condition of the FSSD, becomes crucial. As discussed earlier, this thesis aimed at generating the knowledge of how *economic sustainability* can be embedded into the planning of industrial ecosystems. By addressing the feasibility of the biogas-for-traffic industrial ecosystems, an important goal was achieved: the *total* sustainability (environmental, social and economic) was embedded into the design of the solution. Indeed, profitability and viability of the overall system and its individual elements, i.e. businesses, defines whether a solution is able *in practice* to contribute to sustainable development. This is in line with the observation made by Arias-Maldonado (2013) that the extensive discussion and conceptual work around sustainable development has led to the situation when sustainability is seen as a state that can never be achieved.

In order to regain a practical meaning, the definition of a sustainable business, solution or production mode needs to encompass a number of pragmatic criteria:

- Potential to be implemented fast enough and to ‘gain momentum’
- Potential for utilising existing infrastructure and technical solutions if they do not contradict sustainability
- Profitability and viability without extensive external support
- Flexibility in terms of adjusting to changing business conditions

The design of the biogas-for-traffic solution discussed in this thesis was largely guided by these pragmatic rules. The reason for that is in the fact that while considerable attention has been paid to the environmental sustainability of various solutions, while their actual ‘*implementability*’ has been neglected. Definitely, these criteria need to be perceived only within the total sustainability vision (for example, as a part of the four system conditions defined in the FSSD) so as to avoid shifting the environmental burden from one industry or geographical area to another (Baumgartner and Korhonen, 2010).

As a result of embedding the economic dimension into planning industrial symbiosis, the business model of an ecosystem integrator became the key finding of this study. The business model is not discussed in detail in terms of its elements as is often done in business model studies (Afuah and Tucci, 2001; Chesbrough and Rosenbloom, 2000; Linder and Cantrell, 2000; Osterwalder, 2004; Teece, 2010). Instead, the main stress is put on the characteristics of such a business model that allow its ultimate goal to be reached, namely: integrating the business ecosystem required for successful develop-

ment of biogas-for-traffic industrial ecosystem. The two crucial characteristics of this business model are the ability to ‘span the boundaries’ through specially designed collaboration mechanisms and the capability to replicate industrial ecosystems thereby achieving economies of repetition (Davies and Brady, 2000). Such focus is largely effected by the features of the biogas-for-traffic industry as envisioned in this thesis.

Firstly, in the move from fossil-based industry structures to one compliant with the essence of bioenergy, fuel production needs to rely on local, distributed production and consumption systems. The old logic based on reducing costs through mass-production appears to be obsolete in a bioeconomy as well as a contradiction to the sustainability of biofuel. In order to make the production of biogas feasible, there is a need to make the distributed mode competitive. Bringing in the knowledge on replication (Davies and Brady, 2000; Jonsen and Foss, 2011; Winter and Szulanski, 2001) and functional modularisation (Hellström, 2005) allowed the replication strategy to be developed in order to extend the local industrial ecosystems based on an unconventional structural outlook on ecosystems (see section 4.2) and the reuse of *business* (rather than only technical) knowledge. As a result, the designed business model of the ecosystem integrator acquired the necessary flexibility in order to adjust to local conditions, and this played a crucial role in the IS (Baas, 2011).

Secondly, the question of collaboration within the business ecosystem appeared to be critical due to a number of reasons:

- Business ecosystem restructuring bears a large portion of uncertainty in terms of new investments and faces strong resistance as regards investments in an existing infrastructure that have already been made. This is in line with Geels’ (2002; 2005) observation that it is hard to break prevailing technological regimes and overcome a ‘cartel of fear’ situation when business actors are afraid to be the first to modify to a new regime and accordingly make new investments.
- Collaboration within industrial ecosystems is even more challenging given the fact that the industries that need to be integrated, e.g. farming, vehicle sales, waste management, biogas production, are not accustomed to working with each other (Desrochers, 2001). Although the proximity of the physical business actors can aid in integration, the varying and non-intersecting business logics can be integrated only if some of the actors alter their strategies. Here, the business model of the ecosystem integrator needs to be the most innovative and ‘proactive’ so as to make collaboration within the ecosystem sustainable and feasible. The business models of other ecosystem actors are also likely to change if proper collaboration mechanisms are developed.

It can be concluded that the increased interdependency among the ecosystem actors is able to generate both system benefits, i.e. benefits that are inac-

cessible for a separate element on its own (Simon, 1962), and high uncertainty, especially regarding investments. Since there is a need for both creating and capturing system value, identifying value drivers in each ecosystem member's individual business is a pre-requisite for establishing the ecosystem. However, there seemed to be barriers to exploiting these drivers. For this reason, collaboration mechanisms developed in this study are designed to address the uncertainty by sharing risks among the ecosystem stakeholders and to make the value drivers come into play through tighter integration of the activities of certain actors (e.g. joint production planning of the biogas producer and a farmer discussed in Paper II). The business model of the ecosystem integrator is also shaped through the development of collaboration mechanisms. These mechanisms function by reflecting and addressing the *system* value creation and capturing, so that the business model becomes boundary-spanning (Wikström et al., 2010; 2011).

Not only the notion of a modular and boundary-spanning business model for the ecosystem integrator can be identified as a result of this study, but also the process of its development, which is articulated in Papers III and IV. This process represents the *actionable knowledge* because the logics employed can be used to develop the business model of an ecosystem integrator for industries other than biogas-for-traffic, which face a similar need for restructuring. In that respect, companies operating in industries that require decentralisation can benefit from the replication strategy described in Paper IV. Companies that operate in industries requiring a large 'reshuffling' of the business ecosystem or the development of a new ecosystem, where the roles of various companies appear in a new light, would benefit from considering and building a boundary-spanning business model with the help of collaboration mechanisms. These mechanisms, however, would be largely context-dependent, although the essence would remain the same: reducing actors' uncertainty regarding investments and structural changes, as well as increased integration of the actors' business operations.

Thus, the detailed design of the business model of an ecosystem integrator serves as a normative model of how to develop the biogas-for-traffic ecosystem from a company perspective. This is due to the fact that the stipulations given at the business model level are able to drive companies into action, whereas description and discussion of the benefits of industrial ecosystems and renewed business ecosystems are not able to prescribe the way the change can be achieved.

5.2. Theoretical contribution

The research presented in this thesis attempts to bring together two research fields: industrial ecology and management studies. In addition, the methodological approach employed in the study provides new insights into both areas. As a result, the thesis contributes to these research fields in the following way:

- **Industrial ecology:** the thesis addresses the call for more studies on the business level of industrial ecosystem formation (Korhonen, 2004; Lombardi and Laybourn, 2012) and particularly the implications for the business models of the involved actors. A normative model for business-driven development of industrial ecosystems is proposed in addition to the policy-makers' level approaches proposed earlier (Agarwal, 2011; Baas, 2011; Boons and Howard-Grenville, 2009; Elabras Veiga and Magrini, 2009).
- **Management studies:** the thesis specifically addresses the topic of system innovation (Ceschin, 2013; Gaziulusoy et al., 2013; Geels, 2005) and innovation in business ecosystems (Gulati et al., 2012; Moore, 1996; den Ouden, 2012) by explicating how business model innovation (Amit and Zott, 2012; Chesbrough, 2007; 2010) can be the trigger for achieving more sustainable industry structures, such as those relying on IS.

5.2.1. Contribution to research on development of industrial ecosystems

The first contribution of this thesis is that it develops and explicates the business-driven approach to the creation of industrial ecosystems. This approach is expected to complement the middle-out approach proposed earlier (Costa and Ferrão, 2010; Mirata et al., 2005). The replication approach proposed in this paper is argued to be a sustainable and feasible strategy for organising businesses based on distributed production and IS. The novelty of this approach is the fact that the primary driver for building new industrial ecosystems is not the pursuit of optimising material and energy flows, and thereby costs, in one location, but rather the development of the business ecosystem around the integrating company along the lines of IS. Thus, inter-organisational learning becomes a valuable capability, inaccessible to companies that try to replicate industrial ecosystems based on intra-organisational learning. Such learning leads to the development of collaboration mechanisms with the various types of stakeholders who have a similarity in their business models and logics.

Although common ideas and trends appear in the literature on planned industrial ecosystems (Agarwal, 2011; Baas, 2011; Behera et al., 2012; Elabras Veiga and Magrini, 2009), the perspective taken on these issues is fairly different in this study. For instance, the study by Behera et al. (2012: p. 106) proposes that risk management within IS networks and the rules for developing the required business models need to be discussed among companies willing to establish IS. However, since the paper addresses the perspective of policy-makers or outside facilitators, any detailed explanation of how risks can be mitigated and what the business models should be like is insufficient. Moreover, such approaches are often based on a presumed willingness of companies to participate in industrial ecosystems, which has been criticised (Lombardi et al., 2012). The approach proposed in this study builds on a business model innovation strategy that strives to engage ecosystem actors even if not originally interested in collaboration or initially opposed to it. This is achieved by business reasoning and designing ways

to develop win-win situations or 'lock-in', i.e. through collaboration mechanisms. Moreover, the business model level is addressed in this study, further complementing the policy-makers' perspective proposed in previous studies.

The need to address business models in greener industry structures, and IS in particular, has been formulated in previous writings on the topic (Korhonen et al., 2004; Posch et al., 2011). It has also been noted that industrial ecology became too focused on the material side of IS. Thus, the challenging task was to embed and elaborate the business side of industrial ecosystems relying only on the research in industrial ecology. The research on business ecosystems (den Ouden, 2012; Gulati et al., 2012; Moore, 1996) was helpful not only due to the similarity of the terms, but also due to its close connection with the formation of new industry structures based on IS. The present research is therefore seen as contributing to merging knowledge on business and industrial ecosystems in the pursuit of developing more sustainable industry structures. By doing so, it was possible to move the focus of industrial ecology from highly context-dependent, unique, and trust-based exchanges to a more transactional model for a biogas industry relying on the principles of IS.

5.2.2. Contribution to research on system innovation

As a second contribution, the present research developed the notion of *actionable knowledge* for making system innovations (Ceschin, 2013; Gaziulusoy et al., 2013; Geels, 2005) through a business model innovation (Amit and Zott, 2012; Chesbrough, 2007; 2010) in the context of a biofuel industry that needs to depend on material flow exchanges as envisioned by IS. Current studies on business ecosystems often focus on, for example, the ICT sector, where material flows play a secondary role, while knowledge integration is the key (Osterwalder, 2004). The biogas-for-traffic industry serves as a specific example of business that requires a business ecosystem change in order to succeed and which also involves large investments, infrastructure development, and material flow planning. Moreover, since this business ecosystem is designed to be based on IS and to be able to compete with prevailing unsustainable fossil fuel-based industry logics, this change can rightfully be ascribed to be an eco-innovation.

It has been noted that many 'eco-innovations' are the result of isolated companies striving to optimise their production and operations thereby remaining at an incremental level (Larson, 2000; Wagner and Llerena, 2011), as well as leading to 'sub-optimising' and to completely ignoring the systemic perspective (Boons, 2009). System and radical innovation has been argued to be a better way to bring new, greener technologies into operation through restructuring unsustainable modes of production (Ceschin, 2013). The challenge was seen in the need of a larger system-wide effort (Boons et al., 2013) and an extensive reconnection of industries as traditionally defined (Moore, 1996). Although the need for system innovation has been articulated, the prescriptive knowledge on how a company, which strives to deliver such innovations in the highly chal-

lenging and unusual context of IS, can shape the business ecosystem still remained to be developed. Moreover, the potential of a company to conceive a systemic perspective of the industry and, based on that, *lead* the change was still to be explored. For example, Geels (2005) argues that companies are not able to affect the larger landscape of their business, but rather they can affect the business ecosystems only when ‘windows of opportunity’ appear. In this thesis, a different perspective is taken, namely that while certain opportunities, such as the rising price of fossil fuels, are able to foster the use of biogas as traffic fuel, the biogas company, i.e. the ecosystem integrator, *needs*, in fact, to shape the business landscape (Ceschin, 2013) through innovating its own business model (Amit and Zott, 2010; Chesbrough, 2010).

Recently, there have been attempts to connect the theory on business models with eco-innovation (Boons and Leudeke-Freund, 2013; Boons and Wagner, 2009). It has been noted that companies striving to make radical system innovations need to shift the innovation effort from the products or processes they control to the larger systems of which they are part. Moreover, they need to actively construct the appropriate business model and engage the relevant stakeholders in such a development (Boons et al., 2013). Boons and Leudeke-Freund (2013) defined how business model innovation could contribute to eco-innovation:

“Business model change on the organizational level is about the implementation of alternative paradigms other than the neoclassical economic worldview that shape the culture, structure and routines of organizations and thus change the way of doing business towards sustainable development; a sustainable business model is the aggregate of these diverse organizational aspects.”

Boons and Leudeke-Freund, 2013: p. 15

Thus, the thesis contributes to the field of system innovation, and system eco-innovation in particular, by articulating the design of an ecosystem integrator’s business model that would enable large industry restructuring to become more symbiotic, reciprocal, and distributed. The ability to understand other ecosystem actors’ business models and incentivise them based on that knowledge (Turner and Simister, 2001) serves as the basis for the integrator’s business model, which will ‘lock in’ the stakeholders in a sustainable manner. The ecosystem integrator connects to other actors’ business models not only through vision development and knowledge sharing (as proposed e.g. by Baas, 2011) but also through concrete business mechanisms, i.e. the collaboration mechanisms described in Papers II and III. As a result, the structure of the new business ecosystem is in a way reflected in the business model of the integrator, that is, the business model becomes boundary-spanning (Wikström et al., 2011).

The prescriptive knowledge on the structure of such business models and the process of their development are crucial for eco-innovation, because in the current business world, where industry structures and connections are shaped by companies, the change towards more sustainable industry structures is more

likely to succeed if initiated at company level. Business model innovation is therefore seen as the tool for creating business ecosystems that are more resilient and more sustainable in all three dimensions.

5.3. Methodological contribution

The methodological approach employed in this study is seen as a methodological contribution to management studies, especially when connected to industrial ecology and sustainability studies. In the pursuit of sustainability, it is impossible to derive the ways of cleaner production and better management practices from the past. As discussed earlier, mass-production logics lead to overproduction, overconsumption, and depletion of resources (Mirata et al., 2005). At the same time, taking into account the fact that management practices tend to change very rapidly in the constantly innovating business world, post-observation studies may become out-dated before they are accessible for practitioners. Thus, there is a need to use existing explanatory knowledge to envision new industry structures and develop relevant models for enabling them. This, in turn, requires a forward-looking approach, such as implied by the design mode of research (Romme, 2003; van Aken, 2004; van Aken and Romme, 2009). Moreover, in search for more sustainable industry structures, post-observation is able to only provide the knowledge of current situation and therefore the model of ‘what should *not* be done’. This can be informative as in the case of the four system conditions discussed in section 2.1, which reflect the flaws of the basic design in our society. However, such knowledge cannot inform the design of the alternative solutions on its own. The need for Mode 2 research, which would produce practical or actionable knowledge able to drive change, has been articulated earlier (Nowotny et al., 2001).

With regard to management studies in general, it is true that the design mode is not among the widely accepted approaches to generating knowledge. The explanation for this might be due to the fact that testing is the key factor in design. Therefore, to do DSR, there is a need for an access to companies and other relevant actors in order to validate and test the generated management knowledge against practitioners (van Aken and Romme, 2009), which in practice may be considerably challenging and risky. This, in turn, necessitates the requirement for collaborative research practices when a DSR approach is employed. By combining clinical research and DSR, it was possible to develop a comprehensive method that is both constructive and collaborative. Based on the pragmatic research paradigm, such an approach fulfils the need for producing knowledge that is actionable, grounded in a research context, yet transferable to other similar contexts.

Another contribution of the methodology developed in this thesis is its ability to provide a multi-disciplinary outlook on the research problem. Industrial ecologists have stressed the need for employing the knowledge from many research domains in order to develop more sustainable industries and futures (Lombardi

and Laybourn, 2012; Posch et al., 2011). As Côté and Cohen-Rosenthal (1998: p. 185) noted some time ago, the analysis of IS is difficult because it stretches across disciplinary sets that rarely interact, such as, industrial ecology, economic or business frameworks, and the networks of businesses and the surrounding community. By employing ANT and methods derived from it, such as controversy mapping (Latour, 1987; Markowski, 2008), it was possible to take into account human and non-human actors with different natures. That is, when certain technical, political, regulative, social, or business factors appeared to be critical for ecosystem development, they were taken into account and measures to manage them were adopted as the solution was developed. This allowed the technical, business, and social side of IS to be considered in order to achieve a solution sustainable in the environmental, economic, and social dimensions.

As a result, the research methodology developed in this thesis can be characterised by being:

- Constructive
- Future-oriented
- Collaborative
- Multi-disciplinary

The characteristics of the research methodology allowed the production of knowledge capable of driving change (Cohglan, 2009; Schein, 1995) and taking a holistic perspective on the biogas-for-traffic industry. The proof of actionability and thereby validity of the produced knowledge in a *pragmatic sense* (Putnam, 1987) has been discussed in section 3.4. It is important to note that the exact combination of clinical research (Schein, 1993) and DSR (Romme, 2003) can be seen as yet another methodological contribution. Such a merger allowed the action research cycle to be enacted, i.e. the validation of research results and involvement of the research problem, and enabled the creative mode required for solving a clinical problem. As a result, actionable knowledge, which could drive change on the focal industry but also (importantly) was transferable to similar contexts, was produced. Such a methodological approach is expected to address the shortcomings that are often the cause of criticism against action research, i.e. considerable action, but little research. The ability to generalise the knowledge produced within this study is discussed further in section 5.5.

5.4. Managerial implications

The foremost managerial implications of this research include the content and the development process of the business model of an ecosystem integrator. In addition to the companies directly producing and/or distributing biogas, many other companies can benefit from attempting to make their operations more sustainable and gain advantages by becoming an ecosystem integrator in their own industry, or a newly developed one.

Firstly, in order to utilise the models proposed in this thesis, the way companies perceive their business needs to be enhanced. This means that the idea of boundary-spanning (Wikström et al., 2010) or open (Chesbrough, 2003; 2010) business models needs to be expanded from direct value chains to the level of industrial ecosystems, where traditionally disconnected (Chertow, 2000) or diverse (Lombardi and Laybourn, 2012) value chains may be interlinked within an IS. This is especially relevant for businesses that are based on industrial ecosystem thinking, such as biofuel production. However, other industries that require a renewal of industry structure, even without this restructuring being based on IS, are expected to benefit from the following recommendations:

- It is crucial to realise that any company's success is dependent on the business and socio-technical ecosystem around it. Moreover, that an ecosystem usually spans the boundaries of traditionally defined industries (in line with Moore, 1996), and therefore is challenging to embrace using old business logics and models.
- To implement a system eco-innovation a company needs to become an ecosystem integrator, if not overtly then in terms of its role within that ecosystem. This, in turn, requires a boundary-spanning business model that will facilitate the increased cooperation and positive interdependency with the relevant stakeholders.
- The integrator needs to develop capabilities to cover larger parts of the overall system (Gulati et al., 2012) and to focus on the business benefits of all stakeholders or, in general terms, understand the underlying business ecosystem. By taking into account the business model and the inherent logic of the key stakeholders, a business model that ensures their cooperation can be designed and implemented.
- A boundary-spanning business model can be built by considering and addressing the most critical issues in the stakeholders' own business models when radical and system innovations are implemented. These implementations would include operation and capital costs, investment risks, and market uncertainty. Such a business model can be built based on the business mechanisms that reduce the named uncertainties, and which will create value and cash flows among the ecosystem actors (as demonstrated in Paper II).
- Since system innovation requires significant industry restructuring, it is often neither possible nor reasonable for a company to accomplish it on its own. Collaboration and open discussion is an important part of building the business model for an ecosystem integrator.

The other logic and process presented in this study – that of replication – can be utilised by companies striving to develop multiple industrial ecosystems that have to be tailored to fit local conditions. Principally, this is applicable to many biofuel businesses and renewable energy businesses. Any

industry that is inclined to the distributed mode of production can benefit from such an approach. The key recommendations to such companies include the following:

- The business ecosystem needs to be perceived as a combination of a number of functional sub-systems, which have their own business logic. That is, instead of seeing the firm's business as part of a traditional value chain characterised by a supply and demand side, more sophisticated and comprehensive sub-systems need to be identified.
- Upon understanding the different logics within various sub-systems the integrating company can develop business knowledge on how collaboration can be established with one or another stakeholder and consider which other stakeholders will be required. Such knowledge can be reflected in collaboration mechanisms, which can become more transactional as they are repeated over time.
- When replicating industrial ecosystems in new locations this business knowledge can be reused. Moreover, the feasibility, both technical and economic, of various sub-systems needs to be assessed in each case. Based on this, customised industrial ecosystems can be developed through combining the most suitable sub-systems.
- A crucial part of such a replication process is the learning process, which allows continuous improvement and expansion to be made of the knowledge on various sub-systems, their characteristics and mechanisms required for integration.

5.5. Limitations and generalisability

The solutions and the business model developed in this thesis are case and location specific. However, more generic implications can be transferrable to other industries and cases. These include the strategies, processes, mind-sets, and logics explicated in Papers I-IV and the extended summary. As expected from actionable knowledge, it is fairly concrete and detailed, but can be directly taken into practice by practitioners. Nevertheless, apart from the more generic conclusions presented in this study (section 5.1), such actionable knowledge can also be transferred to new contexts. In order to do this it is necessary to follow a similar logic and define the challenges pertinent to the focal industry and the need for its restructuring. If the pre-requisites are similar to this focal case, similar strategies of partitioning the ecosystem and developing the business model of the ecosystem integrator can be utilised. This process is described as decontextualisation and recontextualisation, which depicts the way knowledge produced in design, can be transferred to new contexts. In this respect, the methodological approach utilised in this study is also important, because the explorative, constructive, and collaborative research strategy is required to develop similar actionable knowledge in new settings.

Moreover, the solution developed for the focal biogas-for-traffic business is not the only possible one. The replication framework presented in Paper IV, demonstrates how the business knowledge on industrial ecosystems can be re-used and adjusted to new locations. Thus, the actionable knowledge produced in this thesis is expected to be generalisable not in a positivistic meaning, but in a pragmatic sense – it is transferrable or transportable to similar situations (Schön, 1995). Since testing of the knowledge was an important part of developing the solution to the research problem, the way new actors, testing the knowledge in new contexts, accept these facts will influence the resultant solution in a new problematic situation. The effect of validation is an inseparable part of producing knowledge that is actionable.

These findings are expected to be useful for other types of industry restructuring. Many sectors are presently stagnating, and very often this is because they are not able to embed new technologies and solutions into the old infrastructures and business models. Taking biogas as an example, it is technically identical to natural gas after upgrading, however, the old models of production and sales did not correspond to the nature of the fuel and to the major goals that can be achieved by utilising it. Although in this thesis IS is discussed, the larger picture presents the collision of the old consumption and mass-production based economy with the need for a more sustainable, agile and collaborative one. The need for such fundamental changes can be expected in many other industries, such as, for example, the energy industry in general.

One of the limitations of this thesis that the effect of competition with other bioenergy solutions is not explicated. In the focal case, there was no competition for biomass, since other local bioenergy businesses utilised a different type of biomass. On the other hand, competition for consumers with fossil fuel industry was in the core of research. Competition with other biofuels for consumers follows the same logic as in the case of fossil fuels, because the business models and production modes in traffic biofuel industry are currently blue-printed from the fossil fuel industry. In the future, however, it is possible that a more localised mode of production of other biofuels would compete with the proposed way of producing and utilising biogas.

Taking the perspective of environmental sustainability, biogas is seen as a sustainable replacement of fossil fuels in transportation. Definitely, there are other biofuel technologies available, including biodiesel and bioethanol. These technologies could potentially be seen as competing. However, biogas proves to outperform these options in terms of, for example, emissions: aldehydes are not emitted when burning biogas, unlike bioethanol or biodiesel (Hammel-Smith et al., 2002). Moreover, utilisation of bioethanol and biodiesel in heavy transportation is bound to create a significant demand for certain types of sugar- or oil-containing biomass. Biogas, on the opposite, can be produced of a variety of waste biomass, which is more abundantly available. Finally, the benefits of producing biogas within an industrial ecosystem as envisioned in this thesis have

been explicated earlier. If biogas production can fulfil the local fuel demand in a sustainable manner and fast enough, then it is unreasonable to speculate whether other biofuel options could be a better solution at a later stage.

5.6. Recommendations for future research

Deeper research into collaboration mechanisms would be interesting in order to derive a more comprehensive typology of the ways collaboration can be established given the various challenges in industry restructuring. That is because the mechanisms are expected to differ, depending on which risks cause uncertainty, and how deep integration the collaboration requires.

Following the previous sub-chapter, it would be interesting to apply the developed knowledge to other industries. This can be done following the same research process, i.e. trying to change the ecosystem while also observing it. Although the context would be different, and certain ideas such as replication might be less relevant, the ideas of boundary-spanning business models and collaboration mechanisms for restructuring industries are likely to be applicable.

Although this study only concerns one specific type of industrial ecosystem and IS, there is reason to believe that the same approach is feasible for other types of industrial ecosystems as well. In the pursuit of ‘producing more at a lower price’, which was required for fast economic development, mass production-based industrial systems have developed beyond an optimal position (Mirata et al., 2005). Thus, in many areas of business activity there is a tendency to switch to smaller scale, distributed, and localised production and consumption systems in order to comply with sustainability goals. The most apparent examples of industries that can benefit from such restructuring include the production of other biofuels and bioenergy. In these cases, the replication approach would be able to aid in increasing the feasibility and viability of new industry architectures based on sustainable distributed production through economies of repetition. Further research on the applicability of the replication approach for developing other types of industrial ecosystems is needed in order to validate and improve it further. Moreover, the potential and benefits of utilising this approach for restructuring other industries, not directly based on the principles of IS, is still to be explored.

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Appendix 1

Communications in project A

Actor	Representative	Time	Certain major discussed topics
Local municipal authority	Directors and officers at Environmental Protection Unit and Regional Public Transport Unit	Continuous throughout the project	<ul style="list-style-type: none"> - requirements for local public transportation: economic, environmental and social - decision-making in terms of renewal of public transportation fleet - agenda for environmental improvements in the municipality and potential of biogas-for-traffic business to benefit it
Food safety authority	Senior Inspector (Fertilisers)	Feb 2011	<ul style="list-style-type: none"> - benefits of organic fertilisers compared to synthetic fertilisers - regulations and guidelines in the field of organic fertiliser production - potential for ley farming connected to biogas production
Agricultural Research Institute	Senior Research Scientist	Feb 2011	<ul style="list-style-type: none"> - benefits and challenges in utilising digestate from biogas production as bio-fertiliser - infrastructural and logistical pre-requisites for utilising digestate in farming - control of fertiliser production process and quality by the authority
	Researcher	Mar 2011	<ul style="list-style-type: none"> - biomass availability for biofuel production in the focal country - infrastructural and logistical pre-requisites for establishing biogas-for-traffic business - feasibility assessment of biogas production from various biomasses
Fuel distribution company	Head of Business Unit (2 persons)	Mar 2011	<ul style="list-style-type: none"> - options for biogas distribution - political and legislative environment and its impact on biogas industry - infrastructure development and renewal required for biogas-for-traffic business
Vehicle dealer #1	Product Manager (Passenger cars)	Feb 2011	<ul style="list-style-type: none"> - challenges in sales of gas-driven vehicles - technical and economic characteristics of gas-driven vehicles - feasibility of investment into gas-driven vehicles and factors driving it - competition with other technologies - infrastructure development required for introducing gas-driven vehicles in the focal context
	Sales Director (Buses)	Mar 2011	
	Sales Director (Trucks)	Mar 2011	
Vehicle dealer #2	Country Manager, Sales (Buses)	Apr 2011	<ul style="list-style-type: none"> - challenges in sales of gas-driven vehicles - technical and economic characteristics of gas-driven vehicles - feasibility of investment into gas-driven vehicles and factors driving it - competition with other technologies - infrastructure development required for introducing gas-driven vehicles in the focal context

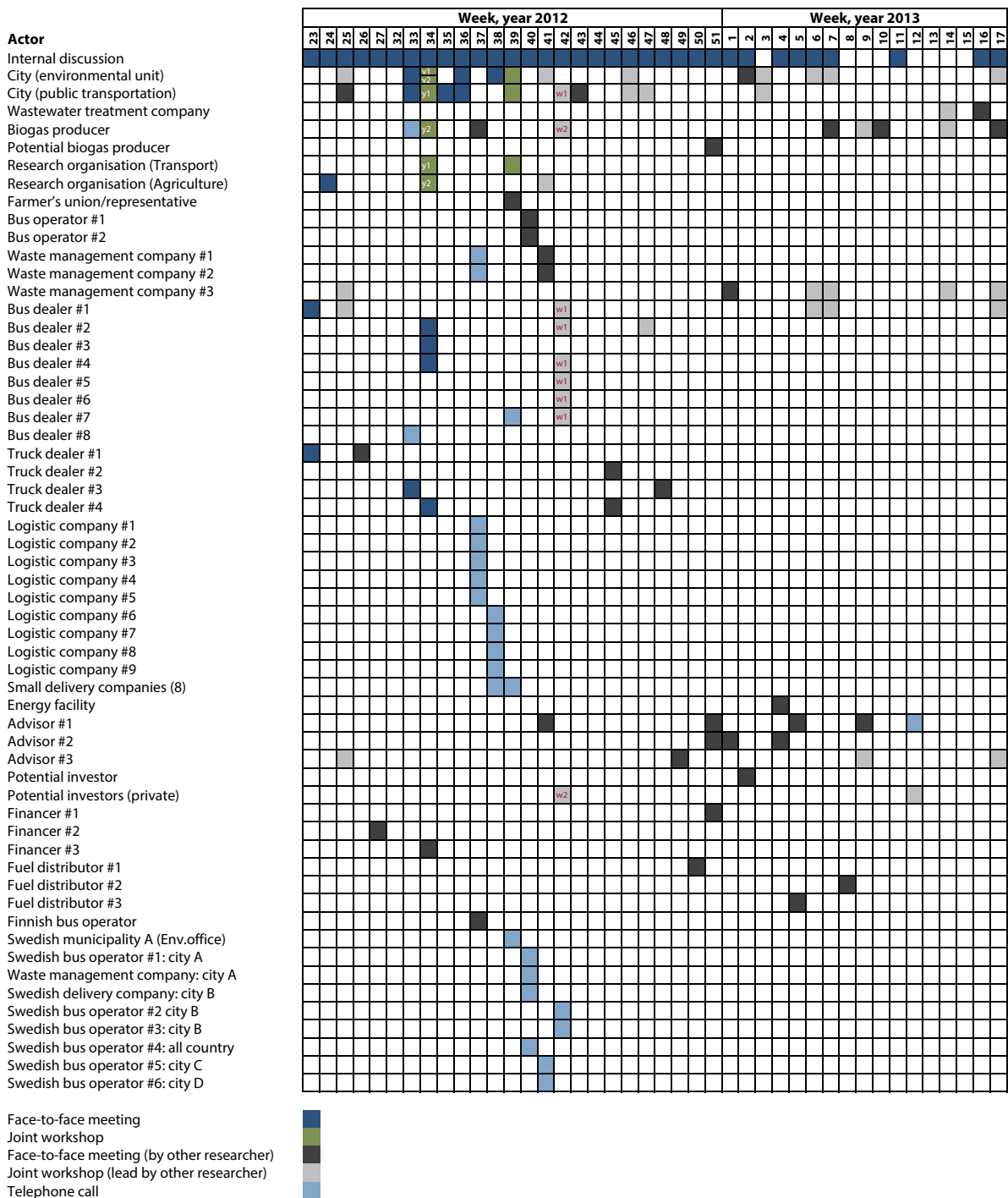
Appendix 2

Communications in project B

Actor	Representative	Time	Certain major discussed topics
Farming company	Managing Director	Dec 2010	<ul style="list-style-type: none"> - potential for innovative bioeconomic solutions in farming - challenges related to environmental, social and economic sustainability of such solutions and farming in general
Biofuel producer	Director (Business Development Unit)	Dec 2010	<ul style="list-style-type: none"> - business model and earning logic of company's biofuel business - situation on biofuel market and potential for development - current and missing actors in the biofuel industry ecosystem - potential cooperation between various biofuel production and renewable energy production industries
Vehicle dealer	Sales Director	Dec 2010	<ul style="list-style-type: none"> - availability of gas-driven vehicles on the market - challenges in selling gas-driven vehicles in the focal country - technological peculiarities of biogas-fuelled vehicles and their effect on end-customer - required capabilities of vehicle suppliers in biogas system: existing and missing
Supplier of energy solutions	Business Development Manager	Dec 2010	<ul style="list-style-type: none"> - role of technology providers in biofuel business - opportunities for technological innovations in the field of bioenergy and current developments - need for political and legislative support for bioenergy industry - roles of various actors in bioenergy ecosystem
Design and consulting in biogas technology	Managing Director	Dec 2010	<ul style="list-style-type: none"> - potential for technological innovations in biogas business - potential for exporting knowledge on biogas business
Bioenergy and bio-fertiliser producer	Managing Director	Dec 2010	<ul style="list-style-type: none"> - challenges, opportunities and threats to biogas business - stakeholders in biogas business: required and existing
Fuel distribution company	Vice President (2 persons)	Jan 2011	<ul style="list-style-type: none"> - future of gas, biogas, and LNG industries, their interconnections - political and legislative environment and its impact on biogas industry - challenges and decision-making in switching to biogas technology - infrastructure development and renewal required for biogas-for-traffic business - challenges in biogas-for-traffic business pertinent to the focal country
Environmental research institution	Director of a business unit	Jan 2011	<ul style="list-style-type: none"> - general challenges to bioeconomy - policy-making and legislative aspects of bioeconomy development - production of biofuels locally and from local materials

Actor	Representative	Time	Certain major discussed topics
Food safety authority	Senior officer (Feed control)	Feb 2011	<ul style="list-style-type: none"> - potential and obstacles in connecting biofuel and feed production - safety regulations and control in animal feed production - animal feed production as side-business and concrete examples
	Director (Plant production)	Feb 2011	<ul style="list-style-type: none"> - utilisation of biofuel production side-flows for fertilisation: risks, regulations, benefits - regulative structure and tools in plant production control - current successful and unsuccessful examples of symbiosis between biofuel production and plant growing

Appendix 3 Communications in project C



II PART II
PAPERS

Anastasia Tsvetkova

Designing sustainable industrial ecosystems: The case of a biogas-for-traffic solution

Current industrial organisation requires a transition to more sustainable modes of fulfilling society needs. There is a clear trend towards functional economy and dematerialisation, which calls for the switch from owning to delivering functionality. Still, energy and therefore fuels need to be produced in order to procure, for example, transportation services. Biofuels are able to overcome the problems of emissions and scarcity associated with fossil fuels if produced and utilised in a sustainable manner. In this thesis, the metaphor of industrial symbiosis, which implies material and energy cycling among industries, serves as an inspiration for a circular and distributed way of organising biofuel production. A biogas-for-traffic solution is utilised as an empirical case in this study. The key challenge of making such an industrial organisation economically sustainable is addressed by proposing replication and business model innovation strategies that allow creating a resilient business ecosystem around biofuel business.

