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## **An Ecosystem Analysis of Industrial Symbiosis Development in Aalborg, Denmark**

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Master Thesis

"An Ecosystem Analysis of  
Industrial Symbiosis Development  
in Aalborg, Denmark"

Andrea Milani  
Leonie Schlüter

Supervisor:  
Allan Næs Gjerding



AALBORG UNIVERSITET



# AALBORG UNIVERSITY

## STUDENT REPORT

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**Abstract:**

Our economic system needs to undergo an unprecedented rate of change to stop environmental degradation and to assure sustainable access to natural resources in the future. This means moving away from our current linear economy and its 'take-make-dispose' mantra and building an economy that is circular and waste-free by design.

The concept of '*Industrial Symbiosis*' (IS) is seen as a key enabling factor for this circular economy. In these industrial networks that resemble biological symbioses, wastes of one company become a resource for another, which leads to economic and environmental benefits.

The present paper sheds light upon drivers, facilitators, and barriers to IS through analyzing its development in Aalborg, Denmark. By investigating the historical development of selected synergies in the area, it facilitates a better understanding of the local conditions that influence the IS development. Supplemented by an analysis of non-IS synergies and third parties involved in these, barriers to IS are identified. Patterns in development factors are analyzed according to the type of synergies and companies involved in them, and a holistic picture of the positions of different ecosystem actors are drawn. The analysis found that in general the incentive for IS was based on the individual project's commercial value. The incentive structure of Aalborg Symbiosis is thus primarily economically driven. In many cases, however, it was fully or partly motivated by certain regulatory and technological developments, and often only made possible through high organizational capabilities.

On the other hand, also economic factors were the most encountered barrier that impeded IS development. Technical difficulties have been shown to hinder the process to some extent, but regulatory and organizational obstacles played a minor role.

The most important facilitator of Aalborg Symbiosis was Aalborg Kommune, who took the position of a coordinator, particularly in the development of exchanges of heat. Overall, in the establishment of synergies of energy, a much higher presence of barriers but also facilitators could be noticed, compared to the exchanges of materials and liquids.

*"We don't inherit the earth from our ancestors, we borrow it from our children."*

**Chief Seattle**

# Preface

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## Context

This paper was completed within the context of the M.Sc. program Innovation, Knowledge, and Entrepreneurial Dynamics at the Department of Economics and Business Administration at Aalborg University. It represents the authors' master thesis.

The present research is, at the same time, part of the ongoing project "Miljø++", which is a joint endeavour of Aalborg University, Aalborg Havn, and The House of Energy, and an EU-supported project with the vision of the port of Aalborg and its surrounding being an incubator for sustainable solutions and business models in the environmental area of the region.

## Acknowledgements

Writing this thesis would not have been possible without the support of several parties. Therefore, we would like to thank everyone that supported us within this process and made the research of this topic possible.

First, we would like to thank our brilliant supervisors. Our academic supervisor Allan Næs Gjerding provided us with excellent guidance and constant feedback. Without his insights, expertise, and support this research would not have been possible. Also, Lucia Mortensen, our supervisor from the Miljø++ and Aalborg Havn side, supported us all along the way. Not only did she provide us with valuable practical advice, but also pointed us in interesting academic directions.

Our deepest gratitude should, moreover, be expressed to Jesper Raakjær who allowed us to conduct the research in collaboration with the port of Aalborg and whose constant support encouraged us. A special appreciation also goes to the people involved in the Miljø++ project who supported our work.

Moreover, our sincere thanks and gratitude go to all the professional experts that participated within this study. Through being open for interviews they have provided valuable insights for our study through their experiences with our topic of investigation.

Of course, we also would like to thank the other professors in our faculty of the University of Aalborg, for providing us with the proper knowledge and tools to conduct this research.

Finally, we would like to thank our friends and families for their on-going support and encouragement. All these years of study and this thesis would not have been possible without them. Thank you.

# Summary

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Global use of natural resources has accelerated during the past decade and emissions and waste have grown in line with increasing extraction of natural resources. And not only the extraction of resources has become an issue, also their disposal is increasingly problematic: Today, around 1,3 billion tonnes of solid waste are generated by the world cities per year.

Our economic system needs to undergo an unprecedented rate of change, not only to stop environmental degradation but also to assure affordable, equitable, and environmentally sustainable access to natural resources in the future. This means moving away from our current linear economy and its 'take-make-dispose' mantra and building an economy that is circular and waste-free by design.

The concept of '*Industrial Symbiosis*' is seen as a key enabling factor for this circular economy. In these industrial networks that resemble biological symbioses, wastes or by-products of one company become a resource for another. Industrial systems mimic the way biological systems function by engaging traditionally separate industries in a collective approach involving physical exchange of materials, energy, water, and by-products. This approach leads to environmental savings as it often diverts waste from landfill and reduces carbon emissions. On a company level, Industrial Symbiosis can reduce raw material needs and waste disposal costs and allows businesses to create new revenue from residues and byproducts.

The present paper aims at shedding light on the complex interplay of drivers, facilitators, and barriers to Industrial Symbiosis through analyzing its development in Aalborg, Denmark. By investigating the historical development of selected industrial synergies in the area, this paper facilitates a better understanding of the local conditions that influence the development of Industrial Symbiosis. It views industrial symbiosis from an ecosystemic perspective and identifies important stakeholders that act as facilitators to the process in the area.

While motivations behind the establishment of the different synergies in Aalborg vary, our analysis showed that in general the incentive was based on the individual project's commercial value. The incentive structure of Aalborg Symbiosis is thus primarily economically driven. In many cases, however, it was fully or partly motivated by certain regulatory and technological development, and often only made possible through high organizational capabilities.

On the other hand, economic factors were also the most encountered barrier that impeded industrial symbiosis development. Technical difficulties have been shown to hinder the process to some extent, but regulatory and organizational obstacles played a minor role.

The most important facilitator of Aalborg Symbiosis was Aalborg Kommune, who took the position of a coordinator, particularly in the development of exchanges of heat. Overall, in the establishment of synergies of energy, a much higher presence of barriers but also facilitators could be noticed, compared to the exchanges of materials and liquids.

Within the ecosystem that facilitates IS development in Aalborg, several key players were identified. While Aalborg Kommune and the sustainability network NBEN act as coordinators, on the industry side it became apparent that cement producer Aalborg Portland and power plant Nordjyllandsværket take the role of industrial anchors of the IS. An institutional anchor is represented by Aalborg University. Moreover, the port managing company Aalborg Havn and the utility company Aalborg Forsyning positioned themselves as relational brokers within the system. Joint projects between actors have been identified as major accelerators for the development of industrial symbiosis in Aalborg, with a past NBEN project and a current project between University and Aalborg Havn called Miljø++ fulfilling orchestrator- and relational broker-like roles in the system.

# Structure

The present paper starts by immersing the reader in a problem analysis (**Part I**) centered around resource scarcity, environmental degradation, economic reasons, and solutions (**CH. 1**). Here, it emphasizes on resource management necessities on a city-level (**CH. 2**), before the problem analysis is narrowed down to the local challenges of the city of Aalborg in Denmark (**CH. 2.3**).

The problem analysis is followed by the introduction of the research objective (**Part II**).

Subsequently, the literature review builds the academic foundations of the present work (**Part III**). Within it issues of our current linear economic system and solution of a so called circular economy are laid out (**CH. 4**). Then, we, as authors, focus on one specific concept and tool of the circular economy: Industrial Symbiosis (**CH. 5**). We define what industrial symbiosis means, how it can be differentiated from other kinds of waste exchanges, and we take an in-depth look into what factors promote or hinder its development.

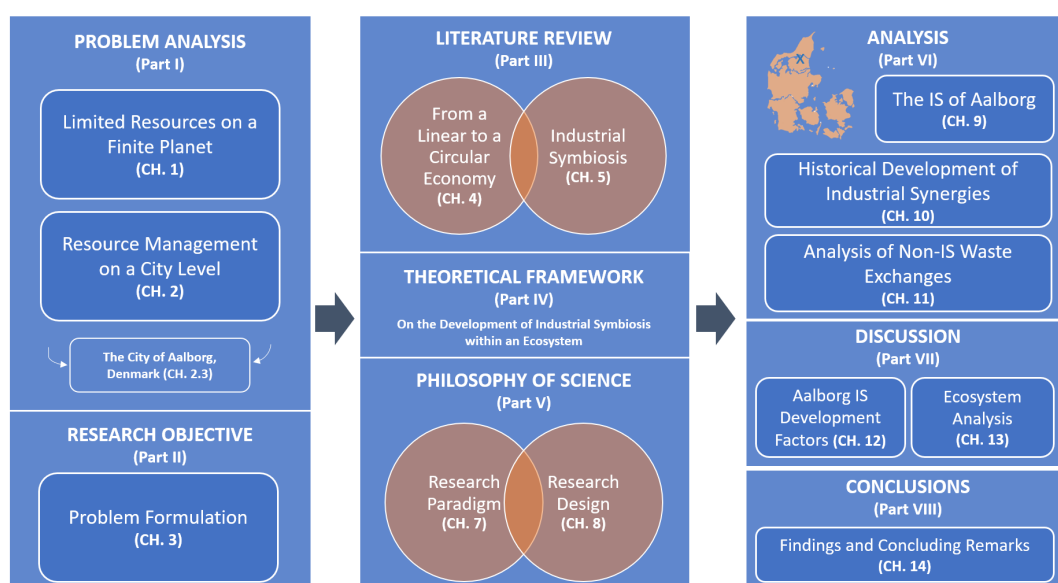
Based on this elaboration, we create a theoretical framework (**Part IV**) that will provide the basis of the following analysis. This framework views IS development from an ecosystemic perspective and units the complex factors that influence it.

In the part concerning the philosophy of science (**Part V**), first the underlying assumptions and perspectives of the work are going to be presented (**CH. 7**), before an overview and justification of the used methods and techniques, the scope, and data collection and analysis, takes place (**CH. 8**).

The analysis (**Part VI**) starts with a comprehensive visualization of the Industrial Symbiosis of Aalborg (**CH. 9**). Then, the historic development of selected synergies within it is being analyzed (**CH. 10**). We supplement this by an analysis of non-IS synergies and third parties involved in these (**CH. 11**).

In the next part (**Part VII**), we identify patterns of development factors according to the types of synergies and companies active in them (**CH. 12**) and draw a holistic picture of the positions of different actors within this ecosystem (**CH. 13**).

Concluding, an overview of the paper's finding and implications is going to be presented (**Part VIII**).



**Figure 1:** Structure of the present paper  
Authors' elaboration

# Reading Guide

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**Figures and tables** Figures and tables are numbered according to the particular chapter they are placed in. The first figure in chapter three is therefore assigned with figure number 3.1 and the second 3.2 etc. Descriptive captions for tables are found below tables and figures.

**References** Throughout the thesis all references are listed by the end of the thesis report, in the bibliography. A statement is referred by (Surname, year). If more than one reference from the same year has the same author, these are listed under the same author's name and the repetition is indicated by a dash. The citation of direct quotations includes the page number, if retrieved from a numbered article or book, and an indication of the minute, if taken from a personal, recorded conversation or interview. This reference refers to the bibliography where books are referred by author, title, publisher, edition and year while websites are referred by author, title, year, URL and time of last visit. Interviews and personal communication is referred by interviewee name, interviewers, and year. Technical papers are referred by author, title and year.

**Glossary** Short descriptions of key theoretical concepts of this work are included in the glossary at the end of the paper. Explanations of acronyms and abbreviations encountered in this paper can be found before the glossary.

**Appendix** Due to the scope of data collection and the large amount of interviews conducted, transcripts and summaries are not included in the appendix of this paper, but can however be provided upon request. Interview recordings have been included in the digital submission of this paper.



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## **Part I**

# **Problem Analysis**

# Chapter | 1

## Limited Resources on a Finite Planet

The following chapter shall give an overview of the environmental issues related to our current economic system and highlight the role of materials within it. It introduces two solutions to the issues of resource depletion and growing scarcity and, subsequently, addresses the role of successful management of resources as a prerequisite for both potential solution concepts.

### 1.1 The Issue of Resource Depletion

In this section, the worldwide problem of resource scarcity and depletion is going to be laid out.

Concern is growing about assuring affordable, equitable, and environmentally sustainable access to natural resources and it is well founded. Global use of natural resources has accelerated during the past decade and emissions and waste have grown in line with growing extraction of natural resources (United Nations Department of Economic and Social Affairs, 2017).

Resources are getting increasingly scarce. Materials like antimony, lead, zinc, silver, gold, and copper, for instance, are rapidly declining (Stouthuysen, 2010).

A particularly pressing issue is also the depletion of fossil fuel reserves, which our economy currently runs on. For coal production, we could have about 115 years remaining (Ritchie, 2017a), while global oil and natural gas resources are expected to last only around 50 more years to provide energy (Ruz, 2011).

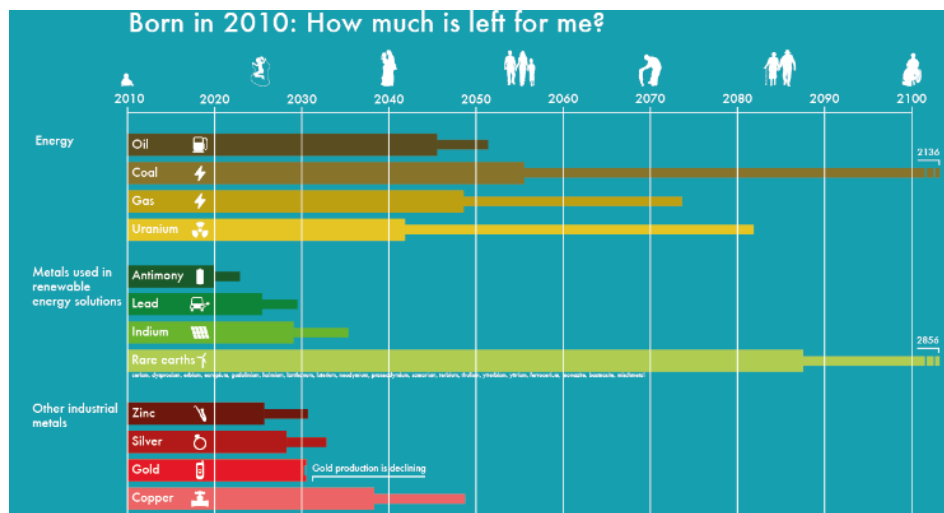


Figure 1.1: Resource depletion  
Derived from Plan C (2011)

Also, the move to bio-based materials is not without significant trade-offs and complications, even on the level of sustainability impacts. Their production generally requires the use of scarce agricultural land. Currently agriculture occupies around half of the plant-habitable surface of the planet (Ritchie, 2017b) and more space is required as food production will need to increase by an estimated 25-70% by 2050 (Hunter et al., 2017). Additionally, putting pressure on scarce agricultural land often results in the expansion of farmlands into previously uncultivated areas, which is the primary driver of tropical deforestation and its associated biodiversity loss (Kennedy et al., 2016). Out of all the planetary boundaries that humans have far transgressed,



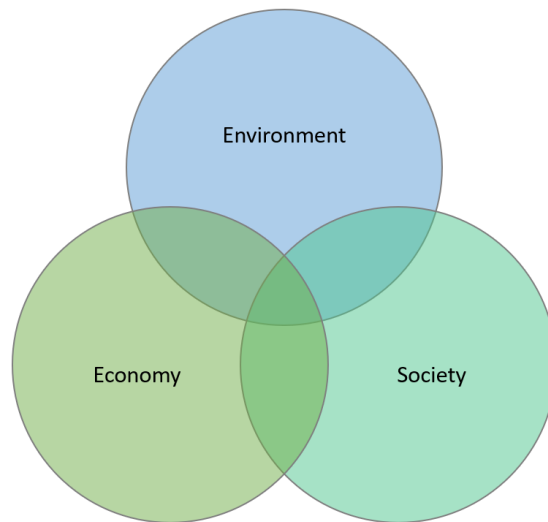
biodiversity is widely believed to be the most severely and irreversibly impacted (Steffen et al., 2015).

And not only the extraction of resources represents an issue, also their disposal becomes increasingly problematic: Today, around 1,3 billion tonnes of solid waste are generated by the world cities per year. By 2025, this volume is expected to increase to 2,2 billion tonnes (Hoorweg and Bhada-Tata, 2012).

## 1.2 The Issue of Infinite Growth

*Growth, a very fundamental aim of today's world economy, puts tremendous pressure on the resources we talked about in the previous section. How this is related is going to be discussed in the following.*

Currently environmental, societal, and economic spheres are viewed as separate entities that influence each other. For example, even though the design of our current economic system is based on an increasing resource throughput and often negative environmental impacts (Ghisellini, Cialani, and Ulgiati, 2016), economic growth is generally believed to also be related to an improved well-being of a country's society (Schulte, 2018).

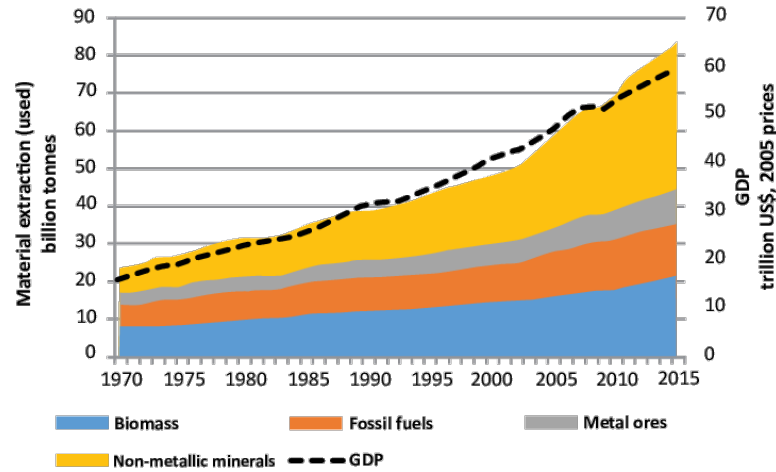


**Figure 1.2:** Current relationship between economy, environment, and society  
Authors' own elaboration based on Schulte (2018)

The overarching theme in this setup and the top priority of nations right now is continuous economic growth. The importance of this target not least became clear when the leaders of the world's most powerful countries met 2014 in Brisbane, Australia, and pledged to grow their economies by 2,1% (Sheet, 2014). The primary measure used nowadays to measure the economic growth of a country is the GDP (Gross domestic product). It takes into account a country's entire economic output and is defined as the market value of all the total goods and services produced in the country for the given period of time (Callen, 2008).

While for decades, GDP has been the measure of all things, many are arguing now that it is not an appropriate indicator to assess the health of our economies and especially the quality of life of the people living in them (Chainey, 2016). Changes in the GDP per capita are often used to measure whether the average citizen in a country is better or worse off, but it does not actually capture factors important to general well-being. Activities like donations to charity, gifts, work citizens do at home like raising children, growing their own food, cleaning, or reparations, are not accounted for in the GDP. Another class-book example of how GDP fails at measuring well-being is the one of a car accident. While it is undoubtedly an incident that decreases the quality of life, resulting medical care, car repair work, new cars purchased, and legal fees will be included in and contribute to the growth of GDP (Zorach, 2010). Similar to this, increased output of GDP may also come at the cost of other factors such as a reduction of leisure time.

It also might involve environmental damage, the depletion of nonrenewable natural resources or other external costs, such as noise (Callen, 2008). Besides inclusive growth and well-being also environmental outcomes are not being accounted for. This is critically judged as in our current economy growth is directly linked to negative environmental impacts like emissions and intensified raw material use (see figure 1.3).



**Figure 1.3:** Global material extraction in billion tons, and global GDP in trillion US \$  
 Derived from Ekins et al. (2016), Material extraction data from (United Nations Department of Economic and Social Affairs, 2017), GDP data from UNSD (2015)

This increasing material use has to be viewed critically, as the planet can only provide for limited resource extraction. The idea that we are living on a finite planet that will eventually reach limits in terms of resource provision is, however, not new. It can actually be traced back to Malthus (1809), (1973) who first raised these kinds of concerns regarding the global food supply. Scientific frameworks relating environmental degradation to critical system limits, according to Sabag Muñoz and Gladek (2017, p.20), then began to appear in greater number from the 1950s onward. Some of the most prominent frameworks relate to safe minimum standards as a supplement to cost-benefit analysis (Crowards, 1998), limits to growth in terms of resource abstraction and emissions clean-up (Meadows et al., 1972), the general carrying capacity of the planet (Daily and Ehrlich, 1992), and to defining guardrails in order to exclude intolerable climate change impacts (Bruckner et al., 2003). The most broadly studied and utilized one is, however, The Planetary Boundaries (PBs) framework. Introduced by the Stockholm Resilience Centre (SRC) in 2009, and defines the safe operating space within our planet. The framework is based on the idea that crossing certain biophysical thresholds could have disastrous consequences for humanity. These planetary boundaries include climate change; rate of biodiversity loss (terrestrial and marine); interference with the nitrogen and phosphorus cycles; stratospheric ozone depletion; ocean acidification; global freshwater use; change in land use; chemical pollution; and atmospheric aerosol loading. Currently, three of nine interlinked planetary boundaries have already been overstepped (Rockström et al., 2009). Even though material extraction is not directly stated as a boundary, abstraction as well as processing of materials is directly linked to many or all of these boundaries. Two examples are the combustion of extracted fossil fuels which contributes to climate change and the extraction of renewable materials like biomass which leads to a change in land use and is the main driver of biodiversity loss.

### 1.2.1 Solution 1: Eco-Environmental Decoupling

*Opinions on how to solve these issues are widely different. One solution to growing resource abstraction is the one of eco-environmental decoupling.*

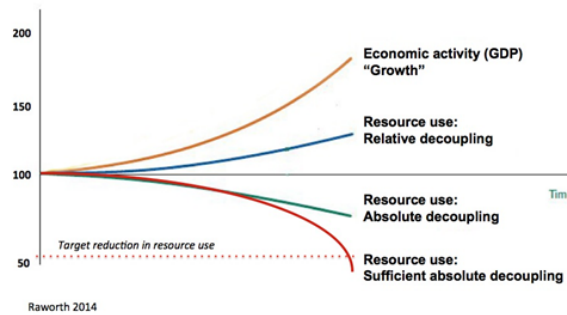
A popular solution to solve the conflict between economic, societal, and environmental aims is still based on the idea that these three main parts are to be viewed as separate entities influencing each other like displayed in figure 1.2. To release pressure of our environmental systems and to stay within these planetary boundaries, mainstream economists suggest decoupling economic growth from environmental impacts like material ab-

straction, GHG emitting, or energy consumption.

Growing the economy while lowering environmental impacts of it can theoretically be achieved through two types of decoupling: **Relative and absolute decoupling**.

**Relative decoupling** means decreasing the environmental impact that one unit of economic output, or GDP, has. In the period 1990–2009, the world economy achieved this “relative decoupling” of economic growth from resource use: global income or GDP increased faster than the amount of used materials (Vienna University of Economics and Business, 2017). Also, energy intensities declined significantly during the last three decades, across the OECD countries in particular. The same is true of material intensities more generally (Jackson and Senker, 2011). However, while the resource impact per unit of GDP growth might decline, it is possible that the absolute resource extraction is still rising. This is currently the case, with material extraction, energy use, and GHG emissions increasing worldwide (*Trends in Global CO<sub>2</sub> and Total Greenhouse Gas Emissions*; Tverberg, 2012; Behrens et al., 2007).

For decoupling to offer a way out of the dilemma of growth and to safe-guard our natural assets to satisfy our future needs, an absolute stagnation or decrease of material use has to occur. Resource efficiencies must increase at least as fast as economic output does and must continue to improve as the economy grows. Only like this, absolute resource impacts can stay within the safe operating space of our planet.



**Figure 1.4:** Decoupling resource use from economic growth  
Derived from Raworth (2014)

The concept of decoupling is embedded in much of today’s economic thinking. We mean **absolute decoupling** if we are talking about buzzword ‘green growth’ for instance - growth, that does not lead to any additional negative environmental impacts. Also, the idea is relevant for most SDGs and thus included in the UN’s aims for sustainable development. Explicitly it is mentioned in SDG target 8.4 and strongly related to SDG 12 (Ensure sustainable consumption and production patterns) (Sabag Muñoz and Gladek, 2017).

It is questionable however, if it is really possible for a strategy of ‘growth with decoupling’ to deliver ever-increasing incomes for a world of nine billion people and yet remain within ecological limits.

One issue is that evidence for absolute decoupling is hard to find. The best that can be observed – in only a couple of countries – is a stabilization in resource requirements, not a decrease. Another issue is that these stabilized material consumption numbers might not mean that the additional growth happened without additional resource abstraction. Especially modern developed countries have tended to move progressively away from domestic manufacturing and like this might only have outsourced the material-intensive productions and extractions to other countries.

History also provides little support for the plausibility of decoupling as a sufficient solution to the dilemma of growth. Historical data series like Material Flow Accounting from EUROSTAT (Eurostat, 2018) demonstrates that no absolute decoupling has happened yet.

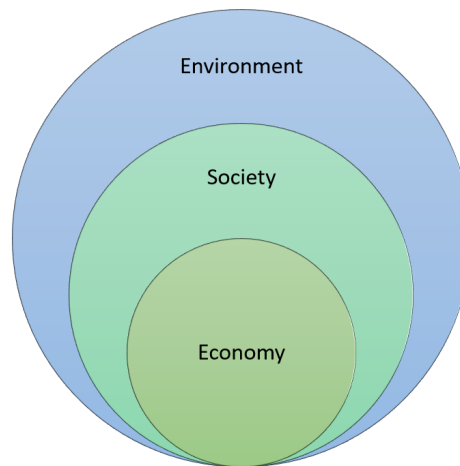
*Could a continued massive technological shift and significant policy effort really achieve enough decoupling to allow for continued economic growth?*

### 1.2.2 Solution 2: Steady-State Economy

*As this critical question remains unanswered, alternative models to our growth-dependent economy have been developed. A much more disruptive solution approach is the vision of a steady-state economy.*

Advocates of the ‘**no-growth**’ or ‘**post-growth**’ movement want to abandon the relentless call of perpetual economic growth and instead move towards a so-called ‘**steady-state**’ economy.

The term was coined by Daly (1991), who combined limits-to-growth arguments, theories of welfare economics, ecological principles, and the philosophy of sustainable development (Bowen, 2012). He described the economy as a subsystem of the biosphere and the issue of our current set-up derived from the fact that while the economy, the subsystem, is geared for growth, the overall system, namely the biosphere, does not grow, and remains the same size. As the economy grows it thus encroaches upon the biosphere. Because we lose ecosystem services as we expand the size of our economy, he described environmental damage as a fundamental opportunity cost of economic growth Daly (1991). The alternative solution of a steady-state economy thus involves a completely new way of thinking, as figure 1.5 illustrates.



**Figure 1.5:** Relationship between economy, environment, and society in the steady-state economy  
Authors' own elaboration based on Schulte (2018)

The economy and society in which it is developed and conducted are viewed as subsystems of the environment of our planet.

In this alternative solution, the economic subsystem would be a steady state economy which is a comparable stable economy without GDP growth as the prioritized aim. This kind of economic concept is now reaching increasing attention in light of the destructive impacts of our current growth-addiction, but has been considered by economists for decades.

It already starts with Smith and McCulloch (1838). While Adam Smith stated that trading in open markets leads to production of the right quantities of commodities, division of labor, increasing wages, and an upward spiral of economic growth, he also recognized a limit to this growth. He predicted that in the long run, population growth would push wages down, natural resources would become increasingly scarce, and division of labor would approach the limits of its effectiveness (Smith and McCulloch, 1838; Center for the Advancement of the Steady State Economy, 2011).

Also the most influential economist of the twentieth century, John Maynard Keynes, envisioned a day when society could focus on ends (like happiness and well-being) rather than means (like economic growth and in-

dividual profit) (Keynes, 1937; Keynes, 2010; Center for the Advancement of the Steady State Economy, 2011). Another economic model related to this idea was developed by Schumacher and was grounded in sufficiency of consumption, opportunities for people to participate in useful and fulfilling work, and vibrant community life marked by peace and cooperative endeavors (Schumacher and Schumacher, 1993).

An important aspect that has to be considered to understand the notion of a steady state economy was already introduced by John Stuart Mill in the mid-19th century. He believed that after a period of growth, the economy would reach a stationary state but that nevertheless *"a stationary condition of capital and population implies no stationary state of human improvement"* (Mill, 1848, Chapter VI).

This quote elucidates that a steady-state economy is not so much about getting rid of growth, but rather redefining what growth and progress mean (Schulte, 2018). Instead of growing material wealth, it suggests to grow time with our societies communities, families, health, sense of purpose, and the ability to pursue passions and interests. Like this, in the steady-state economy we would decouple our well-being from our consumption (Schulte, 2018). The term of no-growth or steady-state economy might be misleading in the sense that really a no-GDP-growth economy is meant. Economic development would still take place, at the level of technological advance (Worstell, 2011). Even though the overall focus would completely shift, improvements in resource efficiencies and yields would still allow for an increase in material consumption, but explicitly only at a rate compatible with our planetary boundaries.

To achieve the goal of not to creating as much money as possible but rather ensuring sustainable well-being for all a prerequisite is the stabilization of the population, which is already expected to happen in this century (United Nations Department of Economic and Social Affairs, 2017). For the development of a steady-state economy also reduced working hours and guaranteed basic income concepts have been suggested, to make people break out of the hedonic treadmill of having to earn more and more money to finance habits of over-consumption (Reichel, 2014). Inevitable would be the minimization of extraction of natural resources to within planetary boundaries. Focusing on labor-intensive, "inefficient" jobs like small-scale farming, artisans, artists, social workers is believed to also be one puzzle piece of the development of a steady state economy and at the same time part of a re-centering on community values. Another step is restraining excessive consumption and ensuring greater economic equality. A central piece of the concept of stopping the addiction to the current GDP growth is halting the debt cycle, which can be achieved through curbing banks' ability to create money and loan it at interest. On a societal level a general rethinking has to occur, that re-frames prosperity not as a function of material wealth, but rather as an ability to have security, maintain healthy relationships, and pursue passion and purpose. While this re-framing sounds rather philosophical, it is crucial to redefine the role of resources in the economy and reach the goal of the steady state economy to provide well-being for all (Reichel, 2014).

Today, other much-cited authors (Jackson and Senker (2011), Raworth (2017), Victor (2008), Dietz and O'Neill (2013), and O'Neill (2012)) support the claim that it is time for this steady-state economy that *"seeks distribution rather than blind expansion"* (Monbiot, 2014) and that does not demand infinite growth on a finite planet.

Concluding, the ongoing discussion between post-scarcity economists who argue that resource decoupling, technological development, and the unrestrained operation of market mechanisms are capable of overcoming any environmental degradation on the one hand, and post-growth economists who argue that only a steady-state economy with a constant stock of capital can provide for equal and lasting prosperity on the other hand, represents a formative divide of this time.

### 1.2.3 Prerequisite: Successful Resource Management

*When talking about the need to manage our scarce resources efficiently we have to bear in mind that this necessity is part of any potential solution to the environmental challenges that we are currently confronted with.*

*Efficient resource use and management is a requirement for both, the concept of eco-environmental decoupling*

(see section 1.2.1) and vision of a steady-state economy according to Daly (1991) (see section 1.2.2). The way we view the management of our resources as a society in general, but also on a company-level, is decisive to implement successful resource management.

### Society Level

An important concept to understand resource management at a society level, is the one of the 'tragedy of commons' which became widely known due to an article written by the American ecologist and philosopher Garrett Hardin (1968, 2009). The term is used to describe a situation in a shared-resource system where individual users act independently according to their own self-interest and like this behave contrary to the common good of all users by depleting or spoiling that resource through their collective action. In our modern understanding commons is taken to mean any shared and unregulated resource such as oceans, rivers, fish stocks, but also the atmosphere, or simply an office refrigerator.

Assuming that we cannot provide growth in both the material quality of life and population, Hardin (2009) invalidated Jeremy Bentham's goal of "the greatest good for the greatest number" (Shackleton, 1993) and concluded that to achieve a high standard of living it needs to be striven for an 'optimum population'. The solution he presented to prevent the tragic result of each person maximizing their self-interest and thus ruining the commons, was limiting the population.

While the simple model of limited resources and their exploitation through self-interest is compelling, it generalized from a faulty historical case study. Common resource systems have been known to collapse due to overuse (e.g. over-fishing) and certainly we know that a commons fails — as the global climate change proves — when power imbalances are so extreme that it is not possible to hold each other accountable. We know, however, that it is possible to take care of our commons and prevent harm before it occurs. In fact many communities have achieved to successfully manage their commons (Myers, 2000). Various examples exist where members of a community with access to a common resource co-operate or regulate to exploit those resources prudently without collapse (US National Research Council, 1986; Cox, 1985). The neoclassical paradigm of a 'homo economicus', that maximizes utility as a consumer and profit as a producer (Rittenberg and Tregarthen, 2009) fails here. These examples rather highlight the fact that humans do not exclusively act out of self-interest and speak more in favor of the concept of a 'homo reciprocans', in which economic actors are cooperative ones with pro-social behavior (Gintis, 2006).

While ultimately the trade-off between human numbers and quality of life remains, population-based theories of resource constraints have been shown to be highly problematic. Not only have blunt forms or coercion such as China's one-child policy been likely to have negative unintended consequences (Myers, 2000), also, today, extremely clean and efficient technology can already allow more people and material consumption than Hardin imagined. Moreover, population numbers are not expected anymore to grow infinitely, but rather reach a plateau with increasing living standards and development (United Nations Department of Economic and Social Affairs, 2017). Anyways, it is necessary to create framework conditions that allow communities to efficiently make use of their commons and facilitate an inclusive material access.

### Company Level

On a company-level, successful resource management is connected to competitive advantage and thus profitability. Generally, competitive advantage has been regarded as linked to the resources that companies own and their ability to use these resources in a way that generates more value than their competitors are able to generate.

Within the area of strategic management this resource-based view has been among the most popular concepts (see Pitelis (2007), Rumelt and Lamb (1984), Wernerfelt (1984), Peteraf (1993), and Barney (1991)). It seeks to explain why some companies are more profitable than others. While resources can be categorized into physical, human and organizational capital resources (Barney, 1991), especially the resources' value, rareness, imitability, and organization are what leads to the generation of competitive advantage (Barney, 1991).

# Chapter | 2

## Resource Management on a City-Level

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*While we talked about resource management on a societal and company level, a crucial focus area to redesign and prepare our economies for future challenges, are cities.*

### 2.1 Challenges of the Cities of Tomorrow

*Before focusing on the resource management of cities, we first want to explain why cities play such an important role in our society and lay out their general challenges.*

Every city and region around the world faces unique challenges, among others depending on the demographic makeup of that particular city (Dirks and Keeling, 2009), yet most are working to achieve similar goals (Metabolic, 2018):

- They have to provide high quality public services with limited resources (Curristine, Lonti, and Joumard, 2007)
- They aim at fostering innovation and facilitating a forward-thinking and thriving economy (Komninos, 2008)
- They need to provide hard infrastructure (physical capital), but also ensure availability and quality of knowledge communication and social infrastructure (human and social capital) (Caragliu, Bo, and Nijkamp, 2011)
- They see the need to connect the city with the global economy but still need to create resilience (Salet, Thornley, and Kreukels, 2003; LeGates and Stout, 2015)
- They should ensure sustainable management of the environment and natural capital (Newman, 2004)
- Lastly, they need to influence local sectors to reach their goals, particularly waste and construction (Hall, 1988)

The last points become increasingly relevant when considering the world's cities occupy just 3 per cent of the Earth's land, but account for 60-80 per cent of energy consumption and 75 per cent of carbon emissions (United Nations, 2016). Given their immense ecological footprint, it is critical that cities make the transition to become sustainable and circular.

This is not only necessary for the sake of the environment itself: Cities depend on resources and ecological services and, especially in today's ecologically strained world, the well-being of their residents is affected by both the health and availability of these ecosystems. This is why the management of a city's resource metabolism is an increasingly central concern to decision makers, especially in the light of the long-lastingness of urban infrastructure which influences resource needs for decades to come.

The danger of building future resource traps is closing in (Wackernagel et al., 2006). To prevent this and to prepare themselves for tomorrow, cities must rapidly embed sustainable approaches into their development. With necessity also comes opportunity; cities can take a leading role in the transition to a sustainable system and help propagate effective strategies, policies, and infrastructure solutions. Opportunities are opening up for fostering resource-efficient and more competitive lifestyles (Wackernagel et al., 2006).

With materials flowing through cities on a daily basis, entering as needed products and leaving as wastes (Ackerman, 2005), future cities must engineer an economy that is regenerative and waste-free by design and provide the recovery of valuable materials (Ackerman, 2005).

## 2.2 Resource Management in Danish Cities

*In the following section we want to narrow down the discussion on resource management in Danish cities and explain national conditions that influence the specific challenges to reaching resource stable and waste-free local economies.*

Like in many countries, also in Denmark there is still a long way to go to reach the aim of creating regenerative cities that are waste-free by design. The country has a long tradition for incinerating waste, reaching back to the beginning of the 20th century. Incineration for energy represented not only a practical solution to the fact that it was becoming more and more difficult to locate suitable locations for landfilling, but it was also an, at the time, innovative way of supplying steam to the district heating systems that became widespread around this time. In 1973 the oil crisis gave incineration a big push forward and in 1997 the introduction of a ban on landfilling of all waste which is suitable for recycling or incineration strengthened the incineration sector even more (Resource Network Denmark, 2018).

Recycling has now long been considered the most valuable form of resource recovery by governmental bodies as compared to incineration, as the Danish Environmental Protection Agency (2000) points out: *"Recycling is the highest ranking waste treatment form – it ensures better exploitation of resources in waste. In Denmark incineration does not count as recycling"* (Danish Environmental Protection Agency, 2000, p.4). However, the reality looks different. Just recently, the city of Copenhagen for example invested more than 500 million euros in a new waste to energy plant. With 400 000 tons of waste annually the capacity of the plant is way too high and an additional 90 000 – 115 000 tons of waste would be needed to reach the required amount of waste (Nicas-tro, 2017). The Danish government has already envisioned attaining this missing amount through imports. Because of nationwide high incineration capacities, a significant increase in imports of waste for incineration could already be observed. In 2015, imports made up 11% of total incineration at the Danish incineration plants (Toft et al., 2015). This import of waste for incineration is not only clashing with Denmark's own resource strategy, but also with the EU's strategy for a future, resource-efficient economy (European Commission, 2017).

While incineration is predominantly used as a technology to process so-called MSW (Municipal Solid Waste), also recycling rates of industrial waste have to be increased. Environmental management, green accounting and economic instruments such as taxes to regulate waste generation in enterprises have gained wider use (Danish Environmental Protection Agency, 2000) and general recycling rates of industrial waste are higher than the ones of household waste (in 2015, 71% as compared to 46% (Toft et al., 2015, p.4)). However, much non-household waste is still incinerated or even landfilled. Incineration rates in Denmark reach from 6% in the building and construction sector and 18% in the industry up to 31% of incinerated waste in agriculture, forestry and fishing, and 41% in the service sector (Toft et al., 2015, p.19). 6% of industrial waste and 6% of construction waste is even still landfilled (Toft et al., 2015, p.19).

Considering the fact that recycling rates often do not differentiate between high value recovery and so-called 'downcycling', where the recycled material is of lower quality and functionality than the original material, and the still existent practice of incinerating and landfilling, industrial waste management in Denmark still has a great improvement potential.

As local councils are responsible for setting up industrial waste schemes, Danish cities have a great responsibility on the way to a resilient and resource-efficient local economy.



## 2.3 The City of Aalborg, Denmark

*After having discussed challenges of cities in general and national circumstances in Denmark, in this section, we will zoom in on the city of Aalborg in Denmark and describe its ambitions and plans to prepare for the future.*

With a population of 211 937 (as of 1 January 2017), the Municipality of Aalborg is the third most populous in the country after Copenhagen and Aarhus (Statistics Denmark, 2017). Recently Aalborg is experiencing a growth at a higher rate than other Danish cities. In particular, young people are attracted to the city and university. Aalborg is also home to more than 10,000 companies. Particularly strong sectors include ICT, energy, transport, and logistics. Also manufacturing and construction are among the fastest growing industries in Aalborg (Invest in Aalborg, 2016).

Viewing Aalborg's resource management, the new waste management plan 'Aalborg uden affald' ('Aalborg without waste') has been introduced in 2014 and set the strategic agenda for 2014-2025. The basis of this strategy is the national resource strategy 'Denmark without waste' (Miljøministeriet, 2013) and the resource plan for 2013 - 2018 (Miljøministeriet, 2014). A primary focus area in the resource plan is to burn less waste and to better exploit the values and resources in the waste.

This goal is mirrored in the new waste management plan of the city of Aalborg: It aims at reaching an optimum use of resources from the "cradle to cradle" perspective. Reuse, recycling, and new uses of resources should be promoted by establishing partnerships and helping business to share resources. Also, advice on waste minimization, recycling, and sustainable behavior should be provided. Moreover, cooperation on recycling and the launch of citizen-based waste campaigns are included. Three municipal strategies are connected to this waste management plan:

1. First, the '**Sustainability Strategy 2016-20**' is the overall strategy for Aalborg Kommune's environmental, nature, and climate policy, and will ensure coherence in the municipal planning within these areas, but also in relation to the municipality's other planning. The elements of the Sustainability Strategy lay as a prerequisite for the aims of the new waste management plan and are incorporated into its objectives. It is composed of four main focus areas: The green agents network, the Network for Sustainable Business Development (NBEN), the center for green transition (CGO) and Smart Aalborg. All of these actors are meant to work in harmony to foster the transition towards a smart and sustainable city (Aalborg Kommune, 2016).
2. Secondly, with the '**Climate Strategy 2012-2015**', Aalborg Municipality wants to prevent further climate change and adapt to the climate change that is coming. The strategy aims at ensuring that climate policies are centrally placed in the municipality's planning. This includes the vision to be independent of fossil fuels and to be greenhouse gas neutral by 2050 and is thus still relevant.
3. Thirdly, a '**Smart City Strategy**' of 2014 has the goal of growth in business and employment through sustainable development driven by digital and intelligent solutions that create new and better welfare services and reduce resource consumption.

Several project and activities have been included in this smart city strategy to move towards a more sustainable and resource resilient city. As one of the focus areas '**Industrial symbiosis**' is mentioned here, which is focused on increasing the industrial symbiosis network in the municipality. In these industrial networks that resemble biological symbioses, wastes or by-products of one company become a resource for another. By this analogy with biological ecosystems, it maximizes the economical use of materials and minimizes environmental impacts. The large concentration of companies in Aalborg East and the location of energy producers in the region of Aalborg give a particularly great potential for industrial symbiosis in Aalborg.

## **Part II**

# **Research Objective**

# Chapter | 3

## Problem Formulation

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### 3.1 Problem Statement

Even though a great potential for further industrial symbiosis development was recognized in the smart city strategy of Aalborg municipality, no holistic overview of the currently existing waste exchanges between companies in the area exists. Partial overviews have been created (see e.g. energy focused overview by Sacchi and Ramsheva (2017) and an overview centered around cement producer Aalborg Portland by Henriksen et al. (2013) and Wessel (2017)), but a comprehensive up-to-date mapping of the industrial synergies between companies in Aalborg municipality, is missing.

Moreover, how neighbouring companies can cooperate and re-use each others' waste in their production processes, has been extensively discussed in literature (Chertow, 1999; Chertow, 2007; Sun et al., 2017; Yu, Davis, and Dijkema, 2014). Various case studies have been conducted on how companies within specific regions can exploit waste for economic and environmental benefit (e.g. in Oman (Gavriş, 2017), the UK (Mirata, 2004), Australia (Beers et al., 2007), China (Zhu et al., 2007), Portugal, Switzerland and also the city Kalundborg in Denmark (Costa, Massard, and Agarwal, 2010)). Also much research has been conducted on drivers of industrial symbiosis (Beers et al., 2007; Chertow, 2007; Yu, Davis, and Dijkema, 2014), barriers to it (Costa, Massard, and Agarwal, 2010; Fichtner et al., 2005; Golev, Corder, and Giurco, 2015; Rehn, 2013; FRIC, 2015) and involved actors, or so-called facilitators (Mirata, 2004; Sun et al., 2017; Boons et al., 2017; Chertow, 2000; Domenech Aparisi, 2010; Gavriş, 2017).

However, little research has been conducted on the regional conditions in the city of Aalborg that influence the further development of industrial symbiosis development. Moreover, an ecosystemic view on drivers, facilitators, and barriers for a specific case is hardly to be found.

### 3.2 Research Question

The present paper aims at shedding light on these elements (drivers, facilitators, and barriers) through analyzing the industrial symbiosis development in Aalborg, Denmark. By investigating the historical development of selected industrial synergies in the area, the analysis of this case will facilitate a better understanding of the local conditions that influenced the development of Industrial Symbiosis.

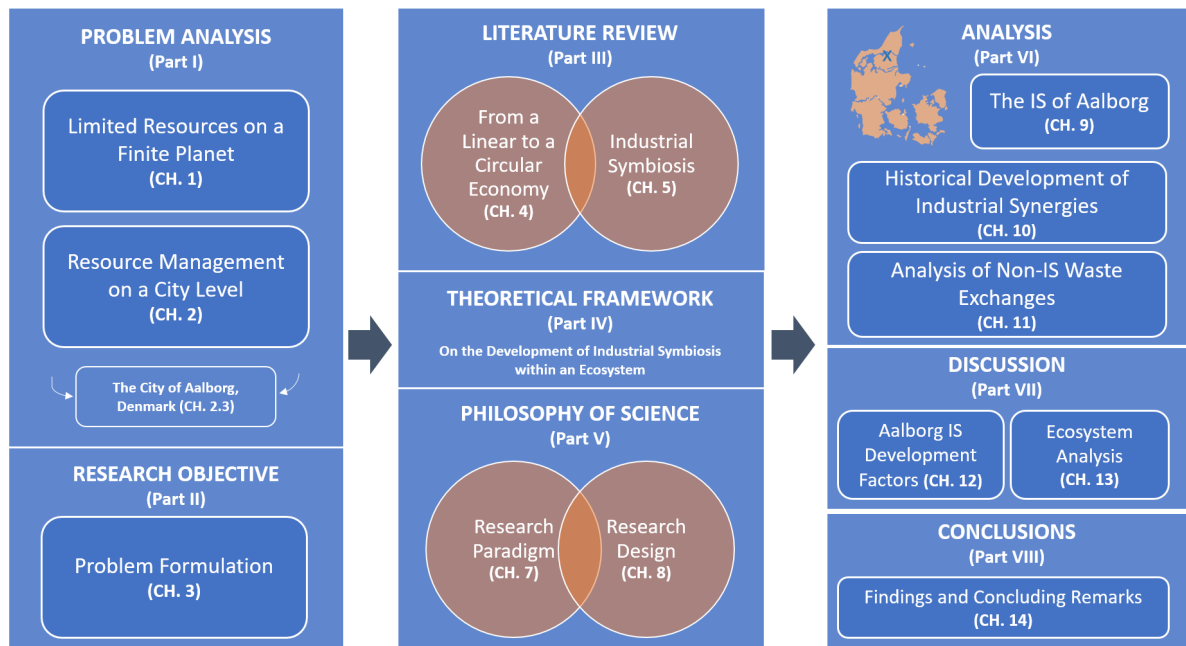
Through exploring the history of several case studies of industrial synergies in the city, drivers, barriers, and facilitators important to the IS development in Aalborg are identified. To strengthen insights on barriers an additional analysis of different types of waste management of companies in the city is conducted, and to clarify the role of facilitators several local actors have been subject of analysis.

The present paper creates a holistic overview of the current state of the Industrial Symbiosis in Aalborg and gives contextual insights into its past development.

Composed within the context of the M.Sc. program MIKE-B at Aalborg University and representing the semester's main project, it is aimed at answering the research question:

***"What does the industrial symbiosis in Aalborg look like and how do ecosystemic factors shape its development?"***

**Structure** Image 3.1 shows the approach that has been taken to address the research question above.



**Figure 3.1:** Structure of the present paper  
Authors' elaboration

This structure eases the answering of the research question. Within this approach, several guiding questions are subject of discussion that address the two distinct parts of the research question:

- **What does the industrial symbiosis system in Aalborg look like?**
  - Which waste exchanges can be defined as industrial symbiosis (CH. 5.2)
  - Which industrial synergies exist between companies in Aalborg? (CH. 9)
  - Which kind of and how much material, water, or energy do they currently exchange? (CH. 9)
  
- **How do ecosystemic factors shape its development?**
  - Which factors typically influence IS development? (CH. 5.3)
  - Which factors played a role in the past development of industrial synergies in Aalborg? (CH. 10,11)
  - Is there any pattern? (CH. 12)
  - What is the position of different actors within this ecosystem? (CH. 13)

**Part III**

**Literature Review**

# Chapter | 4

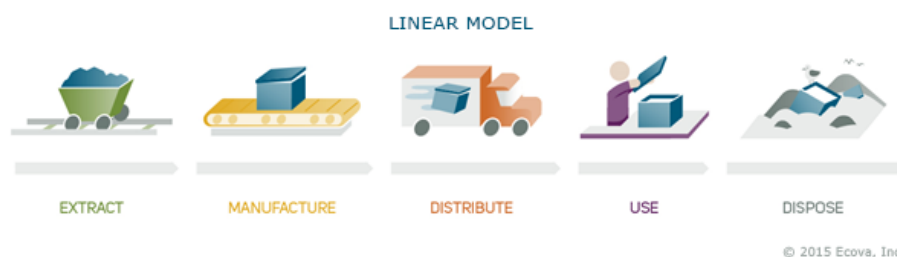
## From a Linear to a Circular Economy

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### 4.1 Resource Management in the Linear Economy

*In this section the reader is introduced to the concept of "Linear Economy" and the issues that are connected to it.*

That our current economic system has to rely on an increasing resource throughput (Ghisellini, Cialani, and Ulgiati, 2016) is strongly related to its production and consumption processes. Its mantra is to "produce, use, throw" or "take, make, dispose" (Ness, 2008). Preston (2012) describes this model quite vividly: *"In today's economy, natural resources are mined and extracted, turned into products and finally discarded"* (Preston, 2012, p.3).



**Figure 4.1:** The Linear Economy  
Retrieved from Bue, 2015

This currently '**Linear economy**' displayed above (figure 4.1) combined with its consumption models, is not compatible with a successful resource management, neither on a macro-level of our society, nor on a micro-level of a single company. The linear economy ignores the implications that follow the intensive resource consumption and sees our economic model as a linear process, at the end of which there is a waste disposal.

This mismanagement is already shocking on an individual level: It has been calculated that humanity would need around four planets with the current lifestyle of US citizens (Wackernagel et al., 2006, p.108). Moreover, on a company level, waste ending up in landfills or incineration plants represents a massive value destruction. What consumption patterns on an individual level and resource management on a company level mean for the society as a whole has been documented in various ways. One example is the 'Earth Overshoot day' which is calculated every year. This day marks the day, when all resources, the world needs to regenerate, are already exploited and there is no sufficient time for recovery. In 2017, this day was reached on the 2nd of August. This means, that even before  $\frac{3}{4}$  of the year passed, the world's natural recovery for resources cannot keep up with our current level of consumption.

## 4.2 Solutions of the Circular Economy

After understanding the issues of the linear economy, the section below introduces the solution the concept of a 'Circular Economy' offers.

The concept of 'Circular economy' (CE) claims to offer a solution - and paves the way out of our resource-intensive and lavish linear economy. This concept aims at keeping products, materials and component at their highest utility throughout the value chain, but at the same time being restorative and regenerative by design (Ellen MacArthur Foundation, 2015).

In its view opposed to the linear economy, this concepts gives the means to develop strategies, ideas and develop a sustainable industrial progress (Kirchherr, Reike, and Hekkert, 2017; Murray, Skene, and Haynes, 2017) and it shows a shift towards an improved harmony between environment, economy and society (Kirchherr, Reike, and Hekkert, 2017).



**Figure 4.2:** The Circular Economy  
Retrieved from anthesisgroup.com

The difference with the linear concept is evident and pronounced. The CE aims at closing the loop in the industries' value chains, as shown in figure 4.2, through avoiding dead ends and instead pursuing a circular path, where a product's life is extended or materials are re-entered in the process. In this concept the paradigm is shifted towards a production that requires less raw materials, and through different ways, avoids the production of waste.

CE is more than an "end-of-pipe" pollution control strategy, but rather an holistic concept that takes into consideration a sustainable industrial development as an hole. The definition given by (Ramesh, Prakash, and Shukla, 2010) describes CE as a "development with low environmental impact, and high economical and social gains". A concept like this considers as important the needs of the current generation but without losing sight of the long run and the needs of the next generations (WCED, 1987).

This holistic vision is not easy to grasp for economists used to the gross domestic product (GDP), as explained in Chapter 1, the same thought of creating things that would last longer goes against their believes (Stahel, 2016). The circular economy concerns a variety of fields, from resources' preservation, to social aspects, to

greenhouse-gas reduction, to sum it up, it is the shift from a world where consumption and direct disposal are acceptable, to one where materials and resources are valuable and need to be preserved or used consciously.

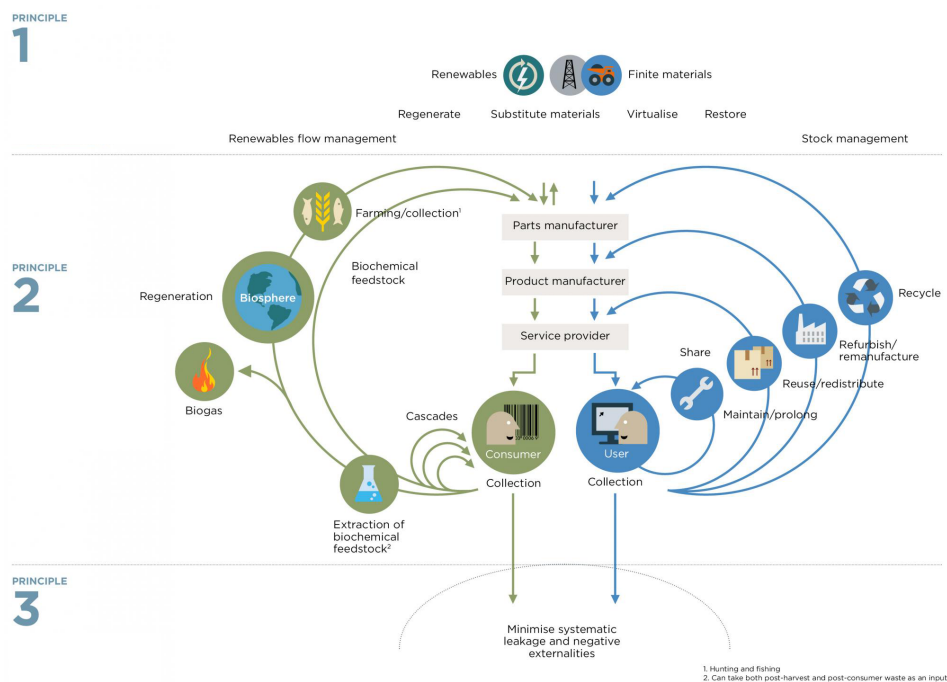
Therefore, starting from the first two steps described in the figure 4.2, a company, when designing a new product should aim to resource efficiency, in particular within European Union where there are specific goals for the 2020 strategy (European Commission, 2016). This goal can be achieved through the use of recycled or renewable materials, in terms of less raw materials and energy used in the manufacturing process. These products, also need to be designed in a way that allows an easier reuse and repair.

Furthermore, also the distribution need to be adjusted, the same solution can be found closer to the production site and the customers, avoiding, for example, the CO<sub>2</sub> emissions derived from long transportation. The use part is probably the one where the social aspect is more relevant. In a circular economy, more and more companies are going to offer products as services and preferring sharing economy business models to the usual ones (Accenture, 2018).

### The Circular Diagram

*The aim of this section is to give a further explanation how the circular economy principles are operating in order to "close the loop"*

As it was illustrated in the previous section, the aim of the circular economy is to close material loops. This goal is achieved through different strategies; resources are not misused, utilization is optimized, and negative externalities are minimized. All of this is displayed in the diagram 4.3 designed by the Ellen MacArthur Foundation (2015).



**Figure 4.3: The Circular Diagram**  
Derived from Ellen MacArthur Foundation (2015)

**Principle 1 - Preservation of Natural Capital** The first principle highlights the importance of preserving and enhancing the natural capital through the control of the finite stocks and the balance of the renewable resources. Utilities are dematerialized and delivered virtually whenever optimal. The natural capital is taken into consideration when conditions for the regeneration, for example of the soil encouraging flows of nutrients are created.



**Principle 2 - Optimization** The aim of the second principle is the optimal use of products, components and materials maintaining them at their highest utility in every stage both in technical and biological cycles. The use of tighter, inner loops, combined with the preservation of energy and value is reflected in an increased importance of activities such as re-manufacturing, refurbishing and recycling. This allows a maximization of the number of consecutive cycles and the duration of each cycle, resulting in an extension of the products' lives and in a reduction of waste due to the increased reuse. Moreover, looking at the left side of the figure 4.3, a circular economy system encourages biological nutrients to re-enter in the biosphere and becoming valuable feedstock for a new cycle. Biological materials find new value in these cycles through a cascade effect that use them for multiple a new applications.

**Principle 3 - Minimizing the Negative Externalities** The third principle rotates around the finding and ousting of negative externalities, minimizing land use, different types of pollution and the release of toxic substances into the environment.

### 4.3 Industrial Ecology School of Thought

*One of the school of thoughts which circular economy is built on is the one of Industrial Ecology. An explanation of this notion is necessary to build an understanding of the theoretical frameworks that surround Industrial Symbiosis.*

CE was not developed at one specific point in time, but emerged through different schools of thought. Industrial Ecology (IE) is one of the scientific disciplines it relies on CE, and especially its aspect of infinitely cycling materials is to a large extent based on this concept of industrial ecology (Preston, 2012). While CE is a very holistic concept, IE is especially geared towards the analysis of material and energy flows through industrial systems (O'Rourke, Connelly, and Koshland, 1996).

Industrial ecology was popularized around 1989 in a Scientific American article by two scholars named Robert Frosch and Nicholas E. Gallopoulos and is based upon a manifest analogy with natural ecological systems (Frosch, 1992), in the analogy different industrial stakeholders reflect a system in which life and waste are strictly connected. Fundamentally, however, industrial ecology is a social construction. The aim is to boost integration, a circular way to use the resources at our disposal and a better and optimized use.

In 1971, Dr. Barry Commoner published a book called *"The Closing Circle: Nature, Man and Technology"* in which he illustrates what he calls *The four laws of ecology* (Commoner, 1971, p.33-48). These laws, played an important role for the academic debate in the subsequent years regarding Industrial Ecology.

1. The first law states that *Everything is connected to everything else*, it means that all the living organisms are in the same environment, in this way, something that affects a particular one has effect also on others. There are species dependent (ex. Symbiosis) or in various ways connected.
2. The second law asserts that *Everything must go somewhere*. Therefore a particular focus is made on the waste, it cannot disappear, there is no waste in nature, the human "waste" then, has to end up somewhere and is going to have an impact based on the choices made about it.
3. The third law says that *Nature knows best*. This means that humans have always shaped technology to improve upon nature but in Commoner's opinion, this change is *"likely to be detrimental to that system [...]"*.
4. The last law affirms that *There is no such thing as a free lunch*. This means that if something is exploited or worse misused, is going to have negative effects on natural resources. Both sides of the natural equation must balance, everything taken from one side is going to have a consequence on the other.

O'Rourke, Connelly, and Koshland (1996) goes beyond these rather philosophical laws and argues in his critical article about industrial ecology that among the many interpretations of IE there are two broad, practical goals. The first one is regards the achievement of closed material cycles, while the second one is about a change of paradigm in our thinking within the industry-environment relations.

- **Closing the loop** According to Lowe (1993, p. 75), *"the ultimate goal of industrial ecology is bringing the industrial system as close as possible to being a closed-loop system with near complete recycling of all materials"*. Moreover, following this path, Ayres (1993, p. 21) debates about the sustainability of the process, stating that *"unless the product cycle and the materials cycle are (very nearly) closed, the [industrial] system as a whole will continue to be unsustainable"*.
- **Using materials efficiently** The improvement of the efficiency of material use is another way the industry can follow, as explained in Chapter 4.1. If the process followed is linear, materials used and then thrown away, then the process followed is not sustainable and efficient as it could be. In our current way of using products, when these wear out or are replaced by updated or newer models, instead of finding another use, being upgraded or recycled, most of the time they are thrown away, wasting precious resources (Frosch, 1997, p. 39). Therefore, it is important to consider both product designs and production processes to increase the efficiency of the overall system. Manufacturers and designers have started to consider the waste, material and energy stream through the life of the product, beyond the point of sale but until its end-cycle, whether it is reuse or disposal. Furthermore, also policy makers have started to act upon this and embody in their legislation measure to reduce waste, cutting taxes on recycling or repairing (The Guardian, 2016) and fighting planned obsolescence (The Independent, 2018).

These two goals represent practical guidelines on the way towards closed material cycles for political and corporate actors.

# Chapter | 5

## Industrial Symbiosis

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### 5.1 Definition

*This section explains the notion of 'Industrial Symbiosis' (IS). After defining IS, the concept is being thematically classified and put into the context of sustainability, industrial ecology, and circular economy. Moreover, the best-practice example of Kalundborg is being introduced.*

Frosch (1992) and his colleagues had a vision for the development of IE which was based on the fundamental question: "Why would not our industrial system behave like an ecosystem, where the wastes of a species may be resource to another species? Why would not the outputs of an industry be the inputs of another [...]?" (Lal, 2005, p.189). The scholars of the field 'industrial ecology' viewed industries as certain kinds of ecosystems, that rely on resources and services provided by the biosphere, because "after all, [both] can be described as a particular distribution of materials, energy, and information flows" (Erkman, 1997, p.1).

Nature, however, is completely cyclical. In biological ecosystems the terms "resources" and "waste" remain undefined as "waste to one component of the system represents resources to another" (Jelinski et al., 1992, p.793).

But how can an industrial system be changed to make it more compatible with the way that natural ecosystems function? In the best scenario, industrial economies should mimic ecosystems "by transforming the waste of one firm into the valuable input of another" (Desrochers, 2002). There needs to be a way to make an industrial system, by analogy with a biological ecosystem, minimize waste and maximize the economical use of materials (Frosch, 1992).

**Biomimicry** This idea is closely related to the bio-mimicry discipline. This discipline, defined by Janine Benyus, is about studying "nature's best ideas and then [imitating] these designs and processes to solve human problems" (Benyus, 1997, p.1). The three key principles are (1) Nature as model in which nature's models are studied. Forms, process, systems, and strategies are emulated to solve human problems. This is the principle the idea introduced above is most related to. The two other disciplines relate to (2) Nature as measure which uses an ecological standard to judge the sustainability of human innovations and (3) Nature as mentor which describes how nature is viewed and valued not based on what we can take from it, but what we can learn from it (Ellen MacArthur Foundation, 2017a).

The vision of "a form of material symbiosis" (Andersen and Jørgensen, 1997) is aimed at by a concept called 'Industrial Symbiosis' (IS). Chertow (2007, p.12) describes IS as the process of "engaging traditionally separate industries in a collective approach to competitive advantage involving physical exchange of materials, energy, water, and by-products". The definition of the England-based Waste and Resources Action Program, called WRAP, is very much in line with this, describing Industrial Symbiosis as "an association between two or more industrial facilities or companies in which the wastes or byproducts of one become the raw materials for another" (WRAP, 2017, p.1).

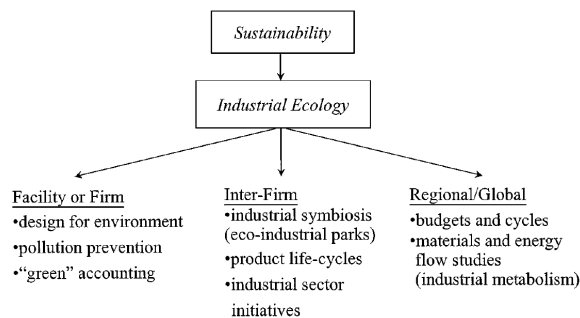
The common idea is that IS involves the adoption of a collective approach between traditionally separate industries to build competitive advantage. Physical exchanges of materials, energy, water or byproducts are incorporated into new business processes, supporting the idea that the power to promote systemic change through green innovation lies in each company's business model and supply chain (Machiba et al., 2012).

The synergistic opportunity arising from geographic proximity through the transfer of physical resources is being exploited for environmental and economic benefit. The openness to new business models leads to outcomes like the reduction of waste disposal costs and carbon emissions and new revenues streams from byproducts, and thus creates both economical and sustainability effects on a company's business (WRAP,

2017). Because of these combined advantages, Industrial Symbiosis has been called an excellent example of systemic innovation vital for future green growth by the OECD (OECD, 2010).

### 5.1.1 Thematic Classification

Industrial ecology allows focus at the facility level, at the inter-firm level, and at the regional or global level. On global and regional levels material flow studies can be conducted and on a company-level environmental accounting, pollution prevention, and many different sustainable business models can be implemented. IS, however, takes place on an inter-firm level (see figure 5.1) and requires collaboration between different companies.

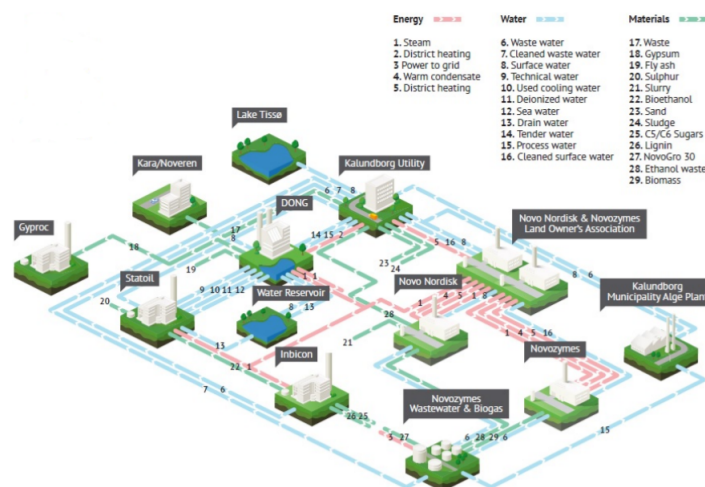


**Figure 5.1:** The Three Levels of Industrial Ecology  
Derived from Chertow (2000)

It becomes evident that industrial symbiosis shares the values the circular economy concept is built on. In fact, implementing circular economy principles on a company level almost inevitably leads to the described exchange of resources among closely situated firms (Ehrenfeld and Gertler, 1997).

### 5.1.2 Best-Practice

**Insights from Kalundborg Symbiosis** The much cited and shining example for IS is Kalundborg in Denmark. In this industrial town a core of big plants, including an oil refinery, a waste water plant, enzyme and insulin factories, and a coal-fired power station built and maintain a web of energy and waste transfer (Ehrenfeld and Gertler, 1997) (see figure 5.2). This systemic approach is facilitated by a specialized network of pipes which criss-crosses Kalundborg and simplifies the logistics. Advantages of this system include minimized waste, low energy and water use, and high savings in carbon emissions (Turney, 2012).



**Figure 5.2:** The Industrial Symbiosis in Kalundborg  
Derived from Dansk SymbioseCenter (2016)

Even though Kalundborg as the first well-functioning industrial symbiosis is now considered a *"textbook example of effective resource saving and cycling of materials in industrial production"* (Ellen MacArthur Foundation, 2017b), the tightly coupled symbiosis network took 40 years to mature. It developed by self-organization from the private sector and thus represents a **bottom-up approach** to industrial symbiosis.

The economic and environmental benefits of Kalundborg Symbiosis have motivated policy makers around the world to support developments of connections and exchanges between companies. These **top-down approaches** sometimes take the form of **eco-industrial parks**, which can be described as purpose-built estates facilitating this material exchange.

## 5.2 Typology

*The following section explains the differentiation between various kinds of waste exchanges and lays out which ones can be defined as industrial symbiosis.*

### 5.2.1 Types of Waste Exchanges

Based on a model proposed by Chertow (1999) a taxonomy of 5 different material exchange types could be developed.

- **Type 1:** Exchange through a third party
- **Type 2:** Exchange within a facility, firm, or organization
- **Type 3:** Exchange among firms co-located in a defined eco-industrial park
- **Type 4:** Exchange among local firms that are not co-located
- **Type 5:** Exchange among firms organized "virtually" across a broader region

These types of material exchanges can be close or further away from the definition of a material exchange that would be defined as an industrial symbiosis. In the following, each type shall be introduced and related to the proximity to the notion of industrial symbiosis.

#### Type 1: Exchange through a third party



**Figure 5.3:** Industrial Symbiosis Type 1  
Authors' elaboration based on Chertow (2000, p.321 ff.)

Many businesses recycle and sell recovered materials through third party brokers and dealers to other organizations. These third parties can be scrap dealers, recycling companies, second-hand shops, or municipal recycling programs. Brokers get more involved in creating the conditions for trading which is why this form of exchange will become increasingly important. However, type 1 exchanges are farthest from the definition of industrial symbiosis.

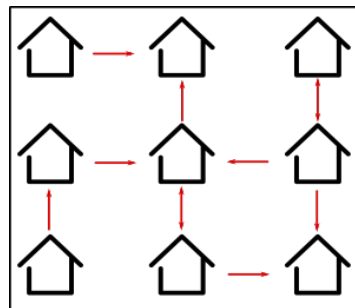
### Type 2: Exchange within a facility, firm, or organization



**Figure 5.4:** Industrial Symbiosis Type 2  
Authors' elaboration based on Chertow (2000, p.321 ff.)

Rather than being an exchange between different companies, some material exchange can occur inside the boundaries of one organization. This is especially relevant for large organizations which can be composed of several entities that act like a multi-firm collaboration. If exchanges are taking place between distinct entities of one company it might be considered industrial symbiosis, as these entities can act like separate organizations.

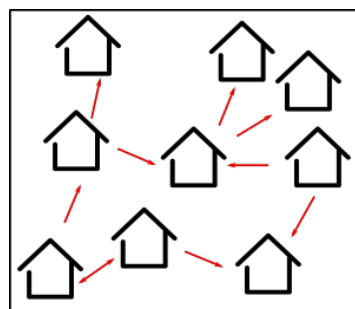
### Type 3: Exchange among firms co-located in a defined eco-industrial park



**Figure 5.5:** Industrial Symbiosis Type 3  
Authors' elaboration based on Chertow (2000, p.321 ff.)

Type 3 exchanges primarily occur within the defined area of an industrial park. Not only tangible materials can be exchanged, but it can go further to share information and services such as permitting, transportation, and marketing. This material exchange type is directly linked to the notion of a rather planned eco-industrial park developed through a top-down approach (see CH. 5.1.2).

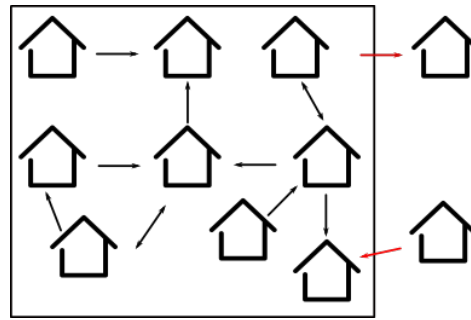
### Type 4: Exchange among local firms that are not co-located



**Figure 5.6:** Industrial Symbiosis Type 4  
Authors' elaboration based on Chertow (2000, p.321 ff.)

This type is closely linked to a bottom-up approach of IS as it takes as a starting point what is already in place within an area and links together existing businesses. Also the opportunity is there to fill in some new ones to strengthen the symbiosis. Kalundborg is an example of Type 4, as the collaboration companies are not directly co-located but still have a high geographical proximity that allowed for the development of a symbiosis.

**Type 5: Exchange among firms organized “virtually” across a broader region**



**Figure 5.7:** Industrial Symbiosis Type 5  
 Authors' elaboration based on Chertow (2000, p.321 ff.)

This type of material exchange does not rely on a high geographic proximity but rather on so-called 'virtual' linkages. Through this type of material exchange industrial symbioses can expand to encompass the regional economic community and the potential to facilitate an exchange of by-products is greatly increased through the additional number of firms. Depending on the distance, companies can be connected by pipeline, or other types of transportation like road or rail transport.

**5.2.2 Conceptual Delineation of IS**

Type	Is regional geographic proximity between companies necessarily involved?	Are different companies necessarily involved?	Are the companies that exchange waste directly connected to each other?	'Industrial Symbiosis'
1	✗	✓	✗	✗
2	✗	✗	/	✗
3	✓	✓	✓	✓
4	✓	✓	✓	✓
5	✗	✓	✓	✓

**Table 5.1:** Waste exchange types' characteristics and the paper's perspective on Industrial Symbiosis

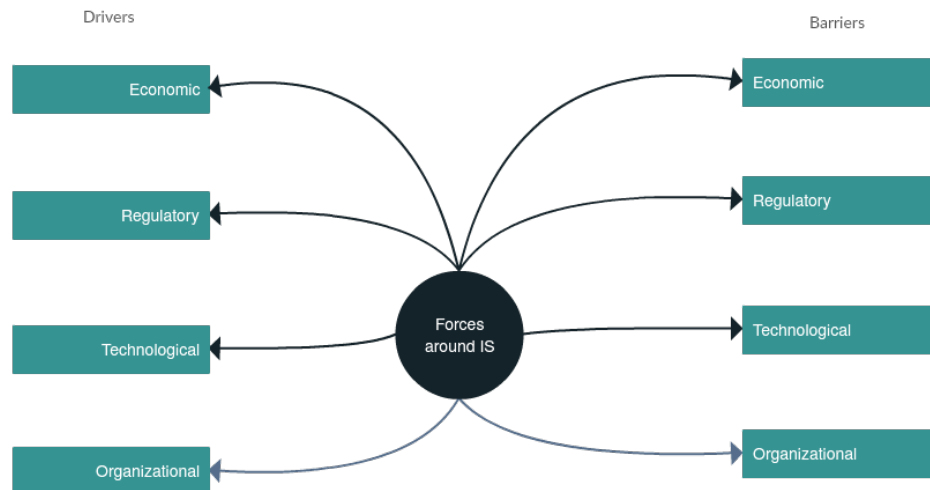
Table 5.1 presents the differences of characteristics in the different waste exchange types of the presented typology. Moreover, in the last column, it highlights what we, within this paper, consider Industrial Symbiosis. We consider industrial symbiosis as a concept that involves the direct waste exchange between two distinct companies. Geographic proximity is often given, but a certain distance nonetheless does not have to be an exclusion criterion, as it can be bridged by transportation and different modes of physical connection (pipes, etc.).

## 5.3 IS Development Factors

*In this chapter drivers, barriers, and facilitators of industrial symbiosis are going to be investigated and summarized.*

While industrial symbioses take different shapes during their evolution (Paquin and Howard-Grenville, 2012), the first development of IS depends on an enabling context of social, informational, technological, economical, and political factors.

Drivers and barriers related to the development of IS are similar and can be located in comparable spheres:



**Figure 5.8:** Categories of Drivers and Barriers  
Authors' elaboration

### 5.3.1 Drivers

There are multiple reasons behind the creation and the development of a new industrial symbiosis. Some authors, such as Beers et al. (2007, p. 67) divide them in a few main categories: Economics, regulations, technical reasons, regional needs, information, and corporate citizenship. Others, like Chertow (2007) make a similar distinction, in business reasons, environmental ones, social and regulatory.

Therefore, after a review of the literature, it has been chosen to sum up these different reasons into four categories. The selection has been made on these specific ones based on the similarities encountered from different sources (Beers et al., 2007; Chertow, 2007; Gavriš, 2017; Yu, Davis, and Dijkema, 2014). It is possible to recognize that the two underlying physical driving forces of IS are the scarcity of materials and physical proximity between companies (Yu, Davis, and Dijkema, 2014). Furthermore, based on the previous mentioned sources we can differentiate between economic, regulatory, technological, and organizational drivers. While regulatory and technological are influencing the company from the outside, the organizational and the economic ones drive it from inside.

#### 1. Economic Drivers

In every business, whose management is concerned in its health and development, it is possible to find some recurrent goals. Most synergy projects make good business sense, because lower operational costs function as a driver together with lower input cost, and/or increased revenues (Beers et al., 2007, p. 14).

Using IS as a discovery tool, managers can build competitive advantage for their business. The strong system perspective which is promoted by the concept can add value and reduce costs in production processes. Sometimes, however, the benefits of tools such as IS are exceeded by the costs of closing material loops. Improved efficiency, cost reductions, and added value can only be gained through IS if



potential innovations are "*screened through the lens of resource productivity*", as Esty and Porter (1998, p.36) stresses. Every innovation should be closely analyzed. To judge its potential and resource productivity, not only direct value added and direct costs should be compared, but also indirect costs and indirect opportunities for value added have to be taken into consideration (Esty and Porter, 1998).

An interesting case can be seen also in the case of Kwinana Cogeneration Plant (Beers et al., 2007, p.15) where the technical obsolescence of an old process equipment resulted in an opportunity to create a new synergy where a company (BP) instead of renovating its old machinery, used the steam and the electricity of the Kwinana Plant, saving A\$15 million per year.

## 2. Regulatory Drivers

Another reason behind the pursuing of symbioses is the response to regulations on different policy levels (Chertow, 2007). Companies are sometimes in the position to obey to rules regarding resource efficiency, emissions reduction, or waste cuts. These regulations can also affect the firm for what concerns water and air quality requirements. In Denmark for example, companies that deal with district heating or waste disposal have to obey to strict regulation for what concerns their activities (Miljøministeriet, 2014; Miljøministeriet, 2013).

Regulatory requirements can hinder the value creation through closing material loops if environmental costs are not fully internalized. This leads to companies which conduct polluting or wasting practices gaining cost advantages (Esty and Porter, 1998).

Another example of how regulations influence the development of IS is describe by Costa and Ferrão (2010). In Portugal, the regulation exists that exchange of waste materials between different companies is only possible if the recipient is a certified waste management operator. The Portuguese Environment Agency requires companies to have specific technologies for recycling and waste management to obtain the permit. This limits waste handling to waste management businesses and makes it necessary to involve them in IS. In Denmark, on the contrary, this type of technological requirement does not exist (Costa, Massard, and Agarwal, 2010) which provides a rather flexible context for IS development (Costa and Ferrão, 2010).

## 3. Technological Drivers

As the above mentioned example demonstrates, regulations on technology requirements influence and can support the development of IS.

Also, technology in general can be beneficial for IS development. As Grant et al. (2010) points out, many ICT tools have been developed in support of IS, for example to facilitate communication that transcends the companies' existing customer/supplier network. Also email, GIS, collaborative project management or document technologies, various modeling technologies, water quality, or energy software can contribute to a successful implementation of synergies between companies (Grant et al., 2010).

More than that, however, technological changes can even represent a driver of IS. Technological changes can cause new opportunities to match material flows. While an overemphasis on the technical aspects of matching material flows does not appear sufficient facilitate the emergence of IS, technological change can lead to IS development, if other drivers (as described above) are already set in place.

## 4. Organizational Drivers

Organizational drivers are related to a company's business model, their organizational culture, and innovation capability.

The innovation capability of an organization relates to and is driven by the organization's "*ability to see connections, to spot opportunities and to take advantage of them*" (Tidd, Bessant, and Pavitt, 2005, p.3). These three sub-tasks of innovation capability are crucial for tapping into existing waste streams and creating cross-industrial synergies out of them. Whether a company has this ability or not is influenced to a large extent by the national system of innovation and the company's market position within the international value chain but also by the capabilities and processes within the firm, and its ability to identify and exploit external sources of innovation e.g. through international networks (Bessant and Tidd, 2007).

Another aspect of a company's business model that is particularly interesting when talking about industrial symbiosis is the notion of **corporate social responsibility (CSR)**.

A company's corporate social responsibility plays a relevant part in driving businesses to the creation of synergies. This is due to the fact that synergies often bring along social and environmental benefits, which adds to a company's performance in terms of CSR (Chertow, 2007; Beers et al., 2007).

Another motive behind establishing an industrial ecosystem, has been pointed out by Ehrenfeld (2003). These synergies provide higher public benefit than normal industrial networks because they allow increased environmental benefits.

These opportunities are pursued from companies because of the reduction of costs that often comes along with them, nonetheless, companies bonded by ethical and corporate social responsibilities, choose this path even if it is not always profitable, this results in a "marketing" investment (Beers et al., 2007).

Furthermore, often, according to Chertow and Lombardi (2005) the environmental benefit of new symbiosis is neglected by the modern literature. In fact, many benefits can arise from these synergies, such as remediation of pollution associated with heavy industry, preservation of resources like fresh water or land, reduction of greenhouse gas.

### 5.3.2 Barriers

While there are circumstances and characteristics of companies which motivate or incentivize IS development, also obstacles toward implementing synergies can often be observed in systems in which IS might develop.

#### 1. Economic Barriers

Synergistic connections are expected to bring a positive economic outcome along with environmental benefits. However, also economic barriers exist. One can be the lack of understanding that wastes may be a valuable resource. If industries do not have a special budget for environmental projects, initial efforts to establish industrial symbiosis might be undermined (Golev, Corder, and Giurco, 2015).

According to the authors also a dominance of economic drivers for the approval of new projects can represent a barrier. Companies might not realize that a more proactive approach for waste reuse projects and a recognition of the the long-term environmental benefits can prepare the company for possible changes in the legislation or higher community concerns and pressure.

Fichtner et al. (2005) states that economy related barriers are more likely occur in small or medium-sized enterprises. They come into existence because resources are assigned to projects with high priority, whereas inter-company cooperations are given importance only in exceptional cases.

Resistance on a personal level comprehends situational barriers such as the workload of alternative tasks and pressure of time (Fichtner et al., 2005).

**Waste flow stability** Another barrier related to economic aspects is rather obvious: The realization of industrial symbiosis depends on the existence of a sufficient amount of homogeneous products. Due to lack of quality, continuity, and quantity of flows to be connected, the risk of introducing new bottlenecks in the procurement process can be seen as a central obstacle to such cooperation (Fichtner et al., 2005).

This risk of waste flow stability is strongly connected with the fear of dependency on partners and the loss of independent control of resources and decisions. Inherent risks of a network in general consist of a diminished control of the whole system, the threat of losing competencies and know-how as well as the fear of a possible dependency on the partners through the industrial symbiosis (Fichtner et al., 2005).

- Regulatory Barriers** Legal barriers are determined by the totality of legal regulations, which inter-company cooperations within industrial production are subject to, such as provisions concerning the interconnection of material or energy flows. One example is the antitrust law that may hinder regional cooperation of industrial companies (Fichtner et al., 2005).

Regulations might prohibit the use of by-products in some applications due to levels of contamination or quality uncertainties. By-products are sometimes classified as waste and must comply with constraints on recovery and reuse set by environmental regulations (Mirata, 2004). In the United States, liability legislation is an especially large barrier for industrial symbiosis (Brand & Bruijn, 1999) (Rehn, 2013).

### 3. Technical Barriers

The technical barrier that could hinder the industrial symbiosis development could be related to the failure to identify a different use for by-products and for incompatibility of the waste streams as Chertow (2000) describes: *"A first-order consideration is whether there is sufficient flow of materials to make industrial symbiosis worthwhile. In a project designed from scratch, quantities could be carefully designed to match the required scale. However, this could prove more difficult when working with existing facilities"*.

Even if the company is ready to find another stream for its waste, not always the market is ready to receive these resources, therefore, these by-products, are sent abroad or discarded (Costa, Massard, and Agarwal, 2010).

**Location and Logistics** Technical barriers also relate to the locations of the companies and the management of the logistics. Geographical location influences what kind of infrastructure is needed for the exchange and if collaborations are possible within companies located in an area. These partnership are fostered when manager have the possibility to know each other and therefore possess knowledge about the business of the surroundings companies (Branson, 2016).

### 4. Organizational Barriers

**Lack of Adaptability and Flexibility** One organizational barrier is related to a company's innovation ability. This ability to change and adapt, to recognize and act upon the signals coming from inside and outside the organization, can be a barrier for the development of an industrial symbiosis when missing (FRIC, 2015). Sometimes this fails because there are no individuals eager to establish cooperations and promoting ideas of symbioses for the enterprise's development (Fichtner et al., 2005). Moreover, the absence of creativity within an organization, might result in losing ideas and approaches that might be beneficial for the company's development (FRIC, 2015).

**Lack of Collaboration and Trust** Another organizational barrier is related to the unwillingness to cooperate and inability to trust. Within an inter-firm collaboration, the trust between the social actors is valuable in order to decrease transaction costs and the risk of establishing short-lasting partnership. The interorganizational trust turns out to be beneficial in the context of an industrial symbiosis, because the trust leads to cooperations and this is the bedrock for enacting exchanges of material and resources (FRIC, 2015).

Fichtner et al. (2005) describes that there are also motivational barriers on a personal level. Industrial cooperation might be missed out on, or might fail in the process, if personal objectives of decision makers do not agree with them. This might derive from an inferior importance of sustainability and cooperations within their personal objectives (Fichtner et al., 2005). Private enterprises are also unwilling to cooperate among each others because often a competitive mindset prevent them to get involved in these symbiotic processes (Fichtner et al., 2005).

**Informational Barriers** Also, informational barriers are part of organizational challenges that can prevent industrial symbiosis development. One issue here is the ability of information sharing and knowledge capacity. In order to establish a symbiosis, is important for the companies involved to have knowledge about the market and its potential for byproducts and different way to threat waste streams (Branson, 2016).

Furthermore, another problem that might occur is the limited knowledge of the inputs and outputs of the surrounding companies. The lack of information in this case results in a diminished range of opportunities to manage materials and create new synergies (Costa, Massard, and Agarwal, 2010).

Also the monitoring of the possible collaboration is relevant in order to spot the upcoming possibilities and the available waste streams the absence of this is therefore a barrier to IS development (Walls and Paquin, 2015).

Especially in enterprises characterized by a rigid structure, where the organizational structure is hierarchical, an obstacle is the lack of communication. Therefore, within these organizations, the information flow, of regional cooperation concepts, is restrained or not happening at all. The reason behind it is the absence of a sustainability information system, that leads to the lack of sustainable targets and moreover to have a foundation for a relevant sustainability controlling.(Fichtner et al., 2005).

Fichtner et al. (2005) refer to this obstacle as a 'cognitive barrier'. They claim that within industrial production neither the potential strategies for inter-company cooperation nor their possible positive consequences for sustainable development are widespread, and that thus cognitive barriers represent a considerable obstacle (Fichtner et al., 2005).

### 5.3.3 Facilitators

Besides the above mentioned external and internal drivers that move a company towards implementing IS, external facilitators are believed to be key enablers of IS (Prosman, Wæhrens, and Liotta, 2017). The power to influence the context in which IS flourishes varies among the agents involved such as the government, businesses or coordinating entities. In the following the 5 most important types of facilitators are going to be introduced.

#### 1. Anchors

As described by Chertow (2000) in the waste exchange type 3 (see figure 5.5), an industrial symbiosis can blossom if there is an institution playing the role of this facilitator in an area. In this paper, "*anchor tenants*" are described as follow: "*Just as shopping malls are built around several large department stores that anchor the commercial development within, one or two large industries can provide the same critical mass for an eco-industrial park*" (Chertow, 2000, p. 333).

Sun et al. (2017) divides anchors in two categories, industrial and institutional.

**Industrial Anchors** are different companies which establish a self-organization process in order to exploit economic benefits (Boons et al., 2017). Usually are one or two with a considerable size, big enough to give them a critical mass necessary to start this process. The anchor brings to the table resources and energy flows for the whole area (Boons et al., 2017; Sun et al., 2017). While the infrastructure and connections between companies depends on local industrial characteristics, often regional public utilities play the role of anchor tenant, around which the main material and energy flows of a regional industrial system could be arranged (Korhonen, 2001; Yu, Jong, and Dijkema, 2014).

On the other hand, the **institutional anchor** does not have a considerable enterprise size to gain the necessary critical mass to start the symbiosis, but it supports and enhances the condition for an industrial symbiosis to prosper. This role could be the one of networking facilitator, stimulating the interaction and communication among the stakeholders. It acts as a knowledge hub, obtaining and sharing it. The institutional anchor serve as regulations helper, to ensure the political and managerial support or in the recruiting of new tenants and actors (Sun et al., 2017).

Activities	Anchor		Broker		Service	Orchestrator	Coordinator
	Industrial	Institutional	Knowledge	Relation			
a) Stimulating interaction and communication between stakeholders		X		X		X	X
b) Building trust, commitment, and cohesion, resolving conflicts				X		X	
c) Identifying of potential IS partners and synergies			X	X		X	
d) Treats by-products before use					X		
e) Facilitating physical delivery of waste					X		
f) Identifying technical and economic feasibility			X			X	
g) Providing a critical mass of resources and energy flows	X						
h) Obtaining and sharing the knowledge		X	X			X	X
i) Ensuring political and managerial support		X		X			X
j) Recruiting the tenants and actors		X		X		X	
<b>Characteristics</b>							
k) Prominence and power, leadership role						X	X
l) Many network connections inside and outside the network				X		X	
m) Long-term vision for sustainability							X

Table 5.2: Facilitators' activities and characteristics

## 2. Brokers

This category encompasses intermediaries who can ease the barriers between the different players in a symbiosis (Domenech Aparisi, 2010). They operate as intermediate agents, in identifying feasibility, potential partners, markets changes and promoting exchanges and knowledge flows (Gavrish, 2017).

Three are the main types of brokers identified in the literature: knowledge, relational and service brokers (Gavrish, 2017).

The first type, the **knowledge brokers** is able to transfer the knowledge between the members of the network (Krenz et al., 2014), this can be no-profit organizations or academic institutions, due to the knowledge possessed, it function also as a lens to identify potential IS partners and synergies. Moreover, it acts as support to identify the feasibility of a specific solution (Chongfeng, Gupeng, and Wei, 2009; Krenz et al., 2014).

Furthermore, the **relational broker** insures the relational cohesion among different actors (Gavrish, 2017) and acts to resolve conflicts, to build trust, commitment and it encourages cooperation and harmony inside the network. It possesses a significant amount of connection within and outside the network. This effort could result in the identification and development of new IS solutions and additionally in the attraction and recruitment of tenants and actors. In this category it is possible to find a company, institution or local leader (Gavrish, 2017). A particular type of relational broker is the *champion*. This is somebody close to the parties who can convince them to establish collaborations, and create commitment around a project. These agents use trust and support of the community as leverage and their strength lies in being close to the ground of the project (Gavrish, 2017).

Lastly, **service brokers**, operate to ease the connection between companies in the area facilitating the physical delivery of the waste, these can be for example the case of an utility company, or a firm which has the necessary expertise when by-products are in need to be treated.

## 3. Orchestrators

Dhanaraj and Parkhe (2006) define an orchestrator as an entity which *"uses its prominence and power to perform a leadership role in pulling together the dispersed resources and capabilities of network members"*. Moreover, the orchestrator should be active in the network, having a central position and being well connected with people inside and outside it (Ryyänen and Patala, 2013). This entity encourages other player in the network to act more entrepreneurially, stimulating the interaction among them. Therefore, the function of the orchestrator, is to share and mobilize the knowledge and to identify new possible synergies. Once these opportunities are recognized and potential partner are discover, it is active in recruiting tenants and in promoting and justifying these new connections. Moreover, this impartial position allows the orchestrator to build trust and commitment inside the network and solve conflicts that might occur (Ryyänen and Patala, 2013).

## 4. Coordinators

The role of the coordinators is to create the necessary environment and build support to the IS development facilitating the interaction and the transfer of knowledge among stakeholders (Domenech Aparisi, 2010). They ensure political and managerial support through a political role and policy power (Gavrish, 2017). Due to their nature, and different from the orchestrator, this type of facilitator has a vision, it operates on a longer period, promoting long-term strategies and having a focus on sustainability (Mirata, 2004).

## Deviations

Within this thesis' research, multiple companies and actors are analyzed. Due to the activities these actors conduct it has not always been possible to pigeonhole each one of them in one of the above mentioned categories. In some cases, it was unfeasible to limit the influence to one type of facilitator. Moreover, not always all the activities and the characteristics of a specific type were fulfilled. Because of the choice of basing our research on the critical realism ontology (Collier, 1994), the categories of facilitators shall serve as a tool for orientation and guidance within the ecosystem analysis.

## **Part IV**

# **Theoretical Framework**

# Chapter | 6

## IS Development from an Eco-Systemic Perspective

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*The following chapter unites the findings on the development of IS reached in chapter 5.3 into a framework that will be the base of the following analysis. Before doing so, business ecosystems as a tool of analysis and foundation of the framework is going to be introduced.*

### 6.1 The framework's fundamentals

Already Rothwell (1974) described the idea of the economy as an ecosystem quite vividly: *From a bionomic perspective, organisms and organizations are nodes in networks of relationships. As time passes and evolution proceeds, some nodes are wiped out and new ones crop up, triggering adjustments that ripple across each network* (Rothwell, 1974, p.213). In his analogy with biological ecosystems, firms serve as biological organisms and industries as species (Peltoniemi and Vuori, 2004).

Business ecosystems can be viewed as an economic community supported by a foundation of interacting organizations and individuals (Moore, 1996, p.26). He first coined the term from a business perspective in his book *'The death of competition: leadership and strategy in the age of business ecosystems'*. The interacting organizations and individuals he talks about represent the organisms of the business world in his analogy.

Adner (2017, p.40) describes an ecosystem as *"the alignment structure of the multilateral set of partners that need to interact in order for a focal value proposition to materialize"*. In the case of our work, we view industrial symbiosis as an ecosystem with *'the focal value proposition'* of economic gains and environmental benefits. The definition of Adner (2017) states that this value proposition materializes through a certain alignment structure that a set of partners build. This alignment structure means that the members of this ecosystem, which are the companies that exchange waste in our case, have defined positions and activity flows among them and that there is some level of mutual agreement among the members regarding these positions and flows (Adner, 2017).

Adner (2017) builds his framework on four main elements:

1. **Activities**, which specify the discrete actions to be undertaken in order for the value proposition to materialize.
2. **Actors**, which are the entities that undertake the activities. A single actor may undertake multiple activities; conversely, multiple actors may undertake a single activity.
3. **Positions**, which specify where in the flow of activities across the system actors are located and characterize who hands off to whom.
4. **Links**, which specify transfers across actors. The content of these transfers can vary— it can be materials, information, influence, funds. Critically, these links need not have any direct connection to the focal actor.

An aligned structure of these elements occurs when positions are satisfactory, the interests of actors are working in the same direction, relationships are mutually reinforcing, and activities are mutually supportive.

We can define our frameworks' elements (drivers, barriers, and facilitators) as follows according to Adner's ecosystem approach:

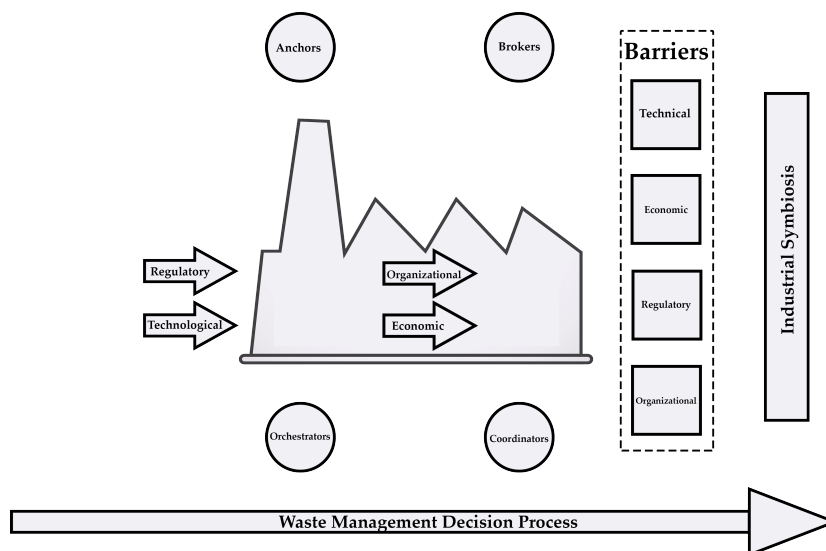


- The **drivers** we defined in our framework in chapter 6 are conditions or events within the ecosystem that makes certain *actors* (organizations) take the *positions* of industrial symbiosis participants. Two organizations (*actors*) build an *alignment structure* which is based on a mutual understanding of fulfilling the *activities* necessary to exchange waste. In the case of industrial symbiosis, the most important activity - the actual exchange of material - also represents a *link*, as material is transferred across actors.
- **Barriers** can be viewed as conditions or events within the ecosystem that prevents an *alignment structure* to emerge. The *actors* are hindered in their ability or will to create the *link* of material exchange. For example, conflicts of interests cannot be resolved or compromised within a joint objective. Or, due to systemic conditions, the relationships cannot be designed in a mutually reinforcing way, and *activities* cannot be mutually supportive.
- **Facilitators** are the *actors* that make the value proposition possible. They are not directly involved in the *links* between the organizations and actors who are part of the industrial symbiosis, but conduct *activities* that are beneficial for links to establish. Through these *activities* they take *positions* within the ecosystem that are important to be analyzed.

Within our analysis we want to use this perspective as a lens to analyze the industrial symbiosis network within the ecosystem of Aalborg's local economy.

## 6.2 The framework's set-up

The framework displayed below was developed based on findings of the literature review. It illustrates the role of different ecosystemic factors in the decision process of a company to establish a synergy in the sense of industrial symbiosis. While the regulatory and the technological aspects drive the decision from outside the company, the organizational and economic drivers influence the process from the inside. Also, facilitators, displayed as circles around the company, are external influencers during the decision process. Along the way companies face certain challenges, which are represented by the barriers on the right side of the image.



**Figure 6.1:** Waste management decision process  
Authors elaboration

Based on case studies of companies involved in different types of waste exchanges, we aim at identifying how the ecosystemic factors are relevant for the IS development. Also, through an in-depth analysis of historical developments of several cases, the importance of the drivers and facilitators as well as barriers (as discussed in Chapter 5.3) to IS is going to be illuminated.

## **Part V**

# **Philosophy of Science**

# Chapter | 7

## Research Paradigm

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When conducting research it is necessary for the researchers to consider their own standing in relation to the research field. Their assumptions, choices of theories and methods, as well as their interpretation are affected by their values and assumptions.

Indeed, the researchers need to bear in mind that their way to perceive different situations is driven and influenced by the results of their investigation. Particularly within the social sciences, the research is inclined to be more qualitative rather than quantitative. Therefore, it is imperative for the researchers to critically reflect upon their position and preconceptions, while investigating in this field.

Within this chapter, we will introduce our perception of paradigms and outline the philosophical view used while conducting the empirical research. Furthermore, the attention will be shifted on techniques and methods utilized for data collection and analysis. The reason behind this is to be able to preserve the validity and reliability of the results.

In order to do so, the “*ultimate presumptions*” underlying the present research (Arbnor and Bjerke, 2008, p.7) are going to be explained.

### 7.1 Ontology

*What is reality?*

The main concern of ontology is the nature of existence and reality. Based on the assumptions about these, it is possible to categorize reality as self-persistent or socially-constructed. In the literature these two approaches regarding the perception of reality are called objectivist and subjectivist (Kuada, 2012).

**Objectivists** perceive the reality to exist externally to human beings and their interactions. Therefore, a particular phenomenon is not connected to individual perception and it exist by itself. One example for an objectivist ontology, also called realism, can be the speed of light. Light is travelling at the same speed, no matter of the individuals perception towards it. Moreover, this type of phenomenon is self-determined and it could be generalized and it is always valid.

**Subjectivists** sense reality as socially-constructed. This ontological view is also referred ad nominalism. In this perspective, there is no absolute truth and the reality diverges between different individuals based on the way they look at it. This is particularly true for novel phenomena that are still in need of investigation. Therefore, the view of it is dependent on different perceptions and the nature of the phenomenon is socially constructed. Each person has a different view of it based on previous experiences and own knowledge. In our problem formulation, we stated our interest in the development of the IS in Aalborg. There are multiple parameters connected to it, we do not expect them to be disconnected but independent and interconnected. The concept itself of Industrial Symbiosis is disputed within the academic community (Chertow, 2007; Chertow, 2000) and the boundaries of it are shifting based on the author.

Both approaches described above are difficult to match with the aim of our paper, as the element of mapping industrial symbiosis can be viewed from a rather objectivist/realist perspective, while the social forces and constructs that lead to its development rather call to be viewed from a subjectivist perspective. Therefore we decided to follow a third path, the so-called **critical realism** (CR) (Collier, 1994). Researchers increasingly abandon the dualistic perspective and the ‘either-or’ choice between subjectivist and objectivist perspectives when analyzing important issues that challenge social science today (Danermark, Ekstrom, and Jakobsen,

2005). Critical realism offers an alternative to "*spurious scientificity of positivism and to idealist and relativist reactions to positivism*" (Sayer, 2004, p.6). Located in between the two ends of subjectivist and objectivist perceptions of reality, the ontological view of CR criticizes empiricism for its reduction of reality to the observable (Bunge (1993), (1979)). However, according to CR, the ability of the authors to find patterns in their research and to realize the extreme complexity of the reality is crucial. Plausible explanations for the observed phenomena have to be defined (Robson and McCartan, 2016). Critical realism does not reject the possibility to understand the *social world* through philosophy or social sciences but instead affirms that some knowledge is closer to reality than other (Collier, 1994):

*"The ability to engage in explanation and causal analysis (rather than engaging in thick empirical description of a given context) makes CR useful for analyzing social problems and suggesting solutions for social change."* (Fletcher, 2017)

Fletcher (2017) describes a main critical realist assumption based on the work of Bhaskar (1998): that reality is layered into three levels.

1. The first level is the so called "*empirical level*" and it is the one we can perceive normally. Events and objects are possible to measure in an empirical way but are experienced through human interpretation and based on the researchers' experience.
2. The second level is called "*actual level*". In this level, there is no interpretation and the events occur even if they are not observed. This often differs from the empirical one (Danermark, Ekstrom, and Jakobsen, 2005).
3. Lastly, the third level is the "*real level*", here *causal structures and mechanisms* exist (Fletcher, 2017). These are implicit properties that act as *causal forces* to produce events.

This layered perception of reality highlights the importance of differentiating between a real world and a conceptual one, between our descriptions of it and the factual reality (Bunge (1993), (1979)).

The ambition of CR is to give an explanation of social events through these causal systems and the effect they produce throughout the *levels of reality*.

Within this paper, CR becomes notably important due to the fact that the reality observed is the result of social constructs and several interconnections.

## 7.2 Epistemology

*How can we know reality/knowledge?*

To explain how knowledge is created and what it "is or should be" (Bryman, 2015), we need to differentiate between stances relating to subjectivist or objectivist/realist ontologies.

Within this research we can relate the positivist stance that structures are real and objective forces, and that their effects can be empirically observed. However, we see threats for the present research arising from the absolute connection between a positivist mindset and the typical positivist thinking of how reality can be known and knowledge acquired. Positivist approaches prefer the systematic observations to create highly reliable knowledge, often proven through various tests and only possible through excluding the interaction of the researcher with the people studied (Livesey, 2006). The idea that strong generalizations are possible through these methods - which is often claimed as an important reason for positivist epistemology (Saunders, 2011) - should not be excepted at this point. However, we do not see the need to keep us, as researchers completely distanced from the objects of research, as long as the researchers are aware of their own assumptions and biases and can differentiate between the different layers of reality according to the critical realist ontology. This means we are accepting the limits of knowledge acquisition through analysis of the *actual level of reality* which often can result in the creation of law-like generalizations that are reducing phenomena to simplest elements. We as researchers, should, however, rigorously defend our reasons and methods of interpreting

subjective meanings of this first level of reality.

Another issue that we consider important here when talking about how we can acquire knowledge is the overall usefulness for the scientific community. The complexity and especially vicissitude of social phenomena and human experiences and also the rapid and constant changes taking place in social systems is an important constructionist point. Considering this sheer complexity, we think approaches of subjective interpretation that describe and explain phenomena from the point of view of those involved, are always a valuable and equal contribution to scientific research. This is because (as contrasted with a positivist stance, whose goal is to a great extent explanation and strong prediction) the constructionist ambition of creating a general understanding and focusing less on what is general, average and representative, but all the more on what is specific, unique, and deviant, is important for the present research. Based on critical realism, we can create this kind of value through moving observations on the empirical level to the real level of reality, in which we analyze causal structures and mechanisms.

### 7.3 Methodology

*What procedure can we use to gather the knowledge?*

After discussing *Ontology* and *Epistemology* we now want to address the procedure used to gather knowledge. Of the first importance there is the choice between qualitative and quantitative methods. Working out our assessment of different epistemological beliefs, the authors' opinion is that both methods, qualitative and quantitative, are relevant in social science research and therefore have been using to conduct this research. Rossman and Wilson (1985) define three different approaches. The first one, the *purist* sees these methods as mutually exclusive, the *situationist* considers them as separate but equal, and the third one, the *pragmatist*, suggest a possible integration between them. Therefore, conducting this research, the *pragmatist* one has been chosen during this thesis work. On the grounds aforementioned, this paper takes an ideographic methodological approach, due to the reason that the best strategy to come at our research problem is through collecting first hand knowledge of the topic under investigation. The nomotetic approach was not taken into consideration being it more suitable for natural sciences and an objective context (Burrell and Morgan, 1979). This track leads us to be more open-ended and exploratory, especially while we were at the start of our research. Consequently, the approach chosen was of an inductive type, in our way to pinpoint patterns in a vast amount of data (Burrell and Morgan, 1979).

# Chapter | 8

## Research Design

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*This second chapter presents the methodology approach used for the posed research question: "What does the industrial symbiosis in Aalborg look like and how do ecosystemic factors shape its development?" and focuses on the methods and techniques of data collection and analysis.*

### 8.1 Research Methods and Techniques

*What tools can we use to acquire the knowledge?*

We chose a multiple-case study method for the present paper, thus aiming at conducting an in-depth study of multiple cases. In investigating a group of relatively bounded phenomenon, our aim as a scholars is to elucidate features of the whole class of similar phenomena (Gerring, 2004). We are aware that we are not making an attempt *"to isolate the phenomenon from its context, but instead, the phenomenon is of interest precisely because of its relation to its context"* (Johnston, Leach, and Liu, 1999, p.203). Like this, the qualitative case study methodology provides a tool for us researcher to study a complex phenomena (Baxter and Jack, 2008) such as industrial symbiosis, an contemporary real-life situation, within its real-life context (Stake, 2013). With the multiple cases we select, we frame particular chunks of reality with a specific research question in mind (Stake, 2013).

Often, case studies have been criticized for lacking in rigor. The research method has been accused of not providing scientific justification, but only belonging to the realm of scientific discovery (Johnston, Leach, and Liu, 1999). Yin (2013), however, argues that this method can be used to address exploratory, confirmatory, as well as explanatory research questions. Contradicting common misunderstandings, Flyvbjerg (2006) states that it is even possible to generalize on the basis of a single case.

However, a multiple case research approach allows us to contrast and compare the findings, which enables us to acknowledge unique and common parameters across the cases (Bryman, 2015). A particular reason to use multiple cases instead of one is that it improves theory-testing and -building, as the research is in a better position to establish the circumstances in which a theory will hold or not (Yin, 2013; Eisenhardt, 1989). At the same time, a comparison might create insights or even suggest concepts that are relevant to existing theory (Bryman, 2015).

### 8.2 Research Scope

*What subjects did we choose to use the tools on?*

Andersen and Kragh (2010) say that the access to and framing of social reality into "cases" is mediated by prior knowledge of the researcher. As, especially for a multi-case research, the cases need to be similar in some way (Stake, 2013), it becomes even more crucial to select appropriate parts of social reality to frame them into cases. A case can be an individual, but also an event or an entity that is less well defined. A school can be case, a decision, can be, but also an implementation processes, or organizational culture (Yin, 1994). Miles, Huberman, and Huberman (1984, p.25) describe a case as *'a phenomenon of some sort occurring in a bounded context'*. While the 'heart' of the research, as they describe it, is kept in focus through a precise research question, it is pivotal to clearly define the boundaries of the cases to be examined. In the present section, we thus plan to point out the boundaries of our research and define which bounded phenomenon we decided to use as a 'case'.

Type	'Industrial Symbiosis'
1	✗
2	✗
3	✓
4	✓
5	✓

**Table 8.1:** Types of waste exchange types that are considered Industrial Symbiosis

To focus on the development of industrial symbiosis, we chose to select parts of this larger phenomenon - single waste exchanges - as cases. As discussed in the typology of waste exchanges (see CH. 5.2) and displayed in figure 8.1 below, we do not consider waste exchanges that are taking place through tertiary companies like waste management companies (waste exchange type 1) or within companies (waste exchange type 2) as belonging to the phenomenon of industrial symbiosis. Hence, they are not framed as a case. However, waste exchanges that develop dynamically (waste exchange type 3), exchanges that are based on a purposely designed eco-industrial park (waste exchange type 4), and those that expand beyond a cluster's or region's border (waste exchange type 5) are considered as Industrial Symbiosis according to our definition.

Within the scope of the present paper, we, however, narrow down the data collection and analysis on waste exchanges that are happening within a certain area's borders. Thus, we exclude exchanges that go beyond these borders (waste exchange type 5) and focus on waste exchanges that develop dynamically (waste exchange type 3) and exchanges that are based on a purposely designed eco-industrial park (waste exchange type 4) (see figure 8.2), within a defined area. Our framing of the cases is thus not only defined by theoretical distinctions of present literature on industrial symbiosis, but also narrowed down by geographic properties.

Type	'Industrial Symbiosis'
1	✗
2	✗
3	✓
4	✓
5	✓

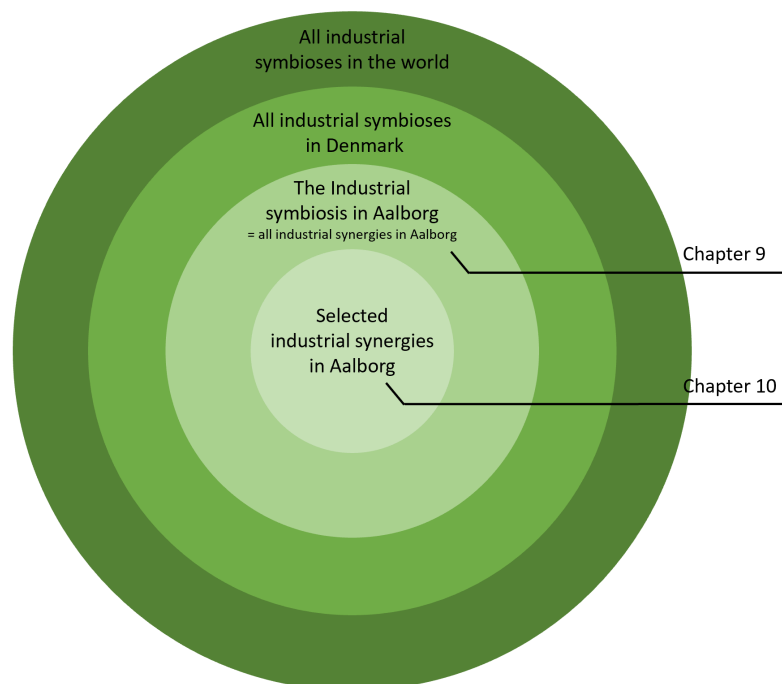
**Table 8.2:** Types of waste exchanges that are subject of the analysis

The area, that we chose as subject of our analysis, goes beyond the city of Aalborg, but encompasses Aalborg as a municipality (see highlighted part of map of North Judland in figure 8.1 below).



**Figure 8.1:** Research Scope  
Authors' elaboration

Waste exchanges within this scope have been considered for the first part of our research (see Part VII, CH. 9), in which all industrial synergies of the area are going to be displayed. For the second part of our work (see Part VIII, CH. 10) we zoomed in on selected synergies and companies within the displayed network, as displayed below (see figure 8.2).



**Figure 8.2:** Focus of the present work  
Authors' elaboration

While we selected interview partners from certain companies, thus *actors* of the ecosystem, the cases we chose as units of analysis are the *links* between them. Hence, when we talk about companies or organization that are active within the industrial symbiosis, we mean *actors* that took certain *positions* within this ecosystem. When talking about the phenomena we defined as cases, we refer to them as *links*, but also as (industrial) synergies or waste exchanges.



### 8.3 Data Collection and Analysis

*Which technique did we choose to collect and analyze data and why?*

While conducting a study with multiple cases, researchers often encounter an issue which Stake (2013) describes as the "case-quintain dilemma". During the work on the analysis of a single case the collection of other cases mostly remains at the back of the mind. The target case demands most of the attention. Each single case and the collection of more cases require attention. To avoid this tension, we, as researchers, chose to take the structured approach displayed below (see figure 8.3). Here, we clearly differentiated between allotted time slots for case selection, data collection, and analysis, which allowed us to focus on each task separately.

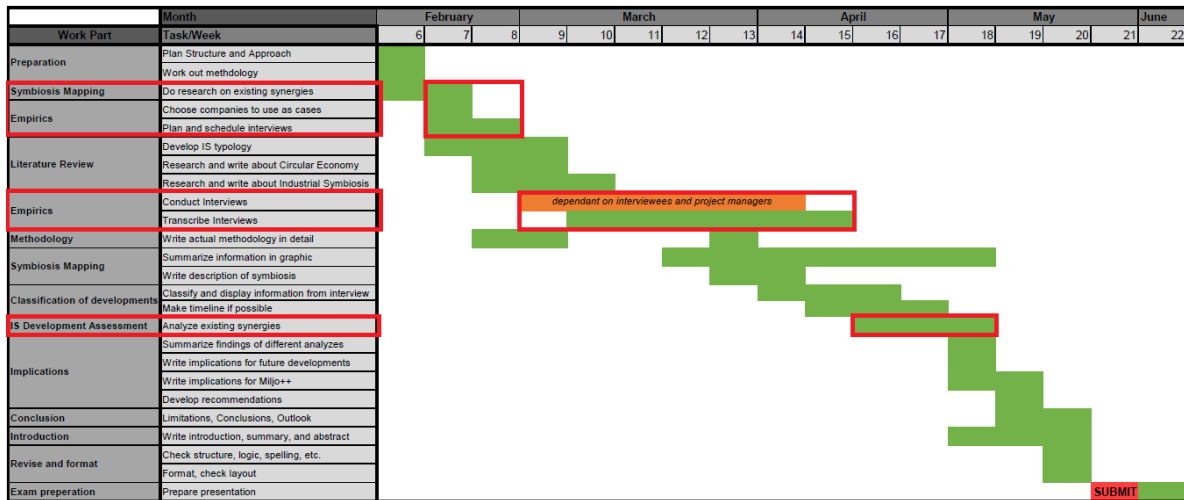


Figure 8.3: Project Timeline  
Authors' elaboration

**Data Collection** *Which technique did we choose to collect the data and why?*

Both primary and secondary data was collected for the case study, preferably from multiple stakeholders connected to the case synergies. The secondary data was extracted from literature, websites and other public information sources, and was used to compile a preliminary case study for the region. A considerable effort was then made to extend and deepen each case study through primary data collection.

We chose to interview companies belonging to four groups to make sense of the development of IS within Aalborg:

1. Companies involved in industrial symbiosis
2. Companies not involved in industrial symbiosis
3. Recycling Companies
4. Other actors

The interview guides for companies in each of these 4 groups were fairly similar:

1. We planned to ask companies who are **involved in the symbiosis (1)** in detail about their existing synergies, and the history and development of these. We also tried to get in touch with several interviewees in these companies, especially for the ones involved in many synergies, as this is the most important information source for us.

While this is the group of companies and *actors* that have a *position* within the industrial symbiosis system and are actively involved in *activities* directly related to the preservation of *links*, there are other *actors* that needed to be considered regarding their position in establishing the *links*.

2. Through interviewing also companies who are **not involved in industrial symbiosis (2)** we planned to find out what the barriers to IS development were and are and what differentiates these companies from the ones that are involved in IS.
3. We ask **recycling companies (3)** about their role as an intermediary and the reasons why companies decide for them instead of direct waste exchange through industrial symbiosis.
4. We also interview **other actors (4)** e.g. from the Kommune or different sustainability initiatives in Aalborg to determine other actors, external factors, and facilitators that influence IS development.

Below (see figure 8.3) the summary of conducted interviews, is structured according to the very same organizing principle.

#	Organization/Topic	Interviewer Position and Name	Date	Interviewer	Type of Interview	Reference
<b>1) IS COMPANIES</b>						
1	Aalborg Forsyning (Vand)	Procesingenør Anne Holm Jensen and Innovation og videndeling employee Rikke Dahl Jensen	13.04.2018	Leonie Schlueter, Andrea Milani	Personal Interview	Jensen and Jensen, 2018
2	Aalborg Forsyning (Varme)	Forsyningschef Jesper Møller Larsen	24.04.2018	Leonie Schlueter, Andrea Milani	Personal Interview	Larsen, 2018
3	Aalborg Portland	Servicekoordinator Bent Ole Borup	08.05.2018	Andrea Milani	Personal Interview	Borup, 2018
4	Aalborg Portland	Environmental Engineer Torben Ahlmann-Laursen	25.04.2018	Leonie Schlueter, Andrea Milani	Personal Interview	Ahlmann-Laursen, 2018
5	Aalborg Portland	PhD Student Romain Sacchi	13.04.2018	Leonie Schlueter, Andrea Milani	Personal Interview	Sacchi, 2018
6	Nordjyllandsværket	Environmental Managers Jørgen Bornø Jensen and Flemming Vestergaard Nielsen	09.05.2018	Leonie Schlueter, Andrea Milani	Personal Interview	Jensen and Nielsen, 2018
7	Nordjyllandsværket	Former Resource Department Manager Anders Klitgaard	11.04.2018	Leonie Schlueter, Andrea Milani, Lucia Mortensen	Personal Interview	Klitgaard, 2018
8	Royal Greenland	Corporate Sustainability and Environmental Manager Lisbeth Schönemann-Paul	01.05.2018	Leonie Schlueter	Written questions	Schönemann-Paul, 2018
9	Reno Nord	Miljø- og Udviklingschef Henrik Kirkegaard	20.04.2018	Leonie Schlueter, Andrea Milani	Personal Interview	Kirkegaard, 2018
10	Aalborg Havn	Miljøkoordinator og Havneingeniør Brian Dalby Rasmussen	07.03.2018	Leonie Schlueter, Andrea Milani	Personal Interview	Rasmussen, 2018
<b>2) NON-IS COMPANIES</b>						
11	Novopan Traenindustri	Indkøbschef Gitte Andersen	04.05.2018	Leonie Schlueter	Written questions	Andersen, 2018
12	Danish Crown & Tulip	Environmental Manager Charlotte Thy	12.04.2018	Leonie Schlueter	Phone Interview	Thy, 2018
13	Hedegaard	Fabrikschef Kim Sørensen	25.04.2018	Leonie Schlueter, Andrea Milani	Personal Interview	Sørensen, 2018
14	Bladt Industries	Manager Technique/Equipment Thomas Møller Pedersen	18.04.2018	Leonie Schlueter, Andrea Milani	Personal Interview	Pedersen, 2018
15	Aalborg Zoo	Driftschef Søren Møller Abildgård	16.04.2018	Leonie Schlueter	Written questions	Abildgård, 2018
16	AAU Service	Projektleder Vibeke Ulriis-Nordberg	24.04.2018	Leonie Schlueter, Andrea Milani	Personal Interview	Ulriis-Nordberg, 2018
17	Better World Fashion	Country Manager Melanie Ihlenfeld	17.04.2018	Leonie Schlueter, Andrea Milani	Personal Interview	Ihlenfeld, 2018
<b>3) WASTE MANAGEMENT COMPANIES</b>						
18	Marius Pedersen	Environmental Consultant Lisa Dreier	10.04.2018	Leonie Schlueter	Personal Interview	Dreier, 2018
19	Uniscrap	Regionschef Anton Korfitsen	12.04.2018	Leonie Schlueter, Andrea Milani	Personal Interview	Korfitsen, 2018
20	HJ Hansen	Kommerciel Direktør Mogens Bach Christensen	11.04.2018	Leonie Schlueter, Andrea Milani	Phone Interview	Christensen, 2018
21	RGS Nordic	Sales Manager Johnny Kristensen	26.04.2018	Andrea Milani	Personal Interview	Kristensen, 2018
22	Daka SecAnim	Plant Manager John Jensen	23.04.2018	Leonie Schlueter	Phone Interview	Jensen, 2018
<b>4) OTHER ACTORS</b>						
23	Aalborg Kommune/ NBEN	Team Leader Environmental Department Henrik Møller Thomsen	28.03.2018	Leonie Schlueter, Andrea Milani	Personal Interview	Thomsen, 2018
24	Aalborg Kommune	Green Agent Zacharias Brix Madsen	13.04.2018	Leonie Schlueter, Andrea Milani	Personal Interview	Madsen, 2018
25	International House/ City Council	Lasse Frimand Jensen	27.03.2018	Leonie Schlueter	Personal Interview	Jensen, 2018b
26	Linköping University	Assistant Professor and IS Researcher Murat Mirata	23.04.2018	Andrea Milani	Phone Interview	Mirata, 2018

Table 8.3: Data Collection: Conducted Interviews

We chose a semi-structured interview design to collect the information from our interview partners. Even though we prepared a list of predetermined questions, these kinds of interviews are supposed to unfold in a conversational manner offering participants the chance to explore issues they feel are important. It is similar to how we talk with people in our everyday lives, but, however, more self-conscious, orderly, and structured (Longhurst, 2003). We chose this type of data collection as we wanted to make sure to get the information regarding barriers, drivers, and facilitators of IS that were needed to answer our research question, while at the same time leaving room for spontaneous questions and relevant topics that were not anticipated before.

Cohen-Rosenthal (2000) states that *"since semi-structured interviews often contain open-ended questions and discussions may diverge from the interview guide, it is generally best to tape-record interviews and later transcript these tapes for analysis"*. Following this advice we recorded all conducted interviews and made written transcripts or summaries of every interview to have them ready for the analysis.

However, some issues were encountered during the data collection as well. One issue was the information that interviewees themselves had and could share with us, as the following example shows.

**Interviewer:** Can you tell us how your waste generation and management changed over the times? Which parties were involved?

**Interviewee:** No, I am new in the job.

Similarly, many interviewees did not have information on our topic of investigation, as many of the synergies we planned to analyze reach way back into the past. For this reason, the amount of interviews we conducted helped us to gather the relevant information.

#### **Data Analysis** *Which technique did we choose to analyze data and why?*

Economic activity is now increasingly viewed as interconnected economic agents forming a network economy. Research includes more dimensions to better understand the continuous interaction and behavior of interconnected organizations (Nohria and Eccles, 1992; Ghisi and Martinelli, 2006) than it did before.

Also when analyzing businesses as compared to the whole economy, rarely, researchers choose a perspective of stand-alone, atomistic economic actors that compete against each other in an impersonal marketplace. This view is becoming *"less adequate in a world in which firms are embedded in networks of social, professional, and exchange relationships with other economic actors"* (Anggraeni, Den Hartigh, and Zegveld (2007, p.2) based on Gulati (1998), Galaskiewicz and Zaheer (1999), and Gulati, Nohria, and Zaheer (2000)).

Also, in our research field of 'Industrial Symbiosis' system-thinking seems to be necessary. As industrial ecologists consider eco-industrial parks and industrial symbioses as the industrial counterpart to biological ecosystems, a systemic view on the development of IS seems not only appropriate, but also necessary to do justice to the concept's systemic nature (Lowe, 1993).

We want to use a structuralist approach to analyze the development of the ecosystem we are talking about - Industrial Symbiosis. We chose to use the framework provided by Adner (2017) to do so, as it is focused on activities, rather than actors, and explains how alignment requirements between actors leads them to positions that allow them to create value (Gjerding (2018) based on Adner (2017)).

To make sense of what conditions in the ecosystem provide the right environment for the value proposition of industrial symbiosis to take place, we chose to analyze various cases: the linkages between companies. We chose to analyze these linkages according to the three categories of drivers, facilitators, and barriers, and rate them according to the strength they showed in each specific case.

#### **Drivers**

0= No driver

1= Awareness of driver

- 2= Not decisive driver, part of a mix of drivers
- 3= Decisive driver

**Facilitators**

- 0= No facilitator
- 1= Awareness of facilitator
- 2= Not decisive facilitator, part of a mix of facilitators
- 3= Decisive facilitator

**Barriers**

- 0= No barrier
- 1= Taken into consideration, but was non-existent or easily overtaken
- 2= Significant challenge, but overtaken
- 3= Barrier that can still influence the actual symbiosis

We chose to separately analyze these development factors of selected synergies (which we call focus-synergies in the following). This will allow us specific case-related insights into the ecosystem that influenced the developments. Additionally, we chose to use the information from our interview groups (2), (3), and (4) to gain further insights into barriers and facilitators of IS. These analyses are presented in chapter 10.3, 11.1, and 11.2.

In the end, we chose to unite our findings from these different analyses to reach a holistic understanding of the ecosystem related to IS development in Aalborg (see CH. VII).

## **Part VI**

# **Aalborg Industrial Symbiosis Analysis**

# Chapter | 9

## The IS of Aalborg

The following section shall give a visualized as well as explanatory overview of the IS of Aalborg and its characteristics.

The following table (see figure 9.1) shows all the individual waste exchanges considered as part of the industrial symbiosis network as introduced in the typology of chapter 5.2. Each exchange is defined as an 'Industrial synergy', together forming the Industrial Symbiosis of Aalborg.

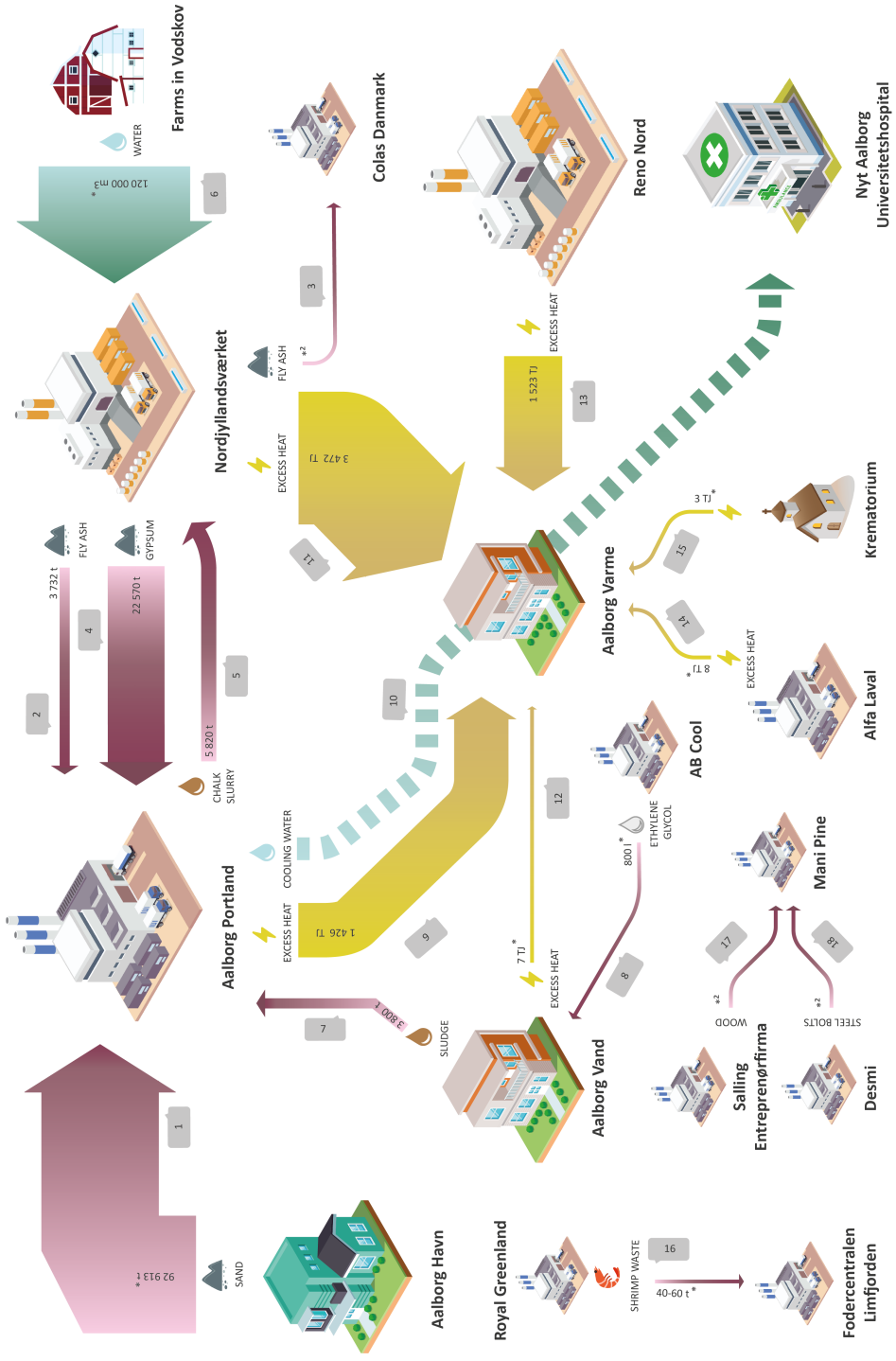
#	Delivering Company	Receiving Company	Material	Amount/year
1	Aalborg Havn	Aalborg Portland	Sand	92 913 m <sup>3</sup>
2	Nordjyllandsværket	Aalborg Portland	Fly ash	3 732 t
3	Nordjyllandsværket	Colas Danmark	Fly ash	
4	Nordjyllandsværket	Aalborg Portland	Gypsum	22 570 t
5	Aalborg Portland	Nordjyllandsværket	Chalk slurry	5 820 t
6	Farmers in Vodskov	Nordjyllandsværket	Water	120 000 m <sup>3</sup>
7	Aalborg Forsyning (Vand)	Aalborg Portland	Sludge	3 800 t
8	AB Cool	Aalborg Forsyning (Vand)	Ethylene Glycol	800 l
9	Aalborg Portland	Aalborg Forsyning (Varme)	Heat	1 426 TJ
10	Aalborg Portland	Nyt Aalborg Universitetshospital	Cooling water	
11	Nordjyllandsværket	Aalborg Forsyning (Varme)	Heat	3 472 TJ
12	Aalborg Forsyning (Vand)	Aalborg Forsyning (Varme)	Heat	7 TJ
13	Reno Nord Power plant	Aalborg Forsyning (Varme)	Heat	1 523 TJ
14	Alfa Laval	Aalborg Forsyning (Varme)	Heat	8 TJ
15	Crematory	Aalborg Forsyning (Varme)	Heat	3 TJ
16	Royal Greenland Seafood	Fodercentralen Limfjorden	Shrimp waste	40-60 t
17	Salling Entreprenørfirma A/S	Mani Pine	Recycled wooden material	
18	Desmi A/S	Mani Pine	Steel bolts	

Table 9.1: Overview of material exchanges within the industrial symbiosis of Aalborg

18 synergies could be identified in the industrial symbiosis of Aalborg. 17 actors are involved in the IS system in Aalborg. There are 11 exchanges of materials or liquids between companies and 7 exchanges of heating and cooling. The IS map (figure 9.1) visualizes the above listed synergies. All of these synergies are, according to the waste exchange typology introduced in chapter 5.2 defined as industrial symbiosis. Moreover, they are taking place within the borders of Aalborg municipality. Deliveries of waste from companies outside this area are excluded. So are deliveries to waste management companies or internal waste recycling within companies.

When we talk about this system of direct waste exchanges within the municipality, we refer to it as 'Industrial Symbiosis' of Aalborg. When we talk about 'Ecosystem' it refers, however, to the surroundings of the industrial symbiosis that influence its development.

Within this paper, we focus on analyzing the history and thus the development of selected synergies. The synergies 1 - 11 are going to be examined in-depth in chapter 10, while a briefer overview is going to be generated of the non-focal synergies in section 10.3. The analysis of the focal synergies is going to be discussed in chapter 12, while insights from both parts are used for the ecosystem analysis in chapter 13.



Leonie Schlueter, Andrea Milani, 2018

Figure 9.1: Industrial Symbiosis in Aalborg, 2018  
Authors elaboration

# Chapter | 10

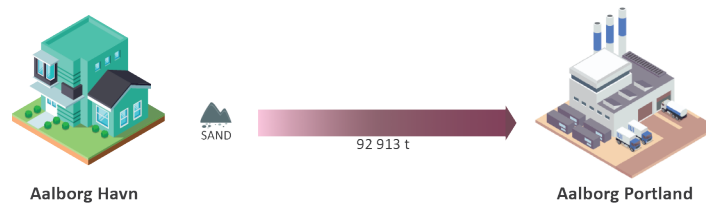
## Historic Development of Industrial Synergies

The present chapter shall analyze thoroughly the development of selected cases of industrial synergies within Aalborg. For each case a timeline of milestones and activities of the history is going to be created and subsequently an analysis of drivers, barriers, and facilitators will take place.

For a better overview, first the focal synergies of solid materials are discussed, then the focal synergies of heating and cooling are going to be analyzed, and concluding, a brief overview of non-focal synergies is going to be given.

### 10.1 Material Synergies

#### 10.1.1 Synergy 1



**Figure 10.1:** Synergy 1: Illustration  
Authors' elaboration

#### Aalborg Havn

The core business of Aalborg Havn is the operation of the port area and other logistics activities. It is a public owned company and Aalborg Kommune holds 100% of the shares. Therefore its development is valuable for the municipality's growth strategy of the East area.

#### Aalborg Portland

Aalborg Portland is a producer of grey and white cement. The company is the world largest exporter of white cement. It was established in 1889 in Aalborg and is part of the Italian Cementir Holding S.p.A. since 2003. It directly provides 261 jobs, not to mention the indirect jobs and contractors (Aalborg Portland A/S, 2017).

#### Sand

The material exchanged in this synergy is the dredged sand coming from the periodic dredging of the Limfjord, which is necessary to allow ships to access the fjord. As sand, combined with chalk, is the main raw material for the production of gray cement, it is used within Aalborg Portland's production process: The sand sludge is mixed with chalk in sludge basins, from which it is pumped to the furnace plant of Aalborg Portland. Before this partnership, the dredged sand was collected and dumped into the open sea.



## Development of IS



**Figure 10.2:** Synergy 1: Timeline  
Authors' elaboration

**Before 1998:** This connection started more than 20 years ago (Ahlmann-Laursen, 2018-04-25).

### Drivers, Barriers, Facilitators

The drivers of this synergy are mainly connected to economic motives.

In 1990-1991, Aalborg Havn became gradually aware of the necessity of Aalborg Portland to find a substitute to their sandy gravel. This was because this resource would not last much longer. At the same time, the 'dredging' activity was carried out since a long time at Hals Bare and Løgstør. It was also an expensive activity because the sand that was sucked at Hals Bare was transported in the Kattegat and dumped in the open sea. Aalborg Portland had investigated whether this sand could be used in its cement production instead as a raw material (Thomsen, 2017).

The amounts of sand taken from the fjord fluctuate, depending on the weather conditions. If there is a storm in winter, for example, more sand has to be dredged from the fjord. The fjord is being dredged at least 2 times a year, and, depending on the weather conditions, sometimes up to 3 or 4 times per year (Rasmussen, 2018-03-07).

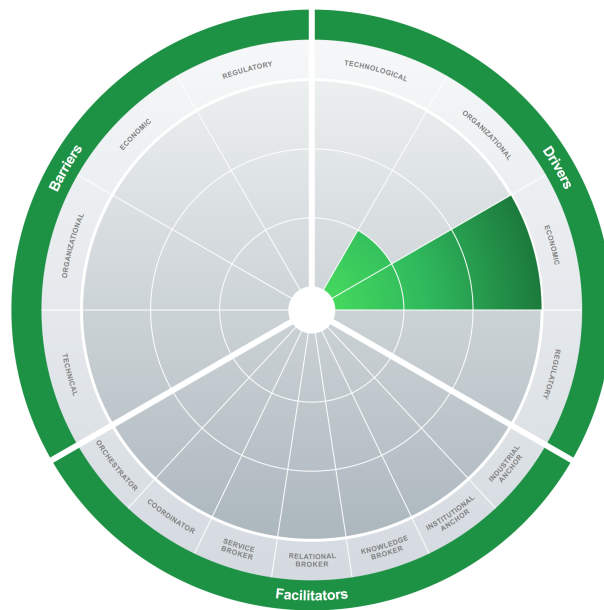
As the dredging is connected to high costs, part of these costs can be counterbalanced with the payments from Aalborg Portland. From the side of Aalborg Havn it this synergy is thus highly economically driven (Rasmussen, 2018-03-07). The same can be assumed from the side of Aalborg Portland, as we found out that their procurement processes are mainly economically driven (Sacchi, 2018-04-13; Borup, 2018-05-08) [**Economic Driver: 3**].

However, the company seemed to be aware of the positive societal impacts that this decision had, which as an organizational inclusion of social corporate responsibility bears witness to the awareness about organizational drivers [**Organizational Driver: 1**], as the following quote shows:

*The alternative was to dump it into the Kattegat for instance. You can also do that, of course, but then, without us receiving it, we would have to get the sand from the landscape. So it is also convenient for the society. It's a win-win situation. (Ahlmann-Laursen, 2018-04-25)*

There was no indication of any facilitators or barriers in the establishment of this synergy.

Despite the limited amount of data at our disposal, it is possible to notice the importance of the economic driver and the limited relevance of the organizational one. No further observations are possible to make.



**Figure 10.3:** Synergy 1: Intensity of drivers, barriers, and involvement of facilitators  
 Authors' elaboration

### 10.1.2 Synergy 2 and 3

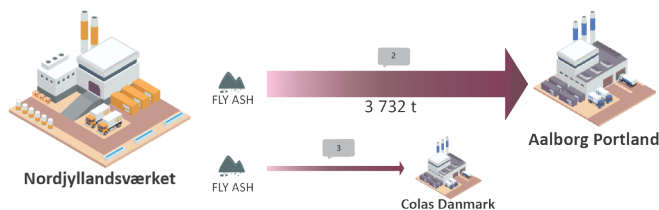


Figure 10.4: Synergy 2 and 3: Illustration  
Authors' elaboration

#### Nordjyllandsværket

This company is a coal power plant which is since 2016 owned by Aalborg Kommune through its utility company called Aalborg Forsyning (Varme). The main plant product is electricity (Aalborg Energikoncern, Nordjyllandsværket A/S, 2017). The company is based in Vodskov, on the northern side of the Limfjord.

#### Aalborg Portland

Aalborg Portland is a producer of grey and white cement. The company is the world largest exporter of white cement. It was established in 1889 in Aalborg and is part of the Italian Cementir Holding S.p.A. since 2003. It directly provides 261 jobs, not to mention the indirect jobs and contractors (Aalborg Portland A/S, 2017).

#### Fly Ash

The fly ash is a combustion product of the power plant, it is made of fine particles of the burned fuel and it is ousted out of the boilers together with the flue gases. It became a standard product used in cement and asphalt production as an additive to enhance these materials' performance. Before finding use in these industries it was land-filled next to the power plant.

#### Development of IS

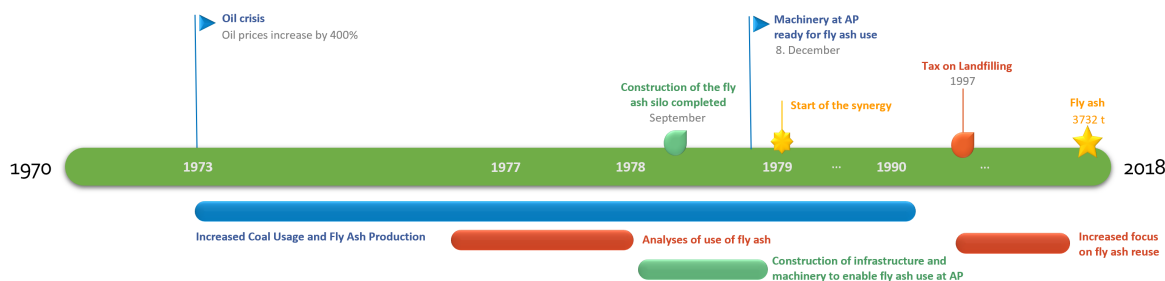


Figure 10.5: Synergy 2 and 3: Timeline  
Authors' elaboration

**1973:** The first oil crisis led to increased usage of coal in power generation and is accompanied by rising amounts of fly ash (Thomsen, 2017).

**1977:** Several parties and industries in Denmark start investigating in a potential use of fly ash in different applications (Portland, 1977).

**September 1978:** The construction of the fly ash silo at Aalborg Portland is completed, installations of various machinery continues (Portland, 1978).

**October 1978:** The use of fly ash is expected to start in October 1978, but is postponed (Portland, 1978).

**December 1978:** The machinery to handle the fly ash is set-up, but the start of the synergy is being postponed until after Christmas and New Years Eve (Portland, 1979).

**January 1979:** The use of fly ash started (Portland, 1979).

### Drivers, Barriers, Facilitators

Even though originally Aalborg's power plants, namely Nordkraft and Nordjyllandsværket, were coal-burning power stations, with the beginning of the oil crisis in 1973 (Akins, 1973) other power stations in Denmark and all over the world increasingly began to burn coal instead of oil for the production of electricity and heat. This led to increasing amounts of fly ash (Thomsen, 2017).

The potential for using fly ash as a supplementary cementitious material in concrete has been known almost since the start of the last century (Anon, 1914) and the topic has been investigated continuously during the 1930's and 1940's (Dolen, 2001). Pioneering research in this area has been for example conducted at the University of California Berkeley (Davis et al., 1937). The first large-scale utilization of fly ash in concrete then took place in the middle of the 1900's century, with the U.S. Bureau of Reclamation using fly ash to repair a tunnel in Hoover dam in 1942 (Thomas, 2007). In the last 50 years, the use of fly ash in concrete grew dramatically (Thomas, 2007) with fly ash today being a standard component in the production of modern concrete (Dolen, 2001). Now "*the use of fly ash in the cement industry is actually pretty widespread*" (Sacchi, 2018-04-13, 03:46). While we view the connection between Aalborg Portland and Nordjyllandsværket on a local level, the technical developments led to worldwide exchanges of this recovered resource (Day, 2016).

After the oil crisis, increased attention has been paid to this potential use also in Denmark. Before the energy crisis in 1973, it was a modest amount of fly ash of a few thousand tons in Denmark, but with the relatively rapid conversion to coal firing, fly ash production grew almost explosively over a few years to reach a level of approx. 1 million tons. As other countries had experience with applications of fly ash in the concrete in Asphalt industry, endeavours in this direction also started in Denmark (E-Mineral, 2018). In 1977, in a collaboration of two parties, it was evaluated whether there are technical and economic possibilities of exploiting power plants' fly ashes in cement production. On the one side there was ELSAM, the electricity association of Jutland and Funen (Dirks and Keeling, 1962), and KRAFTIMPORT, the electricity association of Zealand (Dirks and Keeling, 1962), and on the other side there was FLSmidt, the cement concern, and Aalborg Portland, the local factory of Aalborg, working together (Portland, 1977). Not only were there many technical possibilities to be examined, but also transport and the price of fly ash from different power plants had to be evaluated (Portland, 1977). Moreover, the possibilities for a smooth supply and the quality of the ash were areas that have been investigated (Portland, 1977). However, the project was not the first of its kind, investigating the use of fly ash from power plants. The leader of the Cement Factories' Technical Information Office ('Cementfabrikkernes tekniske Oplysningskontor') was already at that time part of a research group that investigated the opportunities of using incineration residues from power generation as an aggregate for concrete production (Portland, 1977). At the same time the side of the representatives of the power plants also had other studies in place to find the best solution for the use of the fly ash (Portland, 1977) [**Technological Driver: 2**].

We can assume that there were various technical barriers to be overcome: An analysis in 1976, which investigated the incineration of municipal waste in the cement oven of Aalborg Portland, came to the conclusion that is not applicable, as the amount and the chemical composition of the ashes must be able to be fully controlled (Portland, 1976), which was not possible for municipal waste. The consistency and control-ability of components of the resources used in cement production leads to high quality requirements. Back then, it was concluded that "*these conditions will require large homogenization and storage facilities which, for technical and environmental reasons, will make such a plant very expensive*" (Portland, 1976).

Also, even after technical analyses of the usage of fly ash, high investments were necessary, as most of the kilns at Aalborg Portland have been specifically designed to use fly ash (Sacchi, 2018-04-13, 03:46). High technical changes, which implicate economic challenges, thus were present. The actors of the synergy have been aware of these barriers, but overcame them successfully [**Technological Barrier: 1, Economic Barriers: 1**].

As we analyzed above, the present synergy is part of a larger development within the industries. It also just

represents only one component of the whole trade of coal ash (fly ash and bottom ash) that Nordjyllandsværket and Aalborg Portland are involved in. Not only is there another delivery of fly ash to the asphalt producer 'Colas Danmark' within Aalborg (Synergy 3), but also outside, with a delivery of fly ash to the biomass-fired power plant in Studstrup near Aarhus. Moreover, bottom ash is delivered from Nordjyllandsværket to companies outside of Aalborg, namely RC Beton and Rockwool. On the other side, Aalborg Portland also receives fly ash from other power plants than Nordjyllandsværket and bottom ash from bio-mass fired power plants outside of Aalborg (Jensen and Nielsen, 2018-05-09).

To control the trade of this waste product that has been turned into a resource and opened up a whole national market, a separate company was founded. This endeavour was based on the collaboration between ELSAM / ELKRAFT and FL Smidt / Aalborg Portland that began in the mid-1970s. Founded in 1978 the company 'E-Mineral' is owned by the powerplants Ørsted Bioenergy & Thermal Power A/S, HOFOR Energiproduktion A/S, Fjernvarme Fyn Produktion A/S and Nordjyllandsværket A/S and is responsible to trade the ashes of these power plants. When talking about driver of the specific synergy between Aalborg Portland and Nordjyllandsværket, we need to take the decision making process within E-Mineral into account. This has been largely motivated by economic motives, as the interview extract below shows.

**Interviewer:** *"How do they decide where they transport it to and which companies receive it?"*

**Flemming Vestergaard Nielsen:** *"I think they go for the best business contracts"* (Jensen and Nielsen, 2018-05-09, 23:38).

Also, today, the decisions seem to be mostly economically motivated:

**Jørgen Bornø Jensen:** *"When it started 30 years ago, nobody cared about the environmental benefits but only economic ones."*

**Interviewer:** *"And how are these decision make now?"*

**Jørgen Bornø Jensen:** *"I think it is still for the economic benefits."* (Jensen and Nielsen, 2018-05-09, 25:56)

**[Economic Driver: 3]**

However, there were also other factors taken into consideration, as the quote below indicates.

**Interviewer:** *"And how did you choose this company [Aalborg Portland]?"*

**Anders Klitgaard:** *"It was because they offered a good price and they could take all the production each year and it was close."* (Klitgaard, 2018-04-11, 22:01).

In this quote we can see how complex the decision process that leads to the establishment of IS can be. Besides the clear driver of 'a good price' also the demand size ('they could take all the production') and constancy ('each year') combined with geographic proximity ('and it was close') was a main reason for the establishment of this synergy. Geographic proximity is one of the two underlying physical driving forces for industrial symbiosis and it was also recognized as a practical advantage from the two partnering companies. Also the size and constancy of demand for the material from the receiving company has been recognized.

When talking about facilitators in the eco-system that fostered the connection to Aalborg Portland, we can see that the support was mainly coming from within Nordjyllandsværket itself:

**Interviewer:** *"To establish this connection, did you use the help of some external partner, organization, or network?"*

**Andreas Klitgaard:** *"No, because previously in Vattenfall there were three power units, so it was kind of large organization and Vattenfall is a large company, so there was a lot of assistance within the company"* (Klitgaard, 2018-04-11, 23:06) **[Facilitators: /]**.

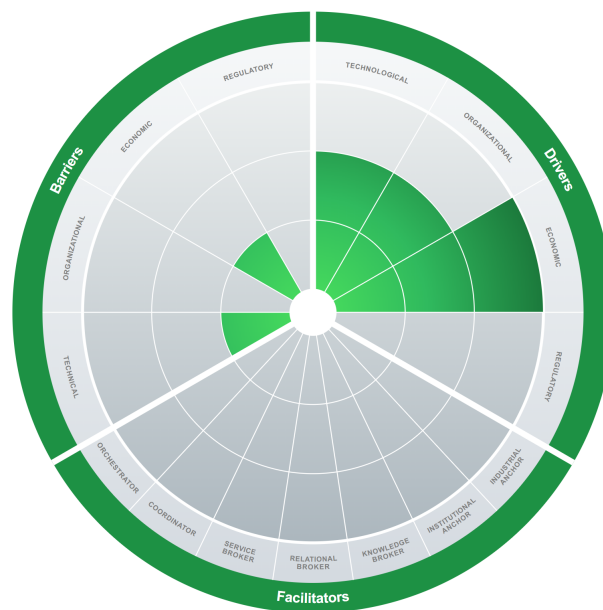
Here we can not only recognize the reason for the absence of external facilitators, but also identify an organizational driver of the industrial synergy. As Nordjyllandsværket belonged to Vattenfall, the organizational set-up of this large organization had the capacity to support the establishment of the partnership with Aalborg Portland.

Also, regulatory drivers played a role. However, these were not decisive in the implementation of the synergy, but rather in its development:

**Jørgen Bornø Jensen:** "The focus for recycling fly ash raised from the end of the 90s. They put high taxes on deposits of fly ash. I think if we bring a ton of fly ash to the landfill, we have to pay nearly 1600dkk per ton. Plus the operations and building up a deposit. So we have to." (Jensen and Nielsen, 2018-05-09, 26:49)

This tax from 1997 that taxed landfilling materials that are suitable for incineration or recycling (Resource Network Denmark, 2018) was implemented at a time when the synergy between Aalborg Portland and Nordjyllandsværket was already well established and rather influenced the whole market of fly ash trading than this synergy itself.

In figure 10.6 the central points of analysis are highlighted: From both companies it was a rather economic decision to use the fly ash residue from power generation, while a strong technological development preceded this decision. Also the organizational set-up of large companies with the capacity to gather and disperse the necessary knowledge played a central role in the development of this synergy. While technological and economic barriers to this synergy existed, and were acknowledged by the participating parties, they have been overcome and a successful material exchange was established.



**Figure 10.6:** Synergy 2 and 3: Intensity of drivers, barriers, and involvement of facilitators  
Authors' elaboration

### 10.1.3 Synergy 4 and 5

Due to the bi-directional nature of synergy 3 and 4, both of them are going to be displayed in this section. Aalborg Portland delivers the chalk slurry to Nordjyllandsværket and, once it is used for the flue gas filtering procedure, the process produces FGD (Flue-gas desulfurization) gypsum out of it and this material is delivered back to Aalborg Portland.

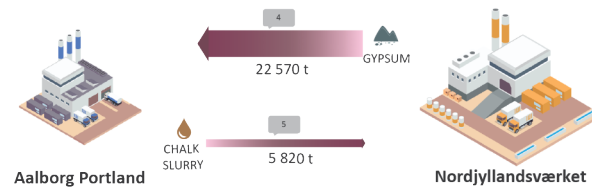


Figure 10.7: Synergy 4 and 5: Illustration  
Authors' elaboration

Aalborg Portland	Nordjyllandsværket	Chalk Slurry	Gypsum
Aalborg Portland is a producer of grey and white cement. The company is the world largest exporter of white cement. It was established in 1889 in Aalborg and is part of the Italian Cementir Holding S.p.A. since 2003. It directly provides 261 jobs, not to mention the indirect jobs and contractors (Aalborg Portland A/S, 2017).	This company is a coal power plant which is since 2016 owned by Aalborg Kommune through its utility company called Aalborg Forsyning (Varme). The main plant product is electricity (Aalborg Energikoncern, Nordjyllandsværket A/S, 2017). The company is based in Vodskov, on the northern side of the Limfjord.	It is a byproduct of the cement production. Aalborg Portland generates it while excavating its quarry. It is used in the Nordjyllandsværket unit 3 since its entry into operation in 1998 to clean the flue gases and produce gypsum.	This is a byproduct of the process used during the filtering of the flue gases. It has a suitable quality for the cement production and that is why it is used by Aalborg Portland. The power unit 3 has been designed having in mind this process so it has been used since the beginning.

### Development of IS

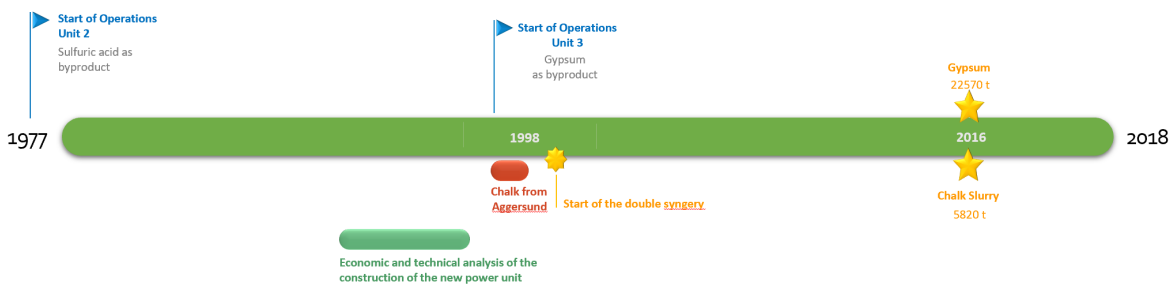


Figure 10.8: Synergy 4 and 5: Timeline  
Authors' elaboration

**1977:** Construction of Nordjyllandsværket unit 2. This unit ran with coal and it was designed to produce sulfuric acid out of the cleaning flue gas process (Jensen and Nielsen, 2018-05-09).

**1990s:** Due to the upcoming end of life of unit 2, the construction of a new unit was decided. Considerations were made on the type of power unit. After many years, the sulfuric acid process was perfected but still many problems were encountered. At that time, a new technology was developed: the use of chalk in a wet process

to produce FGD gypsum, after filtering the flue gas. Therefore, the new power unit was equipped with this new technology (Klitgaard, 2018-04-11; Jensen and Nielsen, 2018-05-09).

**1998:** The new power unit 3 was built and designed to use coal and produce FGD gypsum. For approximately two months the chalk necessary for the filtering process was delivered to Nordjyllandsværket from a open mine in Aggersund (Jensen and Nielsen, 2018-05-09). After that, a business partnership with Aalborg Portland was established. The deal was that Portland delivered the chalk slurry to Nordjyllandsværket and in return received the FGD gypsum to use in the cement production. It is used in order to prevent the cement from hardening too fast during its use. A special lorry was built with particular technical requirement to transport both materials and it commuted from one company to the other to deliver them (Jensen and Nielsen, 2018-05-09; Borup, 2018-05-08). The calculation is made once a year and only the difference is paid out by one of the companies.

### Drivers, Barriers, Facilitators

Within a perspective of development, in the 1990s, the managers of Nordjyllandsværket decided to analyze the different options available for the implementation and the construction of a new power unit. The power unit 2 was operative since 1977 and it was close to its end of life. After many obstacles, mainly of a technical nature, such as low temperature inside the unit or the difficulty to control the sulfuric acid flue, finally the sulfuric acid production was mastered. Nevertheless, another choice was made. The choice was the implementation of a power unit that could produce gypsum out of the chalk used to filter the flue gas, in a so called wet process (Jensen and Nielsen, 2018-05-09). The drivers which led to this choice were of three different types and it is possible to differentiate between reasons of the establishment of this synergy depending on whether the perspective taken is the one of Nordjyllandsværket or of Aalborg Portland.

**Nordjyllandsværket** Although the knowledge gained with the second power unit, managing the sulfuric acid was a very complex process, the upkeep of the plant required a lot of maintenance. Furthermore, there were concerns about the employees' health because of the difficulty to capture all the sulfuric flue gases. It was even necessary to build a new parking lot because of the corrosion created on the cars' paint (Andersen, 2018-05-04).

**Jørgen Bornø Jensen:** *"It was because the sulfuric acid is very difficult to maintain, it is another technique, and the price of sulfuric acid was going down in the market. So it was not a very good business and a health issue for our employees, it was a very nasty environment and difficult to maintain."* (Jensen and Nielsen, 2018-05-09, 08:45) [**Organizational Driver: 2**].

This is an example of an organizational driver because of the environmental aspect of it that made the company change the type of plant.

The second driver, as we can notice in the quote above, weighted during the evaluations prior to the construction was of an economic nature. During the 1990s the price of sulfur was decreasing, a reason for this was the increased number of sources of sulfuric acid production, among them an augmented recycling of acid (Chenier, 2002). This symbiosis therefore reduces also the cost of the disposal of desulphurisation plaster for Nordjyllandsværket and the necessity to add water to the dry chalk received from the mine in Aggersund (Jensen and Nielsen, 2018-05-09) [**Economic Driver: 2**].

Moreover, the wet process for the flue gas desulfurization (FGD) was assessed as the best technology at that moment (Jensen and Nielsen, 2018-05-09) by the departments in charge of the implementation of a new power unit.

**Flemming Vestergaard Nielsen:** *"I think it was because it was the best technology at that time. Of course they hoped they could make some good agreement later, but it was because it was technology as far as I know. Because you can remove over 99 percent, more than 99 percent of the sulphur. So the decision to produce this basically came from the department here that evaluated the opportunity, the construction process."* (Jensen and Nielsen, 2018-05-09, 13:29) [**Technological Driver: 3**].

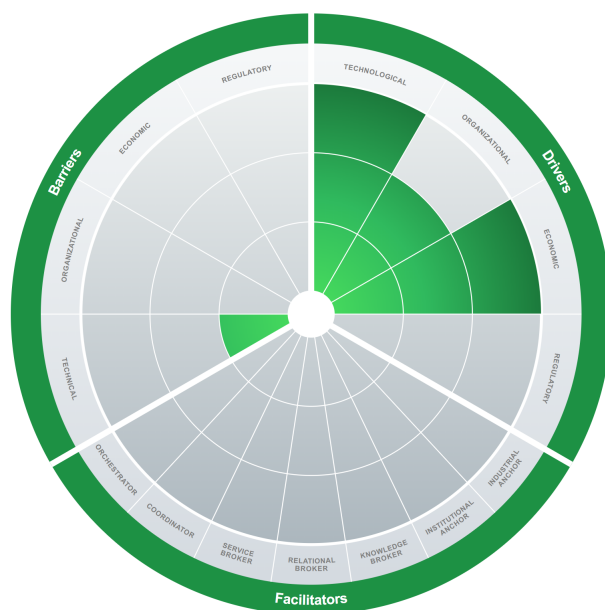


**Aalborg Portland** In the cement production, part of the chalk slurry is used by Aalborg Portland for the purification of its flue gases. However, the company has an excess of it in its excavation process in the chalk pit in the Rørdal area (Aalborg Energikoncern, Nordjyllandsværket A/S, 2017). In 1998, a few months after the construction of Nordjyllandsværket unit 3, the two companies spotted an opportunity in this symbiosis. There are not enough information to clarify if FLSmidth, at that time owner of Aalborg Portland and the manufacturer of the power unit 3, played any role as a facilitator in order to achieve this agreement (FLSmidth & Co. A/S, 2018). The deal was particularly favorable for both parties because in this way, Aalborg Portland could deliver the excess of chalk slurry and get gypsum in return, used in the cement production. This material was before sailed from Canada and Morocco. In this way, they could save the money instead of acquiring the raw material and transport it (Netværk for Bæredygtig Erhvervsudvikling NordDanmark, 2018).

For this symbiosis there is no evidence of significant barriers, the only minor obstacle was the need to build a special lorry for the transportation of both materials

**Jørgen Bornø Jensen:** *"And then when the dealer agreement was signed, we had Aalborg Portland to made a specially constructed lorry with three chambers, two for the slurry and in the middle one to bring the gypsum on the way back. So when it arrives here, it connects to the power plant, they discharge the slurry and at the same time they fill it with the gypsum in the middle chamber."* (Jensen and Nielsen, 2018-05-09, 04:48) **[Technical Barrier: 1].**

In figure 10.9 the central points of analysis are highlighted: The main drivers of this symbiosis were mainly of economic and technological nature, due to the economic advantage for both parties and the newly developed technology. The connection between the two companies possibly played by FLSmidth could have been a relational facilitator. There are no known barriers to this symbiosis, except for the transportation machinery specifically designed to suit this exchange of materials.



**Figure 10.9:** Synergy 4 and 5: Intensity of drivers, barriers, and involvement of facilitators  
Authors' elaboration

### 10.1.4 Synergy 6

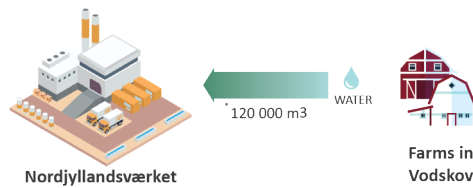


Figure 10.10: Synergy 6: Illustration  
Authors' elaboration

Farms in Vodskov	Nordjyllandsværket	Water
The farms in the surroundings of the power plant, in the Vodskov area, are in need to collect the rainwater and dispose it in order to have proper soil for their crops.	This company is a coal power plant which is since 2016 owned by Aalborg Kommune through its utility company called Aalborg Forsyning (Varme). The main plant product is electricity (Aalborg Energikoncern, Nordjyllandsværket A/S, 2017). The company is based in Vodskov, on the northern side of the Limfjord.	The rainwater is collected in trenches and then a pipe system connects these to the coal power plant. This water then is used in the wet process instead of clean water from the aqueduct. Before this synergy, the farmers were leading this water into the Limfjord.

#### Development of IS

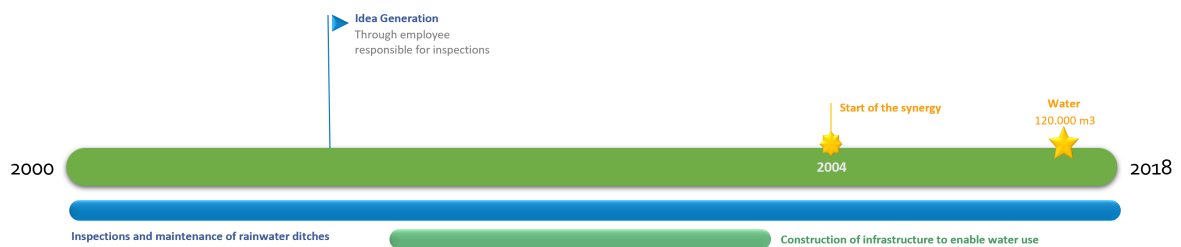


Figure 10.11: Synergy 6: Timeline  
Authors' elaboration

**2004:** Construction of Nordjyllandsværket infrastructure to collect the water from the fields and use it (Jensen and Nielsen, 2018-05-09).

#### Drivers, Barriers, Facilitators

This synergy between Nordjyllandsværket and farmers in the area around the plant started around 2004 (Jensen and Nielsen, 2018-05-09, 29:13). For the farmers it is a necessity to extract the rain water through drains and lead it away from the farms. Until the beginning of the 2000s this excess water was led into the Limfjord. On the other side of the synergy, Nordjyllandsværket have been using ground water in its process of producing gypsum, as Jensen and Nielsen (2018-05-09, 29:13) describes: *"We use it in the process, de-nox and desulfurization we need a lot of water because it is a wet process, so we have to cool it down. The flue gas it is around 140 degrees or something like that. And we go down to 60"*.

This is a direct synergy without any intermediaries involved: *"It is Nordjyllandsværket, they just make deals with the farmers and they put in pipes to connect the pumps to this basin instead of just pumping out in the fjord"* (Klitgaard, 2018-04-11). Also, the synergy has an especially high geographic proximity, with the farms being

just in the surroundings of the power plant.

When we look into the history of the development of this symbiosis we experienced a rather simple explanation:

**Interviewer:** "And how did you come up with the idea to collect the water from the farmers?"

**Jørgen Bornø Jensen:** "There was one of our employees who made an inspection in the surroundings and he looked down in one of the pumping wells of the farmers and he saw a huge amount of water pumped to the fjord."

**Interviewer:** "How come he made an inspection there?"

**Flemming Vestergaard Nielsen:** "We have the ditches. which lead the water, we have to check them, if they can still can move the water. There was a lot of grass and we have to maintain these ditches."

**Interviewer:** "Was it just a coincidence, he came up with the idea?"

**Jørgen Bornø Jensen:** "Yes! We have a box for good ideas [...]" (Jensen and Nielsen, 2018-05-09, 33:16)

Even though there might be an element of coincidence involved in spotting this opportunity because the employee saw the large amounts of water being pumped into the fjord while doing his inspection, the ability to take advantage of it depended on organizational factors within the company. What the interview describes as 'a box for good ideas' is evidence of a process or culture within the organization that allows the appreciation and evaluation of new ideas. During the data collection another factor became evident that supports these processes.

**Interviewer:** "But is this improvement necessary because of a law?"

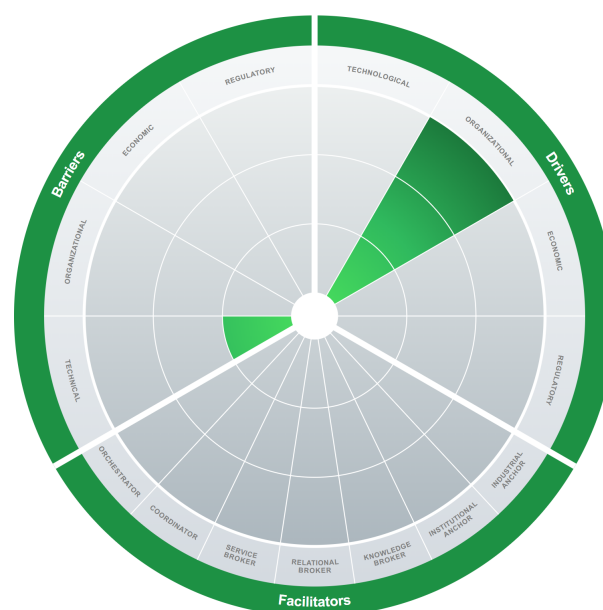
**Jørgen Bornø Jensen:** "No, it is because we have a certified environmental standard."

**Flemming Vestergaard Nielsen:** "The certification says that you have to improve and get better every year to keep the certificate" (Jensen and Nielsen, 2018-05-09, 34:42).

The presence of the environmental standard and its requirement to improve over time was an incentive that influenced the openness for the idea presented by the employee. We can thus view the environmental certification as part of the organizational drivers that led to the development of this synergy.

A pipeline that had to be built between the farmers pump and the power plant was the only technical requirement necessary for the synergy to be realized, representing a technical barrier that the involved companies were aware of.

No external facilitators supported the development of this project.



**Figure 10.12:** Synergy 6: Intensity of drivers, barriers, and involvement of facilitators  
Authors' elaboration

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Due to the limited amount of the data collected regarding this synergy, it is possible to notice only the fundamental importance of the organizational driver (acceptance and development of the employee's idea) and the easily overcame technical barrier.

### 10.1.5 Synergy 7

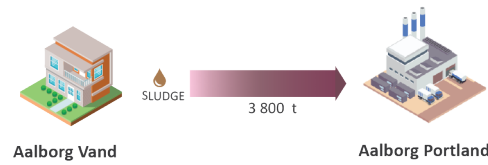


Figure 10.13: Synergy 7: Illustration  
Authors' elaboration

#### Aalborg Forsyning, water and wastewater supply

The sludge drying treatment plant that processes the sludge is based in Rørdalsvej 200, 9220 Aalborg Øst. It collects this material both from the West and the East wastewater treatment plants. The plant was established in 2000.

#### Aalborg Portland

Aalborg Portland is a producer of grey and white cement. The company is the world largest exporter of white cement. It was established in 1889 in Aalborg and is part of the Italian Cementir Holding S.p.A. since 2003. It directly provides 261 jobs, not to mention the indirect jobs and contractors (Aalborg Portland A/S, 2017).

#### Dry Sludge

When the waste water is cleaned in the two facilities in Aalborg East and West, there is a range of residual products. Paper, plastics, and other waste types are removed in the beginning of the wastewater treatment process and incinerated at Reno Nord. The digested, dewatered sludge from the Aalborg waste water treatment plant west is sent to the drying plant of the waste water treatment east, however, and ultimately used by Aalborg Portland as a burning fuel. Before, the sludge was used as nutrients on agricultural fields.

#### Development of IS

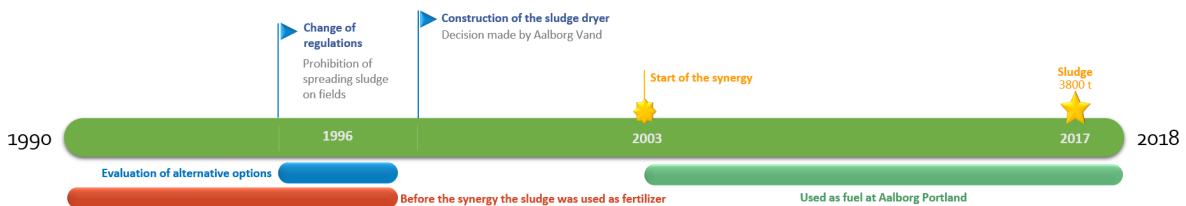


Figure 10.14: Synergy 7: Timeline  
Authors' elaboration

**Before 1996:** In the period prior to 2000, the sludge produced from the waste treatment plant in the water filtering process was sold to farmers and they were using it to fertilize the fields (Jensen and Jensen, 2018-04-13).

**1996:** The city council makes the decision of prohibiting the spreading of sludge on agricultural fields. This regulation was set in place due to a risk of heavy metals and unknown amounts of xenobiotics in the sludge. Therefore, Aalborg Forsyning’s water and wastewater supply decides to build a plant capable of drying the sludge (Aalborg Forsyning, 2018b; Jensen and Jensen, 2018-04-13).

**2003:** The synergy with Aalborg Portland was established. The wastewater treatment plant dries the sludge and then sells it to Aalborg Portland in order to be used as an alternative fuel (Nordjyske Medier, 2003).

### Drivers, Barriers, Facilitators

Interconnected are the main reasons leading to this synergy. Before 2000 the local regulation allowed the waste treatment plant to sell the sludge to the farmers whom could use it to fertilize their fields. When the new law came into force in 2000, the municipality had already foreseen the need of a different processing for the sludge (Aalborg Forsyning, 2018b).

**Anne Holm Jensen:** "Some other utilities, they spread it on the agricultural fields, the dewatered sludge, it looks like soil, because they want to use the nutrients in the sludge because there's a lot of phosphorous and nitrogen in that you can use for fertilizing. But they [Aalborg City Council] made the decision more than 20 years ago to not spread out the sludge on agricultural fields in Aalborg because there is a risk of heavy metals in this sludge. So they thought, what should we do? They ended up building a sludge drying plant and they produce some sort of granulate from the sludge" (Jensen and Jensen, 2018-04-13, 24:06) [**Regulatory Driver: 3, Technical Barrier: 1**].

Therefore, it was decided to build the sludge drier plant. This facility allowed to reduce the water content of the sludge, process the sludge into a granulate, and sell it as a source of alternative fuel (Aalborg Forsyning, 2018b; Jensen and Jensen, 2018-04-13). At that time Aalborg Portland was searching for alternative fuels instead of coal, due to a company policy that aims to substitute fossil fuels with carbon dioxide neutral fuels. A possible source was identified in the waste water treatment plant's dried sludge and the synergy was established (Ahlmann-Laursen, 2018-04-25).

**Torben Ahlmann-Laursen:** "Other treatment plants in Denmark, they deliver it to the farmers to use it as fertilizer. The symbiosis was established because we need lot of energy, and we also have the policy to substitute fossil fuels with carbon dioxide neutral fuels." (Ahlmann-Laursen, 2018-04-25, 15:07) [**Organizational Driver: 2**].

Here the environmental issue taken into consideration is what classify this driver as organizational.



**Figure 10.15:** Synergy 7: Intensity of drivers, barriers, and involvement of facilitators  
Authors' elaboration

In figure 10.18 the central points of analysis are highlighted: This symbiosis is mainly driven by regulative drivers. Due to the change of these conditions it was necessary to build a new facility and to find another way to dispose of the sludge. The economic driver was also influential in order to decide to whom send the end product.

### 10.1.6 Synergy 8

The peculiarity of this synergy is that it is an example of industrial symbiosis but it happened only once in 2016, as an experiment that did not continue after this one time exchange (Jensen and Jensen, 2018-04-13).

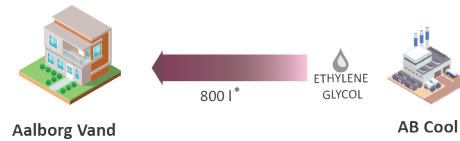


Figure 10.16: Synergy 8: Illustration  
Authors' elaboration

AB Cool	Aalborg Vand	Ethylene Glycol
The company is located in Thorn-dahlsvej 6, 9200 Aalborg. They are dealing with refrigeration systems.	This is the company in charge of the waste water treatment in the Aalborg area. The facility that receives the ethylene glycol is the one located in Mølholmsvej 30, 9000 Aalborg. Aalborg Vand is an utility company owned 100% by Aalborg Kommune.	This is a byproduct of the refrigeration system manufacturing. It is used by Aalborg Vand as nutrient for the bacteria in the waste water cleaning process.

### Development of IS

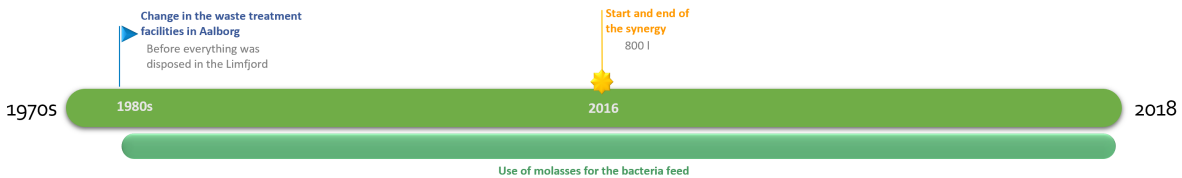


Figure 10.17: Synergy 8: Timeline  
Authors' elaboration

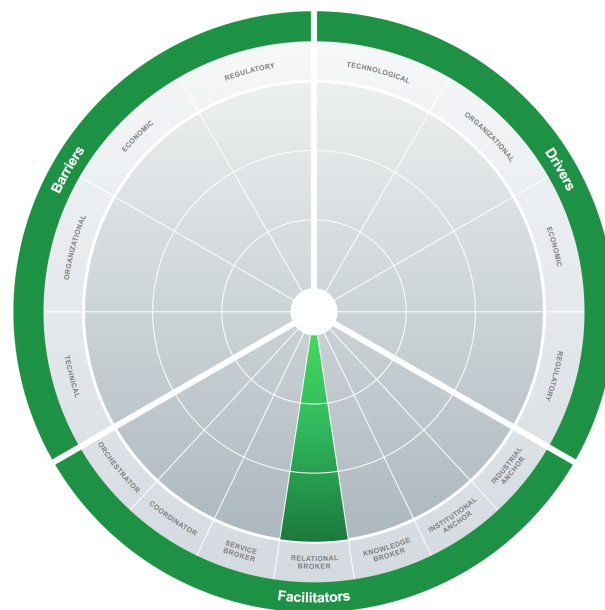
**2016:** During this year there was the testing for using the ethylene glycole as a substitute of organic matter to feed the bacteria in the waste water treatment plant.

### Drivers, Barriers, Facilitators

The initiator of this experiment was Romain Sacchi from Aalborg Portland, he was investigating about industrial symbiosis and he knew about a company, manufacturer of cooling system, that had some excess of ethylene glycol (Jensen and Jensen, 2018-04-13).

**Anne Holm Jensen:** "Last year I was contacted by Romain Sacchi who asked me about industrial symbiosis because there was a cooling company, which had some excess and they were asking: can we deliver it? I was just like, yeah, of course you can, because it's a source of organic matter. Right now we pour in some external organic matter to the process tanks because the bacteria needs some extra and that's molasses. That's a byproduct from the sugar industry. And we buy that. And then they ask you, are you interested in receiving more of like we were just like, yeah, if you can deliver the amounts that we need" (Jensen and Jensen, 2018-04-13, 40:26) [**Relational Broker: 3**].

Therefore, a trial was conducted in 2016 with a limited amount of material, 800 liters, and was not repeated after that time (Jensen and Jensen, 2018-04-13; Sacchi, 2018-04-13). A possible barrier is the requirement of Aalborg Vand to have a stable supply of this organic material. Now the main supplier is a company called Dankalk, a producer of molasses.



**Figure 10.18:** Synergy 8: Intensity of drivers, barriers, and involvement of facilitators  
Authors' elaboration

In figure 10.18 the central points of analysis are highlighted: In this particular synergy, the role of the relational broker stands out, which was essential to establish it. The main problem to the ongoing success of this synergy is the fact that Aalborg Varme is in need of a stable supplier of an organic component and it cannot work with floating supplies.



## 10.2 District energy synergies

District energy infrastructures have an important role to play in making cities tackle one of their main challenges, as presented in chapter 2.1: making scarce energy resources meet future demands. We can differentiate between the district heating which comprises a network of pipes connecting the buildings in a neighbourhood or whole city, supplying heat and hot water to buildings, and district cooling, which distributes cooling water (Lund et al., 2014).

There are a number of separate district heating networks in Aalborg Municipality, but 86% of the net heating demand is supplied by the central DH grid pertaining to the city of Aalborg (Østergaard, 2013).

In future sustainable cities the district heating network is envisioned to be supplied by a variety sources, potentially including combined heat and power (CHP), heat from waste-to-energy, various industrial surplus heat sources as well as geothermal and solar thermal heat (Lund et al., 2014).

The concept of industrial symbiosis meets district energy systems when we talk about excess heat or excess cooling that is used in these systems. As industrial symbiosis is not limited to the exchange of materials, but also encompasses the exchange of water or energy, the use of excess energy often is a large untapped resource, which creates benefits for industry and society, creating a system in which *"waste to one component of the system represents resources to another"* (Jelinski et al., 1992, p.793).

Currently, heat networks can be supplied by a diverse range of sources including. Some of them are included in the industrial symbiosis system of Aalborg:

- power stations (see synergy 11 in chapter 10.2.3)
- energy from waste (EfW) facilities (see synergy 13 in chapter 10.3)
- industrial processes (see synergies 9 and 14 in chapter 10.2.1)

However, sources of district heat can also be biomass and biogas fuelled boilers and CHP plants, gas-fired CHP units, fuel cells, heat pumps, geothermal sources, or electric boilers and even solar thermal arrays.

### 10.2.1 Synergy 9

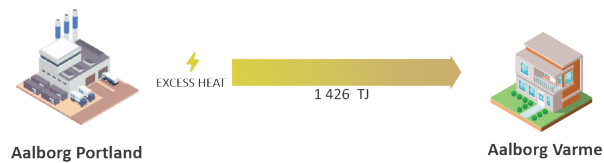


Figure 10.19: Synergy 9: Illustration  
Authors' elaboration

Aalborg Portland	Aalborg Varme	Excess Heat
<p>Aalborg Portland is a producer of grey and white cement. The company is the world largest exporter of white cement. It was established in 1889 in Aalborg and is part of the Italian Cementir Holding S.p.A. since 2003. It directly provides 261 jobs, not to mention the indirect jobs and contractors (Aalborg Portland A/S, 2017).</p>	<p>Aalborg Varme is the city's district heating supplier and part of the municipality-owned utility company 'Aalborg Forsyning' (Aalborg Energikoncern, Aalborg Varme A/S, 2018).</p>	<p>Industrial excess heat is heat that industrial firms cannot use internally in production or support processes. From the viewpoint of the district heating planners, the use of primary energy in heat production can be reduced by using industrial excess heat, which may confer both economic and environmental benefits (Broberg et al., 2012). Within the cement production in Aalborg Portland, part of the heat produced is collected and then fed back to the district heating network. Then, Aalborg Varme if necessary integrates it to reach a certain temperature.</p>

### Development of IS

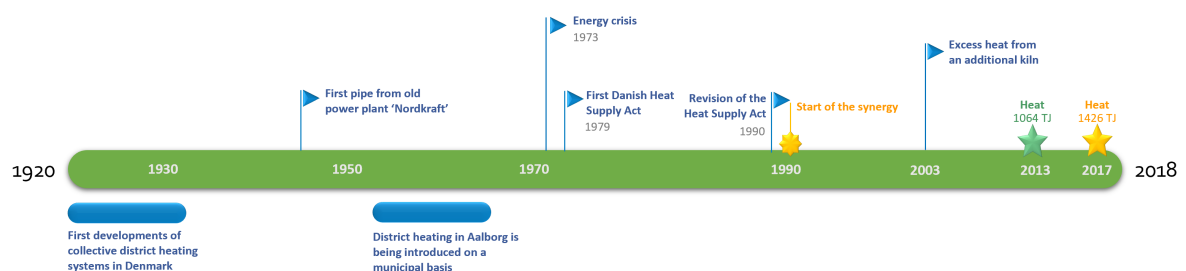


Figure 10.20: Synergy 9: Timeline  
Authors' elaboration

**In the 1920s/1930s:** A collective district heating system started to develop in some Danish cities like Copenhagen, mostly based on waste heat from local electricity production. However, district heating accounted only for around 4% of the Danish heat supply (Danish Energy Agency, 2012).

**Around 1970:** District heating from combined heat and power expands in the larger Danish cities and around 30% of all homes are now heated with the use of district heating systems (Danish Energy Agency, 2012).

**1973:** At the time of the energy crisis, consumer price levels rise dramatically. It becomes evident that it is

necessary to save energy – including energy for space heating –, to lower prices for consumers, and at the same time decrease the dependency of imported fuels. Therefore, combined heat and power systems start to be expanded also to medium and small-size cities in Denmark (Danish Energy Agency, 2012).

**Around 1948:** The first power plant in Aalborg, Nordkraft, uses excess heat to provide a public bathing institution for Aalborg's citizen. Around this time, a first pipe from the power plant down to the city center was built. This small pipe is only supplying heat for a few blocks, but marks the beginning of the district heating system in Aalborg (Larsen, 2018-04-24, 16:02).

**1953:** District heating in Aalborg is being introduced on a municipal level (Hormann, 2005).

**1990:** For the first time industrial excess heat is fed into Aalborg's district heating system. Waste heat from four kilns of the cement factory Aalborg Portland is delivered to the district heating system (Borup, 2018-05-08, 29:49).

**2003:** One of the kilns at Aalborg Portland is rebuilt, making it possible to also recover heat from it. In total, five production lines are now delivering heat to the district heating network (Borup (2018-05-08, 29:49), Ahlmann-Laursen (2018-04-25, 02:49)).

**2013:** With 1064 TJ per year the excess heat from Aalborg Portland represents 16 % of the total energy in the district heating network (Aalborg Varme, 2013).

**2017:** Production at Aalborg Portland increases, and so does the excess heat provided to the network. 1436 TJ are fed into the system now, representing 21% of the total amount in the system (Aalborg Varme, 2018).

### Drivers, Barriers, Facilitators

With Aalborg's Climate Strategy and vision to be independent of fossil fuels and greenhouse gas neutral by 2050, the mix of district heating has to undergo several changes. While traditionally a very high percentage (still 63% in 2013) of heat is provided by Nordjyllandsværket, the future of this coal-fired plant is unclear. This makes the local utility company, Aalborg Forsyning, look into new sources of heat. One of them is industrial excess heat.

While the actual details of the development of this symbiosis could not be fully gained during the data collection, some explanations are to analyze. In the interview with Aalborg Kommune employee Henrik Møller Thomsen, who is very familiar with the IS development of the city through his work in NBEN's project on symbioses, some frame conditions of the development of this specific synergy could be attained (see quotation below).

**Henrik Møller Thomsen:** *"It has been investigated the possibility of recovering the waste heat from the chimneys [...]. This process was just because the infrastructure from the power plant that sent the heat to people in the city passed the Aalborg Portland areas. The heat that could be recovered from the chimney and other processes was considerably large to be sent to the infrastructure"* (Thomsen, 2017)

The reason why the synergy to Aalborg Portland developed seemed to be, in the beginning, a rather practical one - pipes that delivered heat from Nordjyllandsværket to the city passed by the site of the cement factory.

In the process of actually delivering this heat to the municipality's network, the two companies, Aalborg Portland (at that time owned by FLSmidt) and Aalborg Varme, worked closely together, as long-term Aalborg Portland employee Borup (2018-05-08, 30:33) explains: *"We developed it here. FL Smidt and Aalborg boilers industry, they make boilers for [the] ship industry, we have to use that type of boilers to take out the heat"*. Thus, a whole new infrastructure development and technical challenges were part of the project. Also, the boiler industry worked as some kind of service broker, that facilitated the physical delivery of the product. However,

the involvement of this facilitator only took place in the planning stage of this synergy, a long-term involvement was not necessary [**Service Facilitator: 2**].

Two things become clear when taking a look at the following extract of our interview with Henrik Møller Thomsen: a present regulative barrier and an economic driver behind this project.

**Henrik Møller Thomsen:** *"But you say they knew they had all this excess heat so, so basically they wanted to be ... It's a bit like Aalborg Portland delivering to the municipality of Aalborg today. They could deliver more heat as well then they do today. But as also in the end it's a question about how you're not allowed to rise to the prices for the consumers in order to take in excess heat. So it's, it's always something, but you need to find something that's, you could say it's profit for the consumers, but also the companies would also have some kind of interest in making up a plant, because they're not used to run in a district heating network. They are used to produce the cement but establishing an excess heat plant then they would need to be able to run in the district heating. To get a symbiosis running you need to have both parts to see kind of a profit to get something out of that"* (Thomsen, 2018-03-28).

Thomsen (2018-03-28) addresses very clearly the need for Aalborg Portland to make a profitable business case of this synergy [**Economic Driver: 3**]. He also points out a regulation that somehow hinders the further evolution of this synergy. This regulations prevents Aalborg Varme to develop projects for excess heat exploitation that bring along high investment costs and thus higher costs for the consumers. Considering the long-term inclusion of industrial excess heat sources to the system, the current regulative set-up represents a large barrier. This issue was analyzed in-depth by Sacchi and Ramsheva (2017). In their study, Sacchi and Ramsheva (2017) concluded that the price-ceiling for the heat consumers in Aalborg, as a result of a political decision, restricts capital-intensive investments in excess heat recovery and thus drastically limits the potential for future carbon footprint reduction. With different price scenarios the amount of excess heat supplied in the best case could be almost multiplied by two, the study indicates (Sacchi and Ramsheva, 2017) [**Regulative Barrier: 3**].

Today, Aalborg Portland does not provide heat from the production of grey cement to the network but a part of this excess heat is used internally for process purpose. Only the excess heat from the production of white cement is used. If the production of district heating should increase, there would be the need to find a destination for this additional filtrate water from heat recovery, like the environmental engineer of Aalborg Portland, Torben Ahlmann-Laursen, explains:

**Torben Ahlmann-Laursen:** *"It's all what is possible to recover, we recover heat and then the vapor is going to be a filtrate water when you take out the heat and we have to reuse the hot water. And this is going to be a problem, because if we're going to provide more heat, we will produce more filtrate water. And then we need also to find another way to use this water inside the factory"* (Ahlmann-Laursen, 2018-04-25, 06:26).

Aalborg Portland is thus aware of this technical challenge for the company, which in some way could represent a technical driver for the further evolution of this synergy, as one potential destination of this heat can be the district heating system. However, we have no indication that this technical driver was already present during the establishment of this synergy.

On the technical side the barriers that still prevail are much higher than this potential driver. While describing the process to be undertaken (see quotation below), Ahlmann-Laursen (2018-04-25) elaborates on these issues.

**Torben Ahlmann-Laursen:** *"The filtrate water contains some gypsum residues which could contaminate the process flow of chalk slurry. But then we find out that we actually could deliver the filtrate water directly to the kiln 87. It was a technical issue. Sometimes an environmental solution could influence all the system and there are more interconnected things you need to consider if you change something"* (Ahlmann-Laursen, 2018-04-25, 06:35).

It becomes evident that not only the *'technical issue inside this'* is a barrier, but that with the *'main barrier being the payback time of the investment'* the economic barrier of high start investment is even stronger [**Technical Barrier: 3, Economic Barrier: 3**].

While many synergies develop through negotiations between the two organizations who are going to exchange waste, in the case of Aalborg Portland's excess heat delivery to the district heating network, we can see various actors influencing the development of this synergy.

**Facilitator: Aalborg Kommune** The first Danish Heat Supply Act of 1979, as Sperling and Möller (2012) points out, required Danish municipalities to work together with the counties and local utility companies to designate geographical heat supply areas which made it possible to strategically phase out of individual forms of heat supply, such as oil boilers or electric heating, and to begin a transition to collective and more efficient forms of heat supply, including district heating (Christensens, 2018-04-11). Even though now, after the revision of the Heat Supply Act in 1990 (see timeline), long-term strategic aims have been followed less effectively by many Danish municipalities, municipalities still act as project authorities that approve or reject project of the utility companies. Municipalities also have the authority to devise heat plans, which contain general objectives and can be the basis for initiating specific heat supply projects (Sperling and Möller, 2012).

Also the manager of Aalborg Energikoncernen and interviewee within the frame of our project, Larsen (2018-04-24), describes this connection quite vividly: *"Yes. You can say, of course when we make agreements like this as a lot of advice for services, we use engineers and we use financial advisers and stuff like that. But if you see it from a stakeholder point of view, it would be my company, the heating company, it will be the industry, the company of course. And then as a very special thing in Aalborg, I think, we have had this agreement with the municipalities all the time. So instead of just me, the heating company, negotiating with the industrial part, we have a third part with the municipality, [...] the planning department. But that's very special in Denmark because every single municipality would one or more persons responsible for the energy and heat planning"* (Larsen, 2018-04-24, 39:14).

Aalborg Kommune either detracts or ensures political support for this industrial synergy, has prominence and power in a leadership role, and a long-term vision for sustainability. Thus, it fulfils many activities *Coordinators* are known for as IS facilitators. While it is unclear whether or to what extent a stimulation of interaction and communication between shareholders or a support of the sharing of knowledge is facilitated by Aalborg Kommune in this context, a coordinator-like role can be ascribed to it in this context, that still to a large extent influences the evolution of the synergy [**Coordinator: 3**].

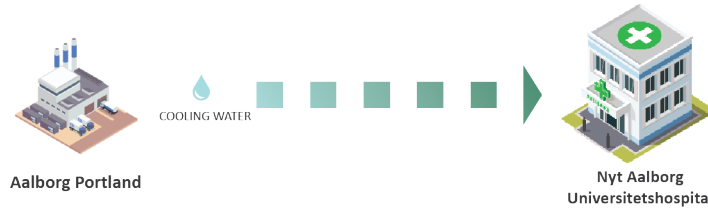
As a result of the analysis, we can see a clear economic driver of this synergy. Various barriers to this synergy have been identified, of which especially regulative and economic barriers still prevail. In the establishment of the synergy a service broker was present, while today, the synergy is still influenced to a large extent by Aalborg Kommune as a Coordinator-type of facilitator.



**Figure 10.21:** Synergy 9: Intensity of drivers, barriers, and involvement of facilitators  
 Authors' elaboration

### 10.2.2 Synergy 10

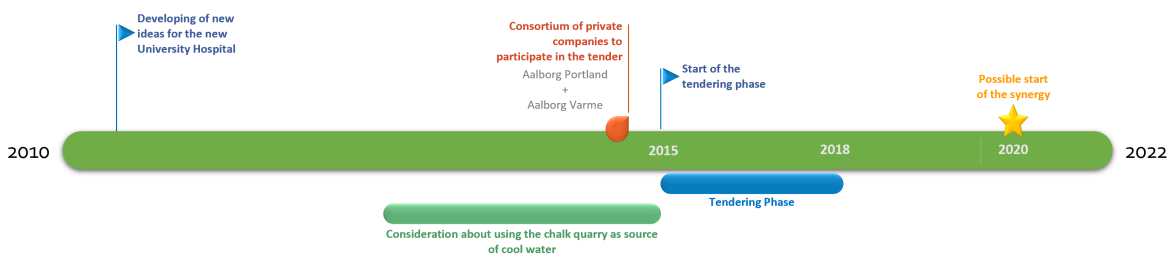
This synergy is certainly different from the other ones analyzed, which is due to the fact that it has not been realized yet. It is currently in the tendering phase, and a final decision is meant to be taken during 2018. It is displayed in this thesis and in this chapter because of its nature of symbiosis and for its likely implementation.



**Figure 10.22:** Synergy 10: Illustration  
Authors' elaboration

Aalborg Portland	Aalborg Varme	University Hospital	Cooling Water
Aalborg Portland is a producer of grey and white cement. The company is the world largest exporter of white cement. It was established in 1889 in Aalborg and is part of the Italian Cementir Holding S.p.A. since 2003. It directly provides 261 jobs, not to mention the indirect jobs and contractors (Aalborg Portland A/S, 2017).	Aalborg Varme is the city's district heating supplier and part of the municipality-owned utility company 'Aalborg Forsyning' (Aalborg Energikoncern, Aalborg Varme A/S, 2018).	The new University Hospital is going to be based in the south-east of Aalborg city. It is supposed to be completed in 2020 ( <i>Projektet NAU</i> ).	The idea behind this synergy is to build a pipe that utilizes the water of the quarry owned by Aalborg Portland, whose temperature is cool enough and stable during the year due to its depth. This should provide the new hospital site with cool water for the cooling system. The project is still in the tendering phase.

#### Development of IS



**Figure 10.23:** Synergy 10: Timeline  
Authors' elaboration

**2010:** In this period the Nordjylland Region starts the development of new ideas for the construction of the new hospital, an extension of the Aalborg South Hospital it is suggested, but eventually it was decided to build a new structure in the East part of the city (*Projektet NAU*).

**2015:** Aalborg Portland and Aalborg Forsyning (Varme) catch sight of the opportunity of using the chalk quarry in Rørdal, owned by Aalborg Portland and realize a pipeline to the East of the city, and, having the new University Hospital as the first customer. A contract between these two parties is signed and they apply to the tendering phase for the hospital's cooling system (Construction and Civil Engineering, 2015; DBDH, 2018).

**2018:** The actors are in the final stage of the tendering phase for the new Hospital Cooling System. The winner will be disclosed in Q2 2018 (Larsen, 2018-04-24).

### Drivers, Barriers, Facilitators

The idea of using the chalk quarry's water as a cooling system, due to its constant and low temperature throughout all the year is not completely new. Indeed, it is used by Aalborg Portland to cool down their computers in the factory's control center (Borup, 2018-05-08). Therefore, we can reasonably assume that the know-how for this process comes from Aalborg Portland.

**Interviewer:** "Who had this idea, was it Aalborg Portland?"

**Bent Ole Borup:** "Yes, maybe, we use the water as cooling water."

**Interviewer:** "Are you already using this process?"

**Bent Ole Borup:** "Yeah. We have a big computer in the control center. And this computer needed a lot of energy to cool down. And we use the cold water from your own lake quarry.[...]So they can take it, there is a lot of water in the lake. [...]" (Borup, 2018-05-08, 33:44).

Besides its use in Aalborg Portland's control center for computers and also for compressors and ventilation systems (Borup, 2018-05-08), the cooling water of the lake is also used for this larger district cooling project. This is partly owed to a technological development in this field. District cooling in its current form is, in general, a much younger development than district heating (EMPOWER, 2014). That natural sources are included in similar projects like this happened just recently in Copenhagen for the first time in Denmark: In 2010 a district cooling plant was built where a retired power plant was located, in the historic inner city (Forbes, 2012) [**Technological Driver: 2**].

Both companies recognized this as a profitable opportunity. Due to this, they wanted to secure the new University Hospital in Aalborg East as a first big customer.

**Jesper Møller Larsen:** "The new hospital is not located at the harbour, but it's in the eastern part of Aalborg...within this area we expect a huge potential for cooling off, for selling cooling and as a starting point we said that we want to secure the one largest customer...the new hospital will have the same cooling demand as the rest of the area...and then we can serve, buy and sell cooling to all the buildings along the pipeline" (Larsen, 2018-04-24, 05:15). [**Economic Driver: 3**]

A contract between these two companies was signed to participate together in the tendering phase.

**Jesper Møller Larsen:** "We partner up (with Aalborg Portland) and we have a contract. I mean we'll be running the business but we have a contract just like we have in the heat systems where we have contracts for companies to deliver the heat. Now we'll have one with Portland for delivering the cooling. " (Larsen, 2018-04-24, 07:54). [**Organizational Barrier: 1**]

For Aalborg Portland this is a way to profit from the chalk quarry which would otherwise be only used as a mine. Aalborg Varme used this opening as a step to move towards a more diversified business, one including not only the district heating but a new district cooling. Moreover this type of district cooling, if realized, will be the first one in Denmark, as only Copenhagen has a similar one, but it uses seawater, which has not a constant temperature throughout the year as the Portland's quarry (Larsen, 2018-04-24). In this synergy it is possible to classify Aalborg Varme as a service broker, due to the fact that it *facilitates physical delivery of waste*. [**Service Broker: 3**] Due to the fact that Aalborg Kommune is involved in the decision processes of Aalborg Varme (Larsen, 2018-04-24), it is assessed as a *Coordinator*. [**Coordinator: 3**]

Another barrier for the development of this symbiosis is the fact that it has to go through the scrutiny of the tendering phase, therefore, while writing this article, is not possible to determine whether this offer or another is going to be accepted. In fact, many are the aspect considered in the tender, this project is not sure to win it, due to different criteria that do not take into consideration only the environmental aspect (Sacchi, 2018-04-13; Larsen, 2018-04-24).

**Romain Sacchi:** "We are competing with other pretenders which would be just normal cooling systems. Obviously it will be good environmentally speaking but I don't know the numbers economically speaking. They need to compete." (Sacchi, 2018-04-13, 25:26) [**Economic Barrier: 3**]





**Figure 10.24:** Synergy 10: Intensity of drivers, barriers, and involvement of facilitators  
Authors' elaboration

In figure 10.24 the central points of analysis are highlighted:

In this figure, it is possible to see some contrast, in comparison with the other synergies. This is due mainly to the fact that it is still in process. The economic factor is at the same time an important driver when it comes to partnering up between Aalborg Portland and Aalborg Varme, but at the same time, it could be also a lethal barrier if the tender is lost.

### 10.2.3 Synergy 11

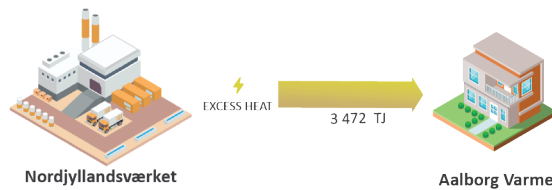


Figure 10.25: Synergy 11: Illustration  
Authors' elaboration

#### Nordjyllandsværket

This company is a coal power plant which is since 2016 owned by Aalborg Kommune through its utility company called Aalborg Forsyning (Varme). The main plant product is electricity (Aalborg Energikoncern, Nordjyllandsværket A/S, 2017). The company is based in Vodskov, on the northern side of the Limfjord.

#### Aalborg Varme

Aalborg Varme is the city's district heating supplier and part of the municipality-owned utility company 'Aalborg Forsyning' (Aalborg Energikoncern, Aalborg Varme A/S, 2018).

#### Excess Heat

Together with the energy production at Nordjyllandsværket, part of the heat produced is collected and then fed back to the district heating. Then, Aalborg Varme if necessary integrates it to reach a certain temperature. Before this synergy this heat was wasted.

#### Development of IS

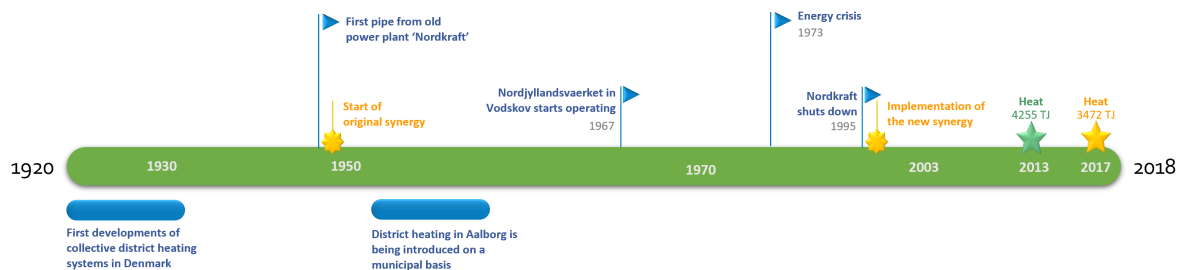


Figure 10.26: Synergy 11: Timeline  
Authors' elaboration

**In the 1920s/1930s:** A collective district heating system started to develop in some Danish cities like Copenhagen, mostly based on waste heat from local electricity production. However, district heating accounted only for around 4% of the Danish heat supply (Danish Energy Agency, 2012).

**Around 1970:** District heating from combined heat and power expands in the larger Danish cities and around 30 % of all homes are now heated with the use of district heating systems (Danish Energy Agency, 2012).

**1973:** At the time of the energy crisis, consumer price levels rise dramatically. It becomes evident that it is necessary to save energy – including energy for space heating –, to lower prices for consumers, and at the same time decrease the dependency of imported fuels. Therefore, combined heat and power systems start to be expanded also to medium and small-size cities in Denmark (Danish Energy Agency, 2012).

**Around 1948:** The first power plant in Aalborg, Nordkraft, uses excess heat to provide a public bathing institution for Aalborg's citizen. Around this time, a first pipe from the power plant down to the city center

was built. This small pipe was only supplying heat for a few blocks, but marked the beginning of the district heating system in Aalborg (Larsen, 2018-04-24, 16:02).

**1953:** District heating in Aalborg is being introduced on a municipal level (Hormann, 2005).

**1967:** The power plant of North Jutland Electricity Supply (Nordjyllands Elektricitetsforsyning, NEFO), which we today call Nordjyllandsværket, is opened in Vodskov, north of the Limfjord (Aalborg Forsyning, 2018a).

**1995** The local energy companies Nordkraft and NEFO merge and become Nordjyllandsværket. The location of the coal power plant Nordkraft in the middle of Aalborg is closed down. Another unit is added to the powerplant in Vodskov (Aalborg Forsyning, 2018a).

**2013:** With 4255 TJ per year the excess heat from Nordjyllandsværket represents 63 % of the total energy in the district heating network (Aalborg Varme, 2013).

**2017:** Production at Nordjyllandsværket decreases, and so does the excess heat provided to the network. 3472 TJ are fed into the system now, representing 52 percent of the total amount in the system (Aalborg Varme, 2018).

### Drivers, Barriers, Facilitators

When discussing this synergy as it is today, we have a long development to look back upon. One key milestone has to be mentioned: The initial set-up of excess heat delivery was taking place from the power plant Nordkraft in the center of Aalborg and started around 1948. Only after the shut-down of this plant, the heat synergy from the power plant that we today call Nordjyllandsværket, in Vodskov, started. This was because a new unit was built that would make up for the lost heat supply through the closing of Nordkraft, and, at the same time, the district heating system to this unit at Nordjyllandsværket was developed [**Technological Barrier: 1**].

The delivering companies in both cases represented combined heat and power (CHP) plants which recover otherwise wasted thermal energy for heating. This is what is also called combined heat and power district heating. Both, Nordkraft and Nordjyllandsværket were/are coal power plants which produce both electricity for the grid and heat for the city's district heating system.

As a main reason for the shut-down of Nordkraft, the expansion of the city center of Aalborg can be named. This made environmental and health problems related to the coal power plant's emissions suddenly moved into the city, as buildings and thus citizens were closing in around it. Klitgaard (2018-04-11, 26:11) stressed this reason: "*Nordkraft was situated in the middle of the city, it was not a good place there also for environmental reasons.*" The decision to close this plant and start the synergy from Nordjyllandsværket, outside the city, can thus be fully attributed to politic actors and thus the regulatory driver [**Regulatory Driver: 3**].

For this synergy (similar to synergy 9 in chapter 10.2.1), Aalborg Kommune as owner of not only one, but in this case both of the participating companies in the synergy, has the full control of its strategic direction and evolution. The previously privately owned and operated Nordjyllandsværket was bought by Aalborg Municipality in 2016. Even though the plant has an efficiency rate of up to 91%, using fuel approximately 20% more efficiently than older coal-fired plants (State of Green, 2017), the city government realizes that a transition away from coal energy is necessary, and so there is a strategic plan to gradually phase out dependence on the power plant and replace supply with renewable sources (State of Green, 2017). With this long-term sustainability in mind, the Kommune takes over the position of a coordinator-like facilitator here [**Coordinator: 2**].

In this synergy, we can see a very clear driver on the regulatory side, with the strategic reorientation of the Kommune's district energy network as the background. Aalborg Kommune now acts as a coordinator of this synergy. While high technical challenges were present through a major infrastructure project to connect Nordjyllandsværket to the district heating network, these challenges have been overcome.



**Figure 10.27:** Synergy 11: Intensity of drivers, barriers, and involvement of facilitators  
 Authors' elaboration

### 10.3 Non-Focal Synergies

*In this section the synergies which we did not focus on in the present paper are going to be briefly introduced, as they are part of the overall IS system. Despite incomplete information this can provide a better understanding of the character of IS development in Aalborg through partial information.*

**Synergy 12: Excess Heat Aalborg Vand** Synergy 12 has with excess heat delivery from the water utility company a rather small contribution to the overall energy generation of Aalborg, but is, however, a great example of an industrial synergy. The manager of the energy concern described the process within Aalborg Vand like as follows:

**Jesper Møller Larsen:** *"They take out the biomass and then they produce gas, burn it and have electricity and heat. Okay. So we have the heat from them as well, this is included in the four percent. So it's a lot of smaller things. We have seven, eight small producers of heat"* (Larsen, 2018-04-24, 13:28)

It can be assumed that organizational and technological drivers are behind this synergy. However, the currently collected data does not allow in-depth insights into the development of this synergy.

**Synergy 13: Excess Heat Reno Nord** Reno-Nord is an incineration company owned by Brønderslev, Jammerbugt, Mariagerfjord, Rebild, and Aalborg Municipality. The company runs an incinerator, a landfill, and a recycling plant for construction waste (Kirkegaard, 2018-04-20). The company is included in the IS mapping of Aalborg, as its incineration plant creates heat which is fed into the district heating network. It is also an important contributor to the amount of heating in the network: 2017 Reno Nord provided with 1523 TJ around 23% of the total heat to the system (Aalborg Varme, 2018).

While we did not gain in-depth inside into the development of this synergy through the conducted interviews, we found in this synergy a case that can be considered industrial symbiosis, and, however, conflicts with the principles of a circular economy. As Aalborg Varme manager Larsen (2018-04-24) explained, how far heat from the incineration plant can be considered waste heat, is, however, a matter of perspective:

**Jesper Møller Larsen:** *"But of course from the incineration plant, [...] they have a main purpose is to incinerate and to get rid of the waste and we see the heat as a residual waste product. But for some people they see that the waste incineration plant have three purposes, producing power, producing heat and burning waste. So that's a matter of how you see it. But in our point of view, we consider it as a waste energy."* (Kirkegaard, 2018-04-20, 14:36)

Our interviewee at Reno Nord, CSO Kirkegaard (2018-04-20), described very vividly what has already been discussed in chapter 2.2: Denmark's proficiency in incineration for energy generation, and its slow path to a CE-like recycling system:

**Henrik Kirkegaard:** *"I think the recycling part in Denmark has been slow. Denmark has been known for incineration. We are extremely good at incineration and the plant here you are sitting on, it's actually one of the top plants in Denmark. We can actually dispose almost every kind of material without any environmental issues because we have an extremely advanced cleaning system [...] We generate electricity and heat, so the business case within this has been useful for Denmark. Maybe we were a little slow, a little bit slow to recognize the possibilities of recycling, as you can see"* (Kirkegaard, 2018-04-20, 14:36)

While our data collection does not allow deep insights into the development of this specific synergy, we can, however, say, that its development and also further evolution is strongly connected to the synergies 9, 11 and other source of heating as presented in synergies 12, 14 and 15.

**Synergy 14 and 15: Excess Heat from Alfa Laval and the Crematory** While at various points of our data collection the deliveries of excess heat from boiler producer Alfa Laval, as well as excess heat from the crematory, came up, no interview allowed us insights into the development of these two district heating synergies.

**Synergy 16: Royal Greenland Seafood A/S** Here some first hand data were retrieved, and together with some previous NBEN publications, it was possible to draw a broad picture of the current synergy. The synergy was established when a NBEN employee after a company visit at Royal Greenland Seafood A/S, noticed the company has this shrimp waste that was sent for incineration at Reno Nord with a cost of 430 kroner per ton (Royal Greenland Seafood A/S, 2016). This person knew a contact at the Fodercentralen Limfjorden, a company which could use this "waste" as substitute for minks' food (*Royal Greenland Seafood A/S og Fodercentralen Limfjorden*).

**Henrik Møller Thomsen:** "They (Fodercentralen) needed to come with a truck everyday to pick up the waste and they thought "what we save will be used in petrol" (Thomsen, 2018-03-28, 23:06).

Indeed, in case of a daily delivery, the expense in petrol was equal to the savings, but Royal Greenland had some storage facility available and it was decided to use them. After that, the agreement was made and the synergy was established. Royal Greenland collects the shrimp waste, it is stacked in blocks and frozen until it is delivered to Fodercentral every two weeks (Thomsen, 2018-03-28). The receiving company pays 50 øre per kilo, this results in a saving of 60,000 kroner annually for Royal Greenland Seafood (Royal Greenland Seafood A/S, 2016).

The driving forces between this synergy was thus NBEN as a relational and knowledge broker, and economic drivers from the two participating companies.

**Synergy 17 and 18: Salling Entreprenørfirma, Desmi and Mani Pine** This double-stream synergy from Desmi A/S and Salling Entreprenørfirma A/S towards Mani Pine has not been addressed in this paper due to the inability to get any response from these companies. Therefore, the following overview is based purely on public available information and this is the reason why it has not been discussed in depth.

In 2015, after a rapid growth, Mani Pine was in need of high quality recycled wood for the manufacture of their handmade sustainable furniture. NBE was the necessary link to get in touch with Salling Entreprenørfirma A/S. This company, due to their activity in demolition of old buildings, and the recycling of as many material as possible, was interested in finding another customer for the wood recovered. Desmi was also involved into this newly established cooperation, and, due to an excess of steel bolts from packaging of supplied pump parts, was interesting in profit from this resource. Before this material was disposed as scrap iron. The material was suitable for Mani Pine furniture production and therefore also this connection started (*Mani Pine og Desmi A/S: Den grønne industri symbiose*; Thomsen, 2018-03-28).

The driving forces behind this synergies were on the one hand the ambition of Mani Pine to create sustainable design furniture, and on the other hand the opportunity for the two other companies to profit from some of their byproducts or unused materials (*Mani Pine og Desmi A/S: Den grønne industri symbiose*).

# Chapter | 11

## Analysis of Non-IS Waste Exchanges

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### 11.1 Non-IS Waste Exchanges

*In this section the focus is upon the companies that are not part of the industrial symbiosis of Aalborg. In this chapter deeper insights into barriers to IS can be reached through investigating in what kept these companies from establishing industrial synergies.*

**Hedegaard** Hedegaard A/S is Denmark's largest privately owned agri-business company with several departments in Jutland and feed production in Nørresundby and Koldding. This company is part of the holding Danish Agro, and the facilities in Aalborg are processing animal feed. The company is situated in Nørresundby.

During the interview we found out that Hedegaard is not able to contribute to the district heating network despite the fact that the factory produces some excess heat. This is because the extra amount is not enough to justify the investment and it is used to heat the offices within the area (Sørensen, 2018-04-25). Hedegaard thus presents an example of internal waste recycling according to type 2 (figure 5.4) of the waste exchange typology presented in section 5.2. Moreover, Hedegaard is member of the network NBEN and our interviewee spoke about regularly attending meetings. We could see that there is no unwillingness or organizational barrier of Hedegaard as a company to participate in industrial symbiosis, but rather technical limitations related to the types and amounts of waste that are being produced at the factory (Sørensen, 2018-04-25).

**Danish Crown and Tulip** The Danish Crown group is the World's largest pork exporter, Europe's largest pork processor and also a major player in the European beef market. Tulip Food Company A/S is a daughter company of Danish Crown and in the meat processing industry. In Aalborg, there is a Danish Crown cattle slaughterhouse in the port area which slaughters around 2,400 head of cattle a week (Danish Crown, 2017). Also, there are two Tulip meat processing factories within Aalborg municipality. One is located in Svenstrup and it's main activity is the production of sausages and salami (Tulip Food Company, 2017b). The other processing facility is closer to the center and produces mainly hamburgers, meatballs, and instant meals (Tulip Food Company, 2017a). Both facilities have a capacity for more than 75 tonnes of finished products per day (Tulip Food Company, 2017a; Tulip Food Company, 2017b).

Some waste of these facilities is turned into meat and bone meal which is then used by cement producer Aalborg Portland (Sacchi, 2018-04-13). However, this processing requires specific capabilities and is also highly regulated (Thy, 2018-04-12; Jensen, 2018-04-23). This is why the company Daka SecAnim in Randers takes over the processing of these by-products. In this case there is thus no direct industrial symbiosis between Danish Crown or Tulip and Aalborg Portland because of these strict regulations for slaughterhouses and animal waste (*Rules in the feed area*) (see also chapter 11.2).

**AAU Service** AAU Campus service is together with AAU's political and administrative management responsible for ensuring optimal physical frameworks - both externally and internally - for the completion of the university's teaching, research and service activities. As our interviewee and project manager within Campus Service, Vibeke Ulriis-Nordberg, stressed, AAU is working towards a much greener profile, especially in terms of waste management (Ulriis-Nordberg, 2018-04-24).

At the moment the campus in Aalborg does not have any example of excess energy, heat or direct waste stream to be configured as industrial symbiosis (Ulriis-Nordberg, 2018-04-24). In this case the main barrier to the establishment of an industrial symbiosis is the fact that each department has the authority to decide how to handle any possible energy excess and the Campus Service does not have the authority to implement

holistic solutions. However, this is a barrier that is being worked on to be overcome as Ulriis-Nordberg (2018) states:

**Vibeke Ulriis-Nordberg:** *"A great fault in the data, is that I only have the waste, that is administrated by Campus Service. [In real life] the institutes are administrating a lot of waste themselves. Waste such as electronics, chemistry, spray cans, concrete, rocks, sand and so forth. We want to move away from decentral waste handling and to create continuity in campus waste management. These are two of the main goals for the work we are enrolling right now."* (Ulriis-Nordberg, 2018-04-24)

**Bladt Industries** is a steel contractor specializing in offshore substations and offshore foundations, as well as oil and gas projects and infrastructural projects. Despite it being an important industry for the Aalborg Area, it has no example of industrial symbiosis. This due to the fact that all the waste produced is sorted and sold to the waste management company K. Knudsen. There is an organizational barrier to IS, as there are few resources allocated to the strategic management of waste. An environmental department existed in the past, but now the waste responsibility lays additionally on the resource management department. However, even though there is no focus on IS, some environmental aspects are incorporated into the company culture: Bladt Industries is interested in the waste management company K. Knudsen being more environmental responsible and investing in it (Pedersen, 2018-04-18).

**Better World Fashion** is an Aalborg-based fashion company which produces unique leather jackets from used leather garments. The company has circular economy principles deeply incorporated in its business model, including sustainable sourcing, leasing options, and buy-back guarantees (Ihlenfeld, 2018-04-17). Also, this company is a prime example of how a circular business model can be shaped in order to avoid the production of waste. Within it, everything is managed and sourced in a way that reduce to the minimum the possibility to have any type of excess material or resources, as our interviewee Ihlenfeld (2018-04-17) stresses in the following quote: *"When we can't use some [leather] parts in the production process of the jackets anymore, we use it [to produce] backpacks and handbags, [...] to really make sure that we don't have any waste [...], that we really can delimit that concept"* (Ihlenfeld, 2018-04-17, 03:14). Referring to the waste exchange typology introduced in section 5.2 this business can be placed in the type 2 (see 5.4) which concerns the *"exchange within a facility, firm or organization"*. Moreover, it represents an example of how waste management and waste recycling companies are used as an intermediary to facilitate the use of waste products:

**Melanie Ihlenfeld:** *"The leather that the jackets are made of is coming from the NGO shops here in Denmark. So from secondhand shops and like the 'red cross boutiques' and we collect it from them and then sew it apart. And then the leather parts get cleaned in sawdust so that they lose all smell they have and get properly cleaned. And then they sew them together in a new way"* (Ihlenfeld, 2018-04-17, 00:21)

In this case, which is related to type 1 of the waste exchange typology, NGO shops and the red cross represent intermediaries which treats and facilitates the physical delivery of the used materials as production inputs for Better World Fashion.

## 11.2 Waste Management Companies

*In this section we want to discuss the role of third parties like waste management companies in the development of industrial synergies in Aalborg. While waste exchanges through third parties are type 1 waste exchanges and do not represent industrial synergies, as discussed in chapter 5.2, they shape the ecosystem in which industrial symbiosis develops.*

Many businesses recycle and donate or sell recovered materials through third party brokers and dealers to other organizations. Historically, scrap dealers have organized in this fashion, as have charities such as the Red Cross (Chertow, 2000). Geng and Côté (2002) recognize the role of scavengers and decomposers in being helpful with environmental and economic processes such as the ones concerning waste handling and in general what is needed to "close the loop". Thus, their role is crucial for the development of a circular economy.



An entire industry of waste treatment and trading companies has also flourished in Aalborg. 16 waste management companies are operating in the area of the port of Aalborg alone (Jakobsen and Bo, 2018).

Our empirical research (see Dreier (2018-04-10), Korfitsen (2018-04-12), Christensens (2018-04-11), Kristensen (2018-04-26), and Jensen (2018-04-23)) led us to understand the main reasons why companies choose to use the help of third parties like waste management companies to handle their waste.

One main point is that the expertise needed to handle some sorts and streams of waste exceeds the **organizational capacities** of some companies.

One example is the network and knowledge on how to handle waste. Our interviewee from HJ Hansen explained that 95% of the materials of their customers that they receive are exported and processed outside of Denmark because it is too expensive to process them in Denmark. Founded in 1829 in Odense, the company developed an extensive network of partners including locations in Europe, Turkey, and Asia, and, moreover, an expertise on waste handling, which their customers can rely on (Christensen and Jensen-Butler, 1982). To develop this kind of knowledge, connections, and processes, high investments are necessary for companies whose core business is not waste management.

Korfitsen (2018-04-12) stated that Uniscrap customers, besides the majority of large industrial players (45%), demolitions, entrepreneurs and hauliers (25%), municipalities (10%) and private customers (10%), are also small companies. They use Uniscrap to handle their waste because of the logistic and also because the amounts of materials are not sufficient to conduct self-organized transport and recycling activities. An important activity of waste management is thus to **bundle small waste streams** so that their treatment becomes profitable.

Also, technical know-how is an important issue when it comes to choosing how to handle waste: Kristensen (2018-04-26) describes that the company RGS Nordic has specialized on treating contaminated soil and construction residues. Especially for hazardous waste, it is indispensable to consult contractors which have the capacities and knowledge to handle it. Examples here are Reno Nord (Kirkegaard, 2018-04-20) and Marius Pedersen (Dreier, 2018-04-10).

Another main issue when talking about expertise is **legislation**. When we asked our interviewee from Marius Pedersen why companies choose to not look into the direction of IS, she clearly referred to legislation as one of the organizational capacities that are necessary to do so:

**Lisa Dreier:** *"I think it's very hard for the companies. There's a lot of legislation and the legislation is not the same in all the municipalities. You need to know the local legislation because if you do something that you're not allowed to do, then that will cost you big fines. It almost requires you to have a whole department, which only concentrates on this issue. It's hardly ever possible for a company to tell one person, with another assignment as his or her primary field of work, that this person needs to handle their waste issues. I don't think one person could do that. And that is why they collaborate with companies like Marius Pedersen A/S."*

**Interviewer:** *"So probably it would be more relevant for big companies?"*

**Lisa Dreier:** *"Yes they need to be larger companies with an organization supporting this part. Like Siemens or Novo Nordisk."*

**Interviewer:** *"... that hire people especially for this?"*

**Lisa Dreier:** *"Yes, They have an organization that can support this part to a greater extent than small and medium-sized SME's." (Dreier, 2018-04-10, 28:11).*

A great example how regulations are necessary, but also prevent direct waste exchange between companies are the waste streams that the company Daka SecAnim handles. Byproducts of meat production activities in Aalborg are turned into meat and bone meal, which cement producer Aalborg Portland uses in its production process. To process these byproducts, however, organizational capacities are needed that go beyond the two companies' capacities and translocates this activity to Randers, where the company Daka SecAnim handles these activities. How complex the regulation that leads to this procedure is was highlighted by plant manager John Jensen:

**John Jensen:** *"Daka Saria group has different production sites which reflects on how the EU regulation of animal byproducts is defining this. In the EU there are three kinds of animal byproducts, we got CAT 1, this is specified waste materials for animals which are containing risk carrying mad cow disease, BSE, fallen stock, cows, ruminants, sheep, and goats, but it's also some of the waste from the cattle slaughterhouses in Aalborg. [...] CAT 3 are veterinarian approved by products, byproducts from slaughterhouses. [...] The last category is CAT 2, that's most easily explained, as it does not contain any risk of BSE but hasn't been approved by veterinarians, fallen stock, most pigs, and horses and also waste from slaughterhouses, byproducts in cattle slaughterhouses"* (Jensen, 2018-04-23, 11:08).

Also, many companies do not have the necessary size or organizational capabilities to draw up their green accounts (*Grønne regnskaber*), which waste management companies can help with.

A more practical issue often makes companies decide to use the services of external waste managers: **space**.

**Lisa Dreier:** *"Typically, companies today don't have much space and that causes problems, because sorting requires that you have more than one container, but there's no room for all these different types of containers so you just pile it all together."* (Dreier, 2018-04-10, 48:25).

We can see that waste management is an additional activity that goes beyond a company's core activities which often leads to high investments and efforts if not conducted by a specialized contractor but by the company itself.

## **Part VII**

# **Discussion and Ecosystem Analysis**

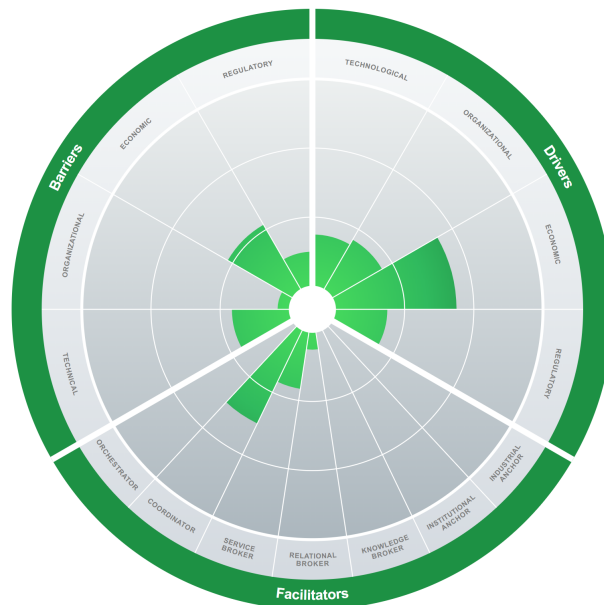
# Chapter | 12

## Aalborg IS Development Factors

In the following chapter, the findings on barriers, drivers, and facilitators of the different IS developments are going to be reconciled and analyzed. Every graph is the sum of all the parameters of the graphs of the same category and it is displayed the average for each factor.

### 12.1 Average

The following graph presents the average of IS development factors of all focal synergies (1-11).



**Figure 12.1:** Intensity of drivers, barriers, and involvement of facilitators - Overall  
Authors' elaboration

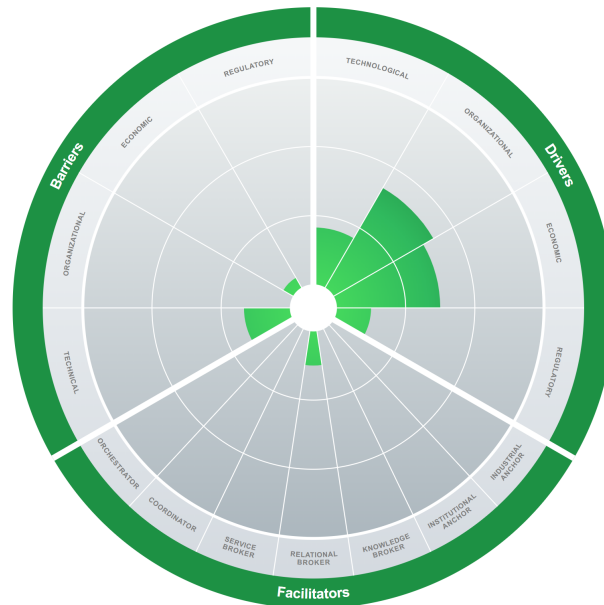
For the average of all focal synergies we can discern a rather high economic driver of the viewed developments, followed by organizational, technological, and regulatory drivers. On the barrier side we can recognize a leading economic barrier, followed by technical barriers and low regulatory and organizational barriers. Facilitators play a role to some extent: Coordinators seem, on average, to have a high importance, followed by relational brokers and knowledge brokers.

While this kind of analysis can give us an overview of the development character of the overall symbiosis in Aalborg, it does not specify differences between the distinct kinds of synergies. This is why, in the following, separate groups of synergies have been identified for analysis.

## 12.2 According to the Type of Flow

### 12.2.1 Materials and Liquids

When uniting the insights from synergies concerning the exchange of **material and liquids** (synergies 1-8), the drivers, barriers, and facilitators displayed in figure 12.2 appear to be of highest importance for industrial symbiosis development.



**Figure 12.2:** Intensity of drivers, barriers, and involvement of facilitators - Materials  
Authors' elaboration

We can see that the drivers of highest importance are organizational and economic ones in these exchanges. Even though the exchange of materials can require specific technological requirements, technological drivers were of much less importance for the selected synergies of Aalborg. Also regulatory drivers were, on average, not especially important for the development of these focus synergies.

A very interesting fact can be observed when viewing barriers: The only barrier of slight importance for the focus material synergies in Aalborg is the technical barrier, which can be ascribed to the fact that often challenges in terms of transportation or treatment of the materials were present (see synergy 2, 4, 5, or 6).

Also the number and variety of facilitators involved in these kind of synergies was vanishingly low. In most of the synergies, the steps from searching for partners, treating materials, or analyzing the economic and environmental benefits, came from the participating companies themselves. Synergy 8 represents the only synergy in which a relational broker was of crucial importance for the synergy's development. It is important to note however, that this assessment just includes the synergies in the focus of the present paper. The development of the synergies 16, 17, and 18 for example, which could not be analyzed in-depth due to missing data, were highly dependent on the involvement of relational and knowledge broker NBEN.

### 12.2.2 Energy

When uniting the insights from synergies concerning the exchange of **heat and cooling** (synergies 9, 10, and 11), the drivers, barriers, and facilitators displayed in figure 12.3 appear to be of highest importance for industrial symbiosis development.



**Figure 12.3:** Intensity of drivers, barriers, and involvement of facilitators - Energy  
Authors' elaboration

Economic motives can be identified as the strongest driver for these synergies that include the exchange of energy (in form of heating or cooling). This is mainly owed to the fact that synergy 9 and 10 have been solely motivated by economic reasons. The medium regulatory driver derives especially from synergy 11, which was solely motivated by regulatory drivers. As the development of one synergy, namely synergy 10, which is the only one exchanging cooling water, is also promoted by a technological development, we can also notice a slight degree of technological driver in the average.

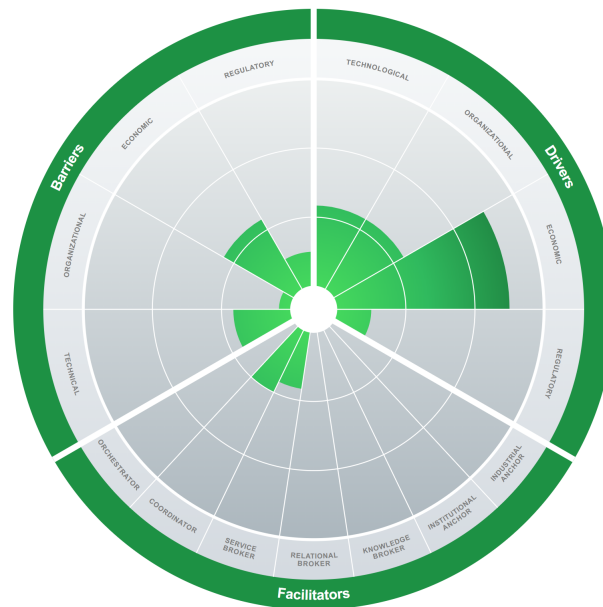
In all synergies, and thus also in this display of the average, some kind of technical barrier had to be overcome - mostly related to extensive infrastructure in form of pipelines to deliver heat and cooling. While these were factors that were considered and overcome, the economic barriers directly connected to these technical barriers were much more profound, as they still up to this date influence the development of synergies 9 and 10.

When we view the energy synergies, it is very interesting to see that these synergies developed under more influence of facilitators than their material counterparts. While Aalborg Varme, in any case, is responsible for treating and delivering the energy, the company holds a special place in the cooling water synergy between Aalborg Portland and the new University hospital (synergy 10) and is present as a service broker. Also Aalborg Kommune as a coordinator plays a very distinct role in the general development of energy synergies in Aalborg.

## 12.3 According to Companies Involved

This section is meant to represent the basis for the discussion on the IS development factors influencing companies' decisions. A threshold of three synergies has been used to filter the results.

### 12.3.1 Aalborg Portland



**Figure 12.4:** Intensity of drivers, barriers, and involvement of facilitators - Aalborg Portland  
Authors' elaboration

When the different factors are weighted for Aalborg Portland's synergies, it is possible to recognize some patterns and acquire some insights about the connections in which this company is involved.

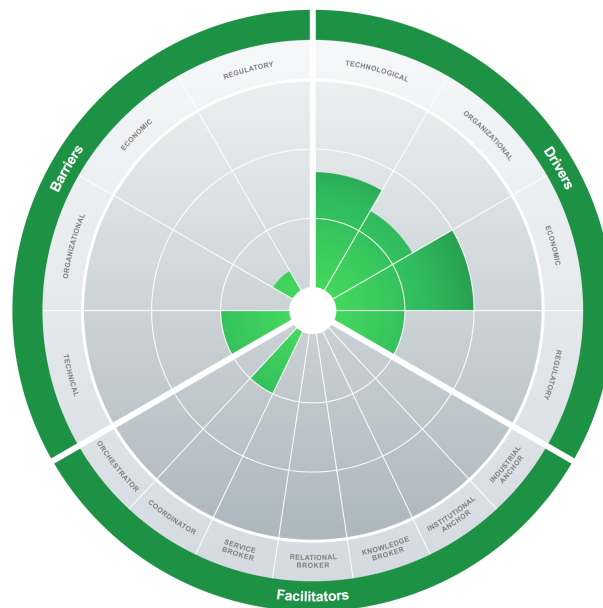
First, the importance of the economic driver stands out when it comes to establish a new synergy. This reason was highlighted multiple times during the interviews conducted with Aalborg Portland's representatives, when the procurement processes were recognized as mainly economically driven (Sacchi, 2018-04-13; Borup, 2018-05-08). It is possible to recognize this pattern also in the development of future synergies, like synergy 10, where there both parties recognized a clear need for Aalborg Portland to make a profitable case out of it (Thomsen, 2018-03-28).

Reflecting this driver, the economic barrier can be identified on the graph as relevant. This due to the fact that an economic evaluation can also hinder a specific synergy. This is due to the fact that Aalborg Portland is a private company, part of an holding (Cementir Holding S.p.A.) and therefore it is accountable to the stakeholders for its business' choices.

Other factors are influencing Aalborg Portland synergies or decision-making but are not considered particularly relevant or are peculiar as a specific synergy and therefore have been already analyzed in Chapter 10.

### 12.3.2 Nordjyllandsværket

*This company is going to be discussed as a separate entity even though it is owned by Aalborg Forsyning nowadays, this because its synergies go back since it was a private company.*



**Figure 12.5:** Intensity of drivers, barriers, and involvement of facilitators - Nordjyllandsværket  
Authors' elaboration

During the scrutiny of the synergies in which Nordjyllandsværket is involved, it is possible to recognize how the most important drivers on average are the economic and the technological ones.

As it was discussed during the interviews with representatives of this company, the decisions concerning the development of new projects are economically driven (Jensen and Nielsen, 2018-05-09, 25:56). This is because, despite being now publicly owned, it has to comply to a budget and to the will of its (public) stakeholders.

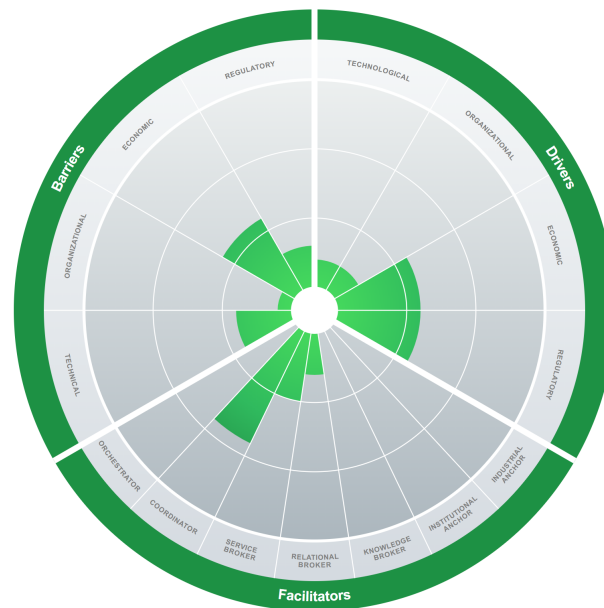
The technological driver is also relevant in this situation. This is because of the specific business in which the company is situated. In fact, the planning of a new power unit or a change in the type of process requires a thorough investigation of the different possibilities and therefore, the best technology at the moment are evaluated (Jensen and Nielsen, 2018-05-09, 13:29).

Nevertheless these technical drivers play a significant role while the decision process is in place. It was possible to observe how these technical issues were not substantial barriers, but easily overcome during the development of the synergies, for example in the construction of the special lorry for the transport of fly ash and gypsum (Jensen and Nielsen, 2018-05-09).



### 12.3.3 Aalborg Forsyning

Within this evaluation has been decided to include the factors concerning both Aalborg Vand and Aalborg Varme, this due to the fact that both companies are strictly interconnected through Aalborg Forsyning.



**Figure 12.6:** Intensity of drivers, barriers, and involvement of facilitators - Aalborg Forsyning  
Authors' elaboration

After the analysis of the combined synergies concerning Aalborg Vand and Aalborg Varme, it is possible to identify some common patterns when it comes to the *IS Development Factors*.

The first noteworthy element is the regulatory driver, it is due to the fact that these company has to obey, for its specific nature of public owned entity, to some particular regulations. These, therefore, are known in advance and the public stakeholder can find solutions that sometimes can lead to the establishment of a new synergy (e.g. sludge spread on fields or Nordkraft inside the city center) (Jensen and Jensen, 2018-04-13, 24:06)(Klitgaard, 2018-04-11).

Also the economic aspects are relevant for the establishment of Aalborg Forsyning's synergies. This due to the fact that the holding and its subsidiaries are publicly owned, and they need to operate within a limited budget (Larsen, 2018-04-24). For example, in the case of the cooling system for the new hospital, securing this contract is vital in order to support financially the construction of the new cooling pipeline (Larsen, 2018-04-24, 05:15).

Lastly, the factor that mostly stands out is the role of the coordinator. In Aalborg the planning department is working close in supporting the subsidiaries (Larsen, 2018-04-24, 39:14).

# Chapter | 13

## Ecosystem Analysis

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*In the present chapter, an overview of the ecosystemic influences on the development of IS in Aalborg is being targeted. First, our insights from the previous individual synergy analysis are going to be presented. Then, a more holistic overview, using all data at our disposal, is going to be created.*

The ecosystem of Aalborg Municipality has a variety of actors which are, to different extents, involved in or concerned with the industrial symbiosis development in the area. Which ownership they have, which goals they aim for, and which involvement they have in the business community of the municipality, shapes which activities they perform within this network, and hence, which positions they choose to take.

In the preceding analysis of individual synergies above, the present paper gave first insights into a handful of actors that influenced the development of these specific material and energy exchanges:

- **Aalborg Portland** Aalborg's cement producer stuck out of our analysis as a very prominent industrial player within the IS network involved in many synergies (*namely synergy 1, 2, 4, 5, 7, 9, 10*). Besides providing a critical mass of resources and energy flows for other organizations to tap into, a multitude of business contacts in and outside Aalborg for the exchange of waste make Aalborg Portland an important actor within Aalborg's ecosystem. Regarding its involvement in the analyzed synergies Aalborg Portland was not yet identified as an actor taking any specific position within the ecosystem, however.
- **Nordjyllandsværket** Similar to Aalborg Portland, also the coal power plant Nordjyllandsværket provides a critical mass of resources and energy flows to the system and is well connected to a variety of actors. Its involvement in various synergies within Aalborg (*namely 2, 3, 4, 5, 6 and 11*) make it a key player in the system. Regarding its involvement in the analyzed synergies Nordjyllandsværket was not yet identified as an actor taking any specific position within the ecosystem, however.
- **Aalborg Forsyning** Partly owed to the nature of a district heating system characterized by waste energy sources, Aalborg Forsyning, is a crucial actor in the system (*with its involvement in synergies 7-15*). Aalborg Forsyning not only has a long-term vision for sustainability, but also plays a key role in ensuring political support within the system, and providing the hard infrastructure needed for the physical delivery of energy streams. Regarding its involvement in the analyzed synergies also Aalborg Forsyning was not yet identified as an actor taking any specific position within the ecosystem, however.
- **Aalborg Kommune** We could identify Aalborg Kommune as a main facilitator with a strong sustainability vision, leadership role, and crucial power over several organizations, especially in the synergies related to the district energy system (*synergies 7-15*). This relates especially to the Planning Department which is responsible for these energy related decisions. Regarding its involvement in the analyzed synergies Aalborg was identified as an actor taking the position of a coordinator.
- **NBEN** We clearly noticed NBEN, the sustainability network, taking the initiative to accelerate green transition in businesses. Especially its past project on Industrial Symbiosis facilitated the development of various synergies in the whole region of North Jutland and also some synergies in Aalborg (*see synergies 16, 17, and 18*). Regarding its involvement in the analyzed synergies NBEN was identified as an actor taking the position of a relational broker.

To identify or verify which role of facilitators these organizations actually fulfill, we have to compare their activities within the ecosystem with the predefined activities typical for Industrial Symbiosis development facilitators, as defined in chapter 5.3.

Activities	Aalborg Portland	Nordjyllandsværket	Aalborg Forsyning	Aalborg Kommune	NBEN
a) Stimulating interaction and communication between stakeholders			X	X	X
b) Building trust, commitment, and cohesion, resolving conflicts					X
c) Identifying of potential IS partners and synergies	X		X		
d) Treats by-products before use			X		
e) Facilitating physical delivery of waste			X		
f) Identifying technical and economic feasibility					
g) Providing a critical mass of resources and energy flows	X	X			
h) Obtaining and sharing the knowledge					X
i) Ensuring political and managerial support			X	X	X
j) Recruiting the tenants and actors			X		
<b>Characteristics</b>					
k) Prominence and power, leadership role	X			X	
l) Many network connections inside and outside the network	X				X
m) Long-term vision for sustainability			X	X	X

Table 13.1: First impression of activities of actors according to the facilitator framework

#### • Aalborg Portland

Aalborg Portland's policy defines the substitution of fossil fuels with alternatives as a goal and this is one of the reasons why Portland constantly looks into possible synergies to substitute coal petcoke and fuel oil with other sources (**c**) (Ahlmann-Laursen, 2018-04-25, 15:07).

Due to its considerable size within the area the company finds itself in a position where it can influence and be involved in many connections (**g**). Occasionally, meetings are organized in which Aalborg Portland meets companies interested in possible collaborations and in which the company explains to the audience what they interested in (**k, l**) (Rasmussen, 2018-03-07; Kristensen, 2018-04-26).

**Positioning:** Aalborg Portland fulfills the activity of an **Industrial Anchor**. It goes further by conducting another activity typical of a knowledge and relational broker and orchestrator: the identification of potential partner and synergies (**c**). Furthermore, it shares two characteristics of the orchestrator's profile: Its prominent role (**k**) and the many connections that it possesses (**l**).

- **Nordjyllandsværket** Similarly to Aalborg Portland, also the history of Nordjyllandsværket dates back over 100 years. Currently the company provides around 52% of the municipal's district heating (Aalborg Varme, 2018). Due to this relevant contribution to the system through critical resource flows (**g**), the company places itself in a favorable place to promote the establishment of new synergies.

**Positioning:** Nordjyllandsværket fulfills the activity of the **Industrial Anchor**. Other than this, the company does not take any other clear position.

- **Aalborg Forsyning** This company owns, besides other subsidiaries, also two companies which are subject of investigation for this paper; Aalborg Varme and Aalborg Vand. It supplies citizens with district heating, gas, water, recycling services and it takes care of the waste water treatment (**d, e**) (Aalborg Forsyning, 2018a). The companies are public owned company owned by Aalborg Kommune. Therefore, they need to follow the directives and work in concert with the municipality. In exchange they benefit of political and managerial support (**i**). Moreover, being inside this public environment means that the companies need to adapt their development to Aalborg Kommune sustainability strategy (**m**) (Aalborg Kommune, 2016). As it was possible to see in synergy 7, where Aalborg Forsyning actively looked for an industrial syenrgy partner, the role of Aalborg Forsyning can go beyond being a spectator but in different situations, after identifying specific needs and potential cooperations even stimulates new interactions and recruits companies for new synergies (**a, c, j**) (Jensen and Jensen, 2018-04-13).

**Positioning:** Aalborg Forsyning, due to the many activities the company conducts, covers most of the **relational broker** activities and characteristics (**a, b, c, i**) and of the **orchestrator** (**a, b, c, f, k, l**). Moreover, it only needs to increasingly obtain and spread knowledge (**h**) to fulfill the one more activity

which the role of the **coordinator** suggests. Therefore, it places itself in a strategic position to be a decisive actor in the establishment of new symbioses.

- **Aalborg Kommune** It is possible to identify this entity as a relevant actor within the area, due to the many functions that it holds. For this ecosystem analysis, the *By- og Landskabsforvaltningen* (Urban and Landscape Department), together with its sub-departments, is relevant, because it is in charge, among other things, of what concerns the development and the sustainability strategies in the Aalborg area (Aalborg Kommune, 2018). Surely, the municipality is steered by national and regional political influences, but the sustainability plans are drawn up in a way that encompass a fairly long time (**i**, **m**) (Aalborg Kommune, 2016). Moreover, the municipality is, due to its prominent role (**k**), active in creating the conditions to establish new synergies, ensuring the necessary support through its departments by stimulating the interaction between stakeholders when meetings and events are organized (**a**) (Larsen, 2018-04-24; Aalborg Kommune, 2016)

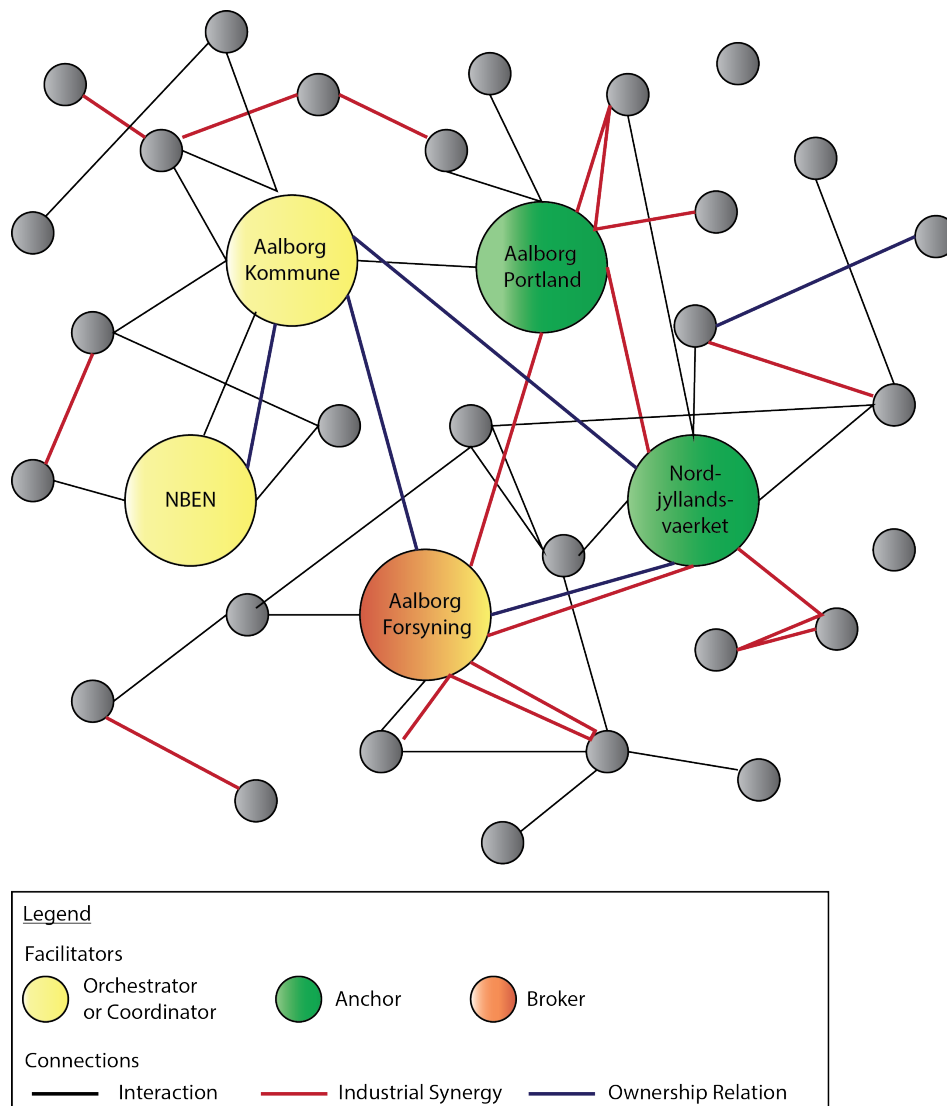
**Positioning:** Aalborg Kommune, or more precisely its urban and landscape department, fulfills all the typical activities conducted by an IS **coordinator**, except the spreading of knowledge **h** which is not specifically implemented in this department. Therefore it plays one of the most important roles in this IS ecosystem.

- **NBEN** The Network for Sustainable Business North Denmark is a private-public cooperation between municipalities in Northern Denmark, local business bureaus, Energi Nord, Aalborg University and private companies. The network's core services consist of, among other things, networking, sustainability screenings, sustainability projects and strategic sustainability plans, as part of creating new sustainable approaches and optimizations for companies in northern Jutland, as our interviewee Henrik Møller Thomsen stressed (Thomsen, 2018-03-28, 04:59).

The aim of the network is to strengthen the participating companies' competitive advantages through targeted efforts towards sustainability. NBEN also regularly hosts meetings where companies discuss sustainability and share inspiration with other companies with the same interests. Like this NBEN is stimulating interaction and communication between stakeholders (**a**) and fosters trust and commitment between them (**b**). Through sustainability screenings and sustainability plans they contribute to the knowledge diffusion in the area (**h**). As the network is owned by the municipalities, it also has some power in ensuring political and managerial support (**i**). Owing to the fact that it aims at being a network between different actors, it has many connections inside and outside the region (**l**). Also it has a strong vision for sustainable business development (**m**) and in this field, takes a leadership role in the region (**k**).

**Positioning:** NBEN fulfills the typical activities conducted by an IS **coordinator** and thus takes this position within the system. It even goes beyond the position of a coordinator with its large amount of connections (**l**) and its trust and commitment building activities (**b**), which are typically not within the activity scope of a coordinator. To become an **orchestrator**, NBEN would also have to conduct activities specifically targeted at IS development, which includes the identification of potential IS partners and synergies (**c**), and the evaluation of technical and economic feasibility (**f**).

Through these different activities the actors above link themselves to the industrial symbiosis ecosystem of Aalborg. As shown below (see figure 13.1) these *activities* lead actors (circles) to take different positions in the system (color of the circle). These positions involve interactions with other actors in the system (black line). These can be knowledge exchanges, business contracts, or alike. Sometimes, like in the case of Nordjyllandsværket which belongs to Aalborg Forsyning, also ownership relations are involved (blue line). However, the most important part is that the activities of the mentioned actors lead to *links* in the ecosystem: exchanges of waste in our case (red line).

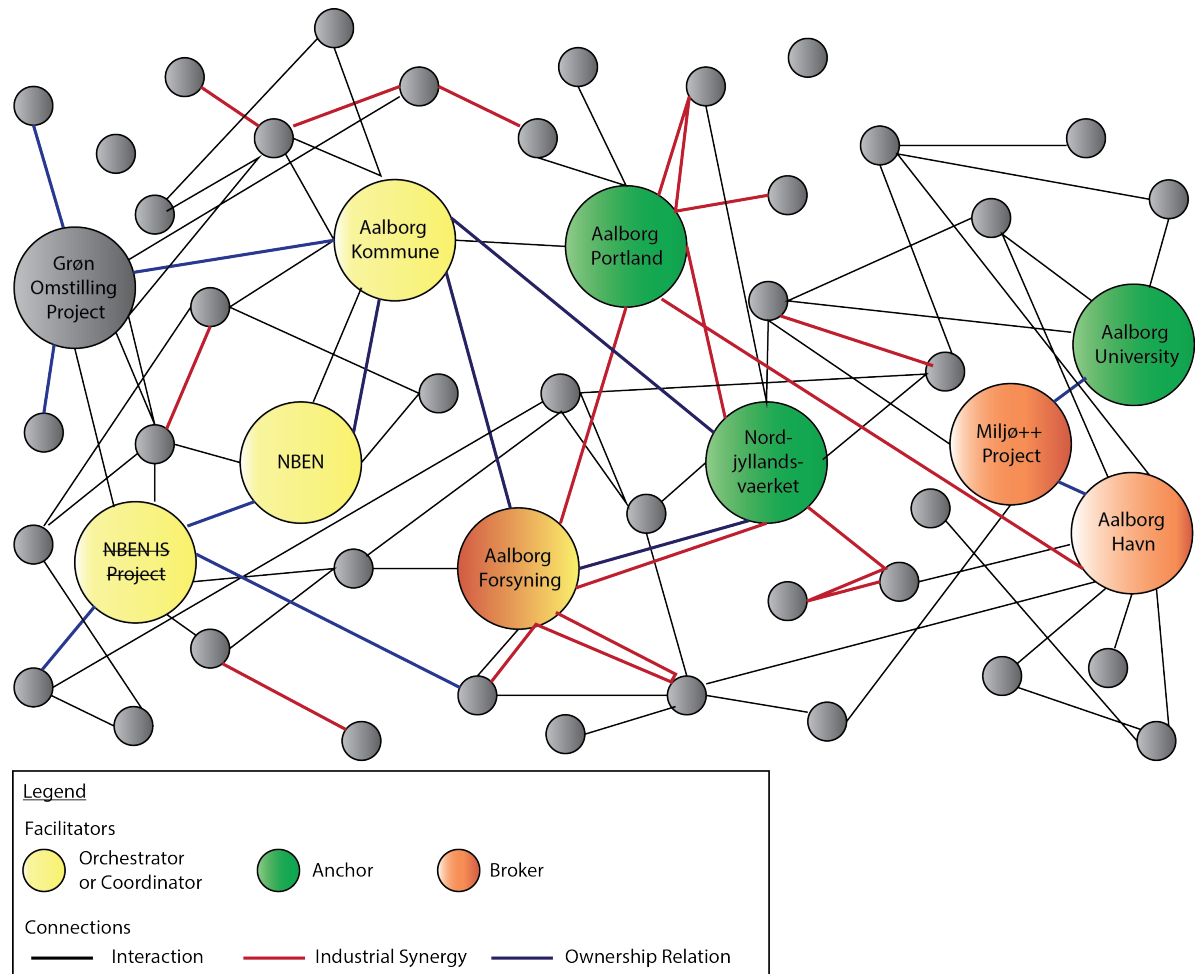


**Figure 13.1:** Ecosystem Display  
Authors' Elaboration

Even though the analyzed actors were directly involved in the development of the focus-synergies of the present paper, from a systemic perspective other actors have to be considered, to be able to holistically display the ecosystem in which industrial symbiosis can flourish in Aalborg.

Through the data collection it became clear that at least two other actors to some extent influence the endeavours regarding IS within Aalborg. These actors are on the one hand Aalborg University and on the other hand the port-managing company Aalborg Havn. Also, three different sustainability initiatives did influence or currently influence the ecosystem relevant for IS development: The project Miljø++, the NBEN industrial symbiosis project, and the Grøn Omstilling platform.

Including these actors, the current ecosystem of Aalborg takes another shape (see figure 13.2 below).



**Figure 13.2:** Advanced Ecosystem Display  
Authors' Elaboration

The activities of these actors and projects are visualized in table 13.2. Subsequently they are further described and compared to the default facilitator types.

- **Aalborg University**, as a public university founded in 1974 and with its main campus in Aalborg, awards bachelor's, master's, and Ph.D. degrees and is involved in research in a wide variety of subjects within humanities, social sciences, information technology, design, engineering, exact sciences, and medicine. Even though Aalborg University is not involved in any industrial synergy mentioned in this paper, it could be identified as an important facilitator for the development of IS by the analysis of several sources (Sacchi, 2018-04-13; Ulriis-Nordberg, 2018-04-24). A general task of universities is to obtain and share knowledge through the region and beyond (**h**). If we talk about waste flows within Aalborg, various student projects have been conducted. These have often been carried out with the support of several actors in the region, stimulating interaction between them (**a**). These topics go in very different directions and e.g. included investigations on the development of a zero-organic waste district in Aalborg (Escutia, 2017), investigations in Aalborg's inter-municipal collaboration on climate change adaptation (Schlecht, 2016), or in stakeholder engagement within strategic environmental management at the port of Aalborg (Mortensen, 2016). While many student endeavours and projects like these concern the environmental or societal assessment of material flows in Aalborg, some are even specifically targeted at IS development in the municipalities (see e.g. Roesen et al. (2016) and Henriksen et al. (2013)). Like this, Aalborg University could even provide the identification of potential synergies (**c**) or evaluations of technical or economic feasibility (**f**), if the right actors come together and companies are aware of this opportunity.

**Positioning:** Aalborg University with its two activities of stimulating interaction between shareholders (**a**) and sharing knowledge (**h**) can still develop its role within the system. By taking taking over activi-

ties of ensuring political support **(i)** and recruiting tenants and actors **(j)** it could take the position as an **institutional anchor**. However, as, discussed above, by providing evaluations of technical or economic feasibility of IS projects **(f)** and identifying potential IS partners and synergies **(c)** it can take the role of an advanced **knowledge broker**.

- **Aalborg Havn** The port area of Aalborg, established in 1682 (Aalborg Havn A/S, 2018a) and consisting primarily of a number of private wharves, is managed by the company 'Aalborg Havn A/S', a private limited company owned by Aalborg Kommune. Aalborg Havn A/S is in charge of an area of 5,3 million square meters where there are around 108 firms located.

Its role in managing logistics and plots of land in the port area is crucial for industrial symbiosis development: On the one hand, on the search for new companies to settle into the port area, Aalborg Havn recruits new potential tenants and actors to the region **(j)**. Through its role as the land owner and business facilitator, the company has prominence in the region **(k)**, many connections to companies in the port area **(l)** and stimulates interaction in the area through several development projects and workshops **(a)**.

On the other hand, nowadays around 90% of the world's merchandise and commodities is transported by ship (Dwarakish and Salim, 2015, p. 297). Therefore, the importance of the presence and the development of Ports it is vital for the development of a region and nation. The ability of the port as a company to attract these trade streams results in new business and work opportunities. Also, new resource flows are created through this activity of Aalborg Havn. Thus, Aalborg Havn facilitates a critical mass of resource flows to enter the system **(g)**.

Besides being a logistics center and handling cargo, goods and cruise ship, Aalborg Havn A/S is a business facilitator. It aims at boosting the business development in the area. It fosters various networks to help the knowledge exchange and the likelihood of agreements among the parts **(b)**. Lastly, a close collaboration with Aalborg University is developed for multiple projects (Aalborg Havn A/S, 2018b).

**Positioning:** Aalborg Havn has a very diversified role within the ecosystem that influences IS development. It fulfills many criteria of an **orchestrator**, and even goes beyond it by providing a critical mass of resources to the ecosystem **(g)**. However, investments in the search for IS partners and synergies **(c)**, knowledge sharing **(h)**, and the evaluation of technical and economic feasibility of projects **(f)** are activities which Aalborg Havn does not conduct to a large extent, but which would be within the scope of a typical **orchestrator**. Only two of these activities, identification of potential synergies **(c)**, and the insurance of political support **(i)** would be required to reach the position of a **relation broker**. Aalborg Portland has, however, two characteristics of an actor which can take a successful position within the ecosystem of IS development and should thus aim high in the position it wants to fulfill in the future.

- **NBEN Industrial Symbiosis Project**

Within the general work NBEN does for its members, a variety of projects are conducted as Thomsen (2018-03-28) explains: *"They have different projects running all the time that they also provide to their members"* (Thomsen, 2018-03-28, 08:09). One of these projects was like he states the project 'Industrial Symbiosis', which besides other projects in the region facilitated the development of synergy 16, 17, and 18. Within this project, Thomsen and his team were responsible to create 16 synergies within North Jutland, while other teams were responsible for other Danish regions in the nation-wide project (Thomsen, 2018-03-28, 11:04). As a nationally funded project with an optional included funding of a financial analysis that the companies could apply for **(f)**, this project made a great contribution towards industrial symbiosis development, also in Aalborg. Not only interactions and communication between stakeholders was facilitated **(a)**, also many potential synergies and IS partners were identified **(c)** and the knowledge about opportunities shared **(h)** with a variety of actors **(l)**. With specifically designated employees for this project, it provided the human resources to create commitment and cohesion between actors and resolve potential conflicts **(b)**.

**Positioning:** The project of Industrial Symbiosis within NBEN conducted a multitude of activities relevant for IS development. With more prominence in the area **(k)** for example through reviving and

prolonging the project, and with developing a clear strategy for industrial symbiosis development in the area (**m**) it could take the position of a textbook **orchestrator** for the area.

Activities	Aalborg University	Aalborg Havn	NBEN Industrial Symbiosis Project	Miljø++ Project	Grøn Omstilling Project
a) Stimulating interaction and communication between stakeholders	X	X	X	X	X
b) Building trust, commitment, and cohesion, resolving conflicts		X	X		
c) Identifying of potential IS partners and synergies			X	X	
d) Treats by-products before use					
e) Facilitating physical delivery of waste					
f) Identifying technical and economic feasibility			X	X	
g) Providing a critical mass of resources and energy flows		X			
h) Obtaining and sharing the knowledge	X		X		
i) Ensuring political and managerial support				X	
j) Recruiting the tenants and actors		X		X	
<b>Characteristics</b>					
k) Prominence and power, leadership role		X			
l) Many network connections inside and outside the network		X	X	X	X
m) Long-term vision for sustainability				X	X

**Table 13.2:** First impression of activities of actors according to the facilitator framework

#### • Miljø++ project

The project 'Miljø++' is a strategic effort to realize the vision of the Port of Aalborg of being an incubator for sustainable solutions and business models. This involves making environmental awareness and planning opportunities decisive competitive factors in retaining and attracting companies and new jobs (**j**). It also involves catalyzing sustainable business development by advancing green business models through industrial symbiosis, which is supported through strengthening spatial framework conditions and local governance (**i**). As the project is conducted by experts from university and Aalborg Havn and even involves an industrial PhD student who is at the same time involved in both, universities and port activities, the project profits from a variety of network connections (**l**).

The project operates with four complementing parts:

- A. strategic frameworks for industrial symbiosis and circular models, which includes the identification of potential synergies (**c**)
- B. strategic stakeholder involvement and capacity building, (**a**)
- C. Resource optimization and creation of symbiosis and (**f**)
- D. Development of life cycle based green business models.

One of the goals of the project is that the Aalborg area will be the first choice for companies due to smooth and professional environmental planning and management, which can be identified as a long-term vision for sustainability (**m**). Companies, authorities and knowledge institutions shall collaborate with the focus on developing industrial symbiosis (**a**), innovation and entrepreneurship in the environment and resources. Also, resource optimization and economic added value in the relationship between companies, ports and the surrounding community shall be ensured (Aalborg Universitet, 2017).

**Positioning:** The Miljø++ project is a prime example of a **relational broker**. There could be some improvements in terms of how far the project facilitates trust and cohesion (**b**) to completely live up to the by-the-book definition of a relational broker. The project could develop in the direction of an orchestrator position by expanding its activities of cohesion efforts (**b**), through increasing knowledge sharing in the area (**h**), and developing a prominent role (**k**) over time.

#### • Grøn Omstilling

The center of green conversion is the platform of Aalborg Municipality for all projects that target sustainability. Thus, this platform is the part of the municipality which has a very strong sustainability



vision for Aalborg (**m**). Common to all projects is partnership with citizens, industry, retail, and knowledge institutions.

Besides others, the projects which are happening within the center of green conversion include:

- **Aalborg Sustainability Festival** (*Aalborg Bæredygtighedsfestival*) which focuses on sustainable initiatives that take place around the municipality of Aalborg in the area of environmental and social responsibility
- **Green Shop Project** (*Grøn Butik*) is a voluntary nationwide eco-label, as small as well as large stores, restaurants, independent, chain stores can be a part of. Green Store is working with sustainability and is an active player in this conversion process. There are 80 Green Shops in Aalborg Municipality.
- **Green Agent Project** (*Grønne Agenter*) is an offer to all citizens of the municipality of Aalborg for assistance in implementing projects that promote sustainability and green change. Aalborg municipality is committed to a broad network and competencies in sustainability that you can draw to realize or develop green projects.

From this extract we can see with which activities the green conversion platform of Aalborg Kommune might contribute to a better industrial symbiosis development. Through projects like the sustainability festival the platform is stimulating interaction and communication between shareholders (**a**). The platform additionally has many network connections (**I**) (Madsen, 2018-04-13).

**Positioning:** Even though the Grøn Omstilling platform has an important vision (**m**) and many connections in the municipality (**I**) and thus has important characteristics for IS development, it cannot be categorized into one of the textbook groups of IS facilitators, as its position rather is related to activities promoting sustainability thinking and community in general, and thus only indirectly forms the playground for IS.

**Part VIII**

**Conclusions**

# Chapter | 14

## Findings and Concluding Remarks

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*In this chapter, the conclusions of the present work are going to be summarized. Implications for industry and policy makers are going to be formulated. Concluding, this chapter presents limitations of this work, but also reveals opportunities for future research.*

### 14.1 Outcomes and Implications

The present paper addressed the research question "**What does the industrial symbiosis in Aalborg look like and how do ecosystemic factors shape its development?**".

#### 14.1.1 Outcomes

One outcome of this project, which was the result of addressing the first part of the research question, is a comprehensive mapping of the industrial symbiosis of Aalborg, including actors, types, and amounts of waste being exchanged.

In order to address the second part of the research question, we conducted an in-depth analysis on ecosystemic factors influencing the development of IS in Aalborg, based on a data collection broad in scope. We took a look into the historic development of selected synergies (CH. 10), supplemented this by an analysis of non-IS synergies and third parties involved in these (CH. 11), identified patterns according to the types of synergies and companies active in them (CH. 12), and drew a holistic picture of the positions of different actors within the ecosystem (CH. 13).

While **drivers** behind the establishment of the different synergies in Aalborg vary, our analysis showed that in general the incentivization was based on the individual project's commercial value. The incentive structure of Aalborg Symbiosis is thus primarily economically motivated. In many cases, however, it was fully or partly motivated by certain regulatory and technological development, and often only made possible through high organizational capabilities.

On the other hand, economic factors were also the most encountered **barrier** that impeded industrial symbiosis development. Technical difficulties have been shown to hinder the process to some extent, but regulatory and organizational obstacles played a minor role.

The most important facilitator of Aalborg Symbiosis was Aalborg Kommune, who took the position of a coordinator, particularly in the development of exchanges of heat. Overall, in the establishment of synergies of energy, a much higher presence of barriers but also facilitators could be noticed, compared to the exchanges of materials and liquids.

Within the ecosystem that facilitates IS development in Aalborg, several key players were identified. While Aalborg Kommune and the sustainability network NBEN act as coordinators, on the industry side it became apparent that cement producer Aalborg Portland and power plant Nordjyllandsvaerket take the role of industrial anchors of the IS. An institutional anchor is represented by Aalborg University. Moreover, the port managing company Aalborg Havn and the utility company Aalborg Forsyning positioned themselves as relational brokers within the system. Joint projects between actors have been identified as major accelerators for the development of industrial symbiosis in Aalborg, with a past NBEN project and a current project between University and Aalborg Havn called Miljø++ fulfilling orchestrator- and relational broker-like roles in the system.

### 14.1.2 Implications

As a first study shedding light on the local conditions for IS development in the area, this paper did not only draw a clear picture on the current industrial synergies between companies and development factors behind it, but could also facilitate insights into the system's further improvement and expansion.

Several actors can take steps to improve the ecosystem in which IS can flourish:

- **Aalborg Havn** has a diversified role in the system by attracting actors and resource flows to the region and stimulating interactions and promoting cohesion among the actors. In the future, the company can, through targeted investment in according activities, either choose to aim for the position of a relational broker or even orchestrator of IS development in Aalborg.
- Viewing the expertise of the people working and enrolled in **Aalborg University**, collaborative student projects could be a great support for economic and technical feasibility studies for new synergies. Involving students in the analysis of potential new synergies would benefit both, companies who would get some additional insights that they usually would not allocate time to and students who would have a practical learning experience.
- The network **NBEN** fulfills important activities that shape sustainability ambitions of companies in the municipality and beyond, but is however missing a specialized team or focus on industrial symbiosis development. Without targeted identification of synergy opportunities and the provision of feasibility assessments, it can not reach the position of an orchestrator for IS development in Aalborg.
- **Aalborg Kommune** takes the role of a coordinator in the ecosystem. Due to its numerous completely or partially owned subsidiaries in key sectors (Aalborg Forsyning, Aalborg Havn, Reno Nord), it can have a strategic role in promoting and supporting new synergies. Obviously, considering its political nature, the IS development needs to be in the majority's agenda.

Ultimately, projects specifically targeted at IS development contributed most to the establishment of more recent synergies. While NBEN's project on industrial symbiosis is terminated, the Miljø++ project between Aalborg Havn and university has the potential to take over or incentivize similar activities this project was conducting. However, due to an often limited lifespan of these projects, the most important task will be to consolidate the key activities with the above mentioned players to guarantee a long-lasting and resilient ecosystem that further supports IS development.

## 14.2 Limitations and Opportunities for Further Research

Many challenges were successfully overcome while writing this thesis and a considerable amount of data was gathered and analyzed. Nevertheless, the boundaries of this work are mainly defined by a time constraint of 5 months. This affected both the number of cases analyzed, and the depth of the analysis. This thesis thus represents a starting point for the further academic support of Aalborg Symbiosis' development, which opens up further opportunities of research:

- Further screening of waste exchanges should be conducted to identify additional, currently existing synergies which are not as apparent.
- Through updating and also communicating the mapping of Aalborg Symbiosis new actors can be attracted to the region which can engage in the ecosystem and even create new synergies.
- Additional data collection and analyses should be recommended for the synergies which were not focal subjects of this project (synergies 12 - 18), to expand the insights on IS development that were made in this paper.
- Another important future research opportunity to measure the development of Aalborg Symbiosis in the future is the quantification of benefits that arise through this kind of system. This should include environmental benefits like material, water, CO<sub>2</sub>, and energy savings as well as economic benefits arising through avoided waste disposal or resource purchasing costs.



**Part IX**

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# Acronyms

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- CE** Circular Economy. 18
- CGO** Center for Grøn Omstilling. 10
- CHP** Combined Heat and Power. 66
- CR** Critical Realism. 36
- CSO** Chief Security Officer. 78
- CSR** Corporate Social Responsibility. 27
- DH** District Heating. 66
- GDP** Gross Domestic Product. 16
- GIS** Geographical Information System. 26
- ICT** Information and communication technology. 10
- IE** Industrial Ecology. 18
- IS** Industrial Symbiosis. 20
- MSW** Municipal Solid Waste. 9
- NBEN** Netværk for Bæredygtig Erhvervsudvikling NordDanmark. 10
- NGO** Non-Governmental Organization. 81
- OECD** Organisation for Economic Co-operation and Development. 4
- SDG** Sustainable Development Goals. 4

# Glossary

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**Activities** is a category of the ecosystem concept of Adner (2017). Activities specify the discrete actions within an ecosystem to be undertaken by actors in order for a value proposition to materialize. 33

**Actors** is a category of the ecosystem concept of Adner (2017). Actors are the entities that undertake the activities. A single actor may undertake multiple activities; conversely, multiple actors may undertake a single activity. 33

**Barriers** are circumstances or obstacles that prevent a particular phenomenon to happen or develop. 27

**Biomimicry** is a discipline that is about studying nature's best ideas and then imitating designs and processes to solve human problems. 20

**Circular economy** presents an economic system in which material loops in industries' value chains are closed, where products' life times are extended or materials are re-entered in the process. 16

**Drivers** are factors which cause a particular phenomenon to happen or develop, and provide impulse or motivation. 25

**Ecosystem** is from a business perspective traditionally understood as an economic community supported by a foundation of interacting organizations and individuals. The present paper uses the definition of Adner (2017) with ecosystems being the alignment structure of the multilateral set of partners that need to interact in order for a focal value proposition to materialize. 47

**Facilitators** are organizations or individuals that make an action or process easy or easier. 30

**Industrial Symbiosis** is understood as the physical exchange of materials, energy, water, and by-products by traditionally separate industries. Within this paper industrial symbiosis refers to the sum of individual synergies between companies in a defined area. 20

**Industrial synergy** is a physical exchange of materials, energy, water, or by-products between companies of traditionally separate industries. Several industrial synergies form an industrial symbiosis. 47

**IS development factors** are factors which influence the development of Industrial Symbiosis, including driver, barriers, and facilitators. 88

**Linear economy** is an economic system in which natural resources are mined and extracted, turned into products and finally discarded. 15

**Links** is a category of the ecosystem concept of Adner (2017). Links specify transfers across actors. The content of these transfers can vary— it can be materials, information, influence, funds. Critically, these links need not have any direct connection to the focal actor. 33

**Positions** is a category of the ecosystem concept of Adner (2017). Positions specify where in the flow of activities across the system actors are located and characterize who hands off to whom. 33