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Nordic Centre for Spatial Development

The potential of industrial symbiosis as a key driver of green growth in Nordic regions

Ingrid H G Johnsen (Ed.), Anna Berlina, Gunnar Lindberg, Nelli Mikkola, Lise Smed Olsen and Jukka Teräs

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Cover photo: Svartengi Resource Park including the Blue Lagoon spa facilities. This Icelandic case is one of the five Nordic regional case studies included in this report. Photo by: Yadid Levy / Norden.org.

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Nordic co-operation is one of the world's most extensive forms of regional collaboration, involving Denmark, Finland, Iceland, Norway, Sweden, and the Faroe Islands, Greenland, and Åland.
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Nordic co-operation seeks to safeguard Nordic and regional interests and principles in the global community. Common Nordic values help the region solidify its position as one of the world's most innovative and competitive.

The Nordic Council
is a forum for co-operation between the Nordic parliaments and governments. The Council consists of 87 parliamentarians from the Nordic countries. The Nordic Council takes policy initiatives and monitors Nordic co-operation. Founded in 1952.

The Nordic Council of Ministers
is a forum of co-operation between the Nordic governments. The Nordic Council of Ministers implements Nordic co-operation. The prime ministers have the overall responsibility. Its activities are co-ordinated by the Nordic ministers for co-operation, the Nordic Committee for co-operation and portfolio ministers. Founded in 1971.

Nordregio – Nordic Centre for Spatial Development
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Stockholm, Sweden, 2015

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Executive summary

In 2014, the Nordic Working Group on Green Growth – Innovation & Entrepreneurship, nominated by the Nordic Council of Ministers, commissioned Nordregio to conduct a study on different approaches to developing industrial symbiosis and its implications for regional development in the Nordic countries. Industrial symbiosis can be viewed as one of the possible approaches to realizing a circular economy (CE) and achieving green growth. The aim of this study is to provide an overview of the potential for growth in industrial symbiosis at the national, regional and local levels, and analyse policies related to industrial symbiosis in the Nordic countries.

The empirical part of the study consists of an analysis of five cases of industrial symbiosis: the Kalundborg Symbiosis in the Zealand region, Denmark; the Kemi–Tornio region in Lapland, Finland; the Svartsengi Resource Park on the Reykjanes Peninsula, Iceland; the Eyde Cluster in the Agder region, Norway; and the Händelö industrial symbiosis in Östergötland county, Sweden.

This study shows that there are differences in approaches to industrial symbiosis in the Nordic countries. In Finland and Denmark, there is generally a strong top-down approach to industrial symbiosis, accompanied by a clear vision and comprehensive strategies for a CE/industrial symbiosis at the national and regional levels. Industrial symbiosis exchanges have been actively facilitated by municipal and regional actors and networks in combination with key private companies.

In Iceland, Sweden and Norway, industrial symbiosis initiatives are often characterized by a bottom-up approach, where private companies and business parks are driving the development, while industrial symbiosis is largely missing from the national-level policy agenda. In the Icelandic and Swedish regional case studies, there are no local policy instruments that directly support industrial symbiosis or a CE, and industrial symbiosis activities are not explicitly a part of regional and municipal development strategies. In order to utilize the full dynamic and regional potential of industrial symbiosis in these regions, there is a need to develop coherent policies and support schemes for industrial symbiosis activities to fill this gap.

According to the study, a key motivation for companies to engage in industrial symbiosis activities has been the desire to increase profitability and competitiveness. Business opportunities are the major driving force behind the development of industrial symbiosis. Among the main hindrances to industrial symbiosis development identified in the regional case studies has been companies' lack of time and resources to implement new business models such as industrial symbiosis, as well as a lack of industrial symbiosis expertise in the region and low awareness about the opportunities provided by industrial symbiosis. In this regard, the presence of a cluster, network or other co-ordinating body that can facilitate collaboration helps to organize exchanges across companies. Disseminating information about industrial symbiosis solutions has played an important role in the Danish, Finnish and Norwegian cases.

Overall, the regional cases showed similarities and differences with regard to the organization of industrial symbiosis networks, the type of support instruments in place to stimulate industrial symbiosis activities, adoption of the term industrial symbiosis and the potential for economic growth. Regarding the potential for new businesses and jobs to arise from industrial symbiosis activities in Nordic regions, exact numbers or quantitative estimates are difficult to obtain. It can be stated, however, that there is significant future potential to expand industrial symbiosis activities and develop new industrial symbiosis-related businesses in Nordic regions.

1. Introduction

Green growth implies that all sectors and industries focus on green parameters, such as resource efficiency, in all areas from production to recycling and reuse. The purpose of the Nordic Working Group on Green Growth – Innovation & Entrepreneurship, under the Nordic Committee of Senior Officials for Regional Policy (EK-R), is to help support and investigate environmental innovation and entrepreneurship in green growth. The goal is to examine factors that have a positive and a negative effect on this area.

Industrial symbiosis (IS) is increasingly being seen as a means to realize a circular economy and as a strategic tool for economic development, green growth, innovation and resource efficiency at all levels in Europe – local, regional, national and international. The development in this direction is inextricably linked to policies and regulations at all levels.

1.1 Key concepts

Green growth means fostering economic growth and development while ensuring that natural assets continue to provide the resources and environmental services on which our well-being relies. To do this, it must catalyse investment and innovation that will underpin sustained growth and give rise to new economic opportunities.

The term "circular economy" (CE) refers to a production and consumption system that creates as little economic loss as possible, and where the majority of the products and the resources used in production processes can be reused or recycled. This changing design of products and production processes can help minimize waste and increase the potential of unused resources, and thereby have a positive environmental impact. In a CE, production processes can, to a larger extent, be based on the reusability of products and raw materials and the restorative capacity of natural resources. In addition, innovative business models can create a new relationship between companies and consumers (European Commission 2014a, p. 4).

The European Commission (EC) stresses that "transition to a more circular economy requires changes throughout value chains, from product design to new business and market models, from new ways of turning waste into a resource to new modes of consumer behaviour. This implies full systemic change and innovation not only in technologies, but also in organisation, society, finance methods and policies" (European Commission 2014a, p. 2). The purpose of a CE is that resources always remain in the economy, even if they are no longer used for their original purpose. This differs from a more linear economy, which assumes that resources are limitless and easily manageable. A CE expands our traditional understanding of what constitutes a resource, by focusing on increasing the value of existing resources by reducing waste and promoting recycling. Policy instruments in support of green growth are one way to help ensure the economic sustainability of such initiatives. Economic sustainability is another important element in this regard, because the ability of the economy to support the economic production of green initiatives is crucial for the future competitiveness of many industrial activities, especially in high-cost countries such as the Nordic countries.

IS is one way to achieve green growth, and can be seen as part of a CE that focuses on keeping the added value in products for as long as possible and at the same time eliminating waste. IS is an innovative way to increase resource productivity (European Commission 2011). It involves the physical exchange of materials, energy, water and by-products (Chertow 2000, p. 314). This is done by engaging traditionally separate industries in a collective approach to gain competitive advantage. While the "greening" of firms tends to focus on individual firms, IS involves synergistic advantages among a network of traditionally separate but geographically proximate firms. It involves exchanging by-products and energy cascades, or the joint provision of utilities and services, to improve the partner firms' overall environmental and economic performance (Deutz et al. 2008). IS can occur between firms that are closely co-located, e.g. in clusters or industrial parks, as well as at the regional level (Paquin 2009). The creation and sharing of knowledge through the networks yield mutually profitable transactions as well as improved business and technical processes (Lombardi & Laybourn 2012).

As such, IS can be defined as collaboration between at least three different entities exchanging two or more

resources (e.g. by-products) that can be used as substitutes for commercial products or raw materials. By taking advantage of the residual material and energy flows, less primary energy is used in production, which leads to advantages for both businesses and the environment. The conceptualization of CE and IS is discussed in detail in Chapter 2.

1.2 Aim and scope

In 2014, the Nordic Working Group on Green Growth – Innovation & Entrepreneurship commissioned Nordregio to conduct a study on different approaches to the development of IS and its implications for regional development in the Nordic countries. Following the report "Bioeconomy in the Nordic region: Regional case studies" (Nordregio Working Paper 2014, 4), this study constitutes the second in-depth study commissioned by the working group, with the aim of providing knowledge of the key topic of green growth by presenting an overview of relevant policy and funding instruments and by exploring "good practice" case studies of innovation and entrepreneurship at the regional level.

The aim of the study is twofold: 1) to provide an overview of i) the potential for growth in IS at the national, regional and local levels, and ii) IS-relevant policies in the different Nordic countries; and 2) to present in-depth regional case studies of IS. This aim is in line with the ambition stated in the work programme for 2013–2014 for the Nordic Working Group on Green Growth – Innovation & Entrepreneurship, commissioned by the Nordic Council of Ministers, which is "to identify 'good practice' of regional (and local) governance in the Nordic countries to support innovation and entrepreneurship for green growth".

The overall research question is: to what extent and how can IS be a driver for green growth in Nordic regions? To address this, the study aims to shed light on the following additional questions:

- What characterizes CE/IS activities and policies in the different Nordic countries?
- Who are the main actors driving/supporting IS development at the regional/local level?
- What type of regional/local policy instruments are in place to stimulate IS activities?
- What is the potential for new businesses and jobs to arise from IS in the regions studied?

The first question relates to the current national-level policies and trends in the Nordic countries that support CE/IS development. A third in-depth study commissioned by the working group will provide a deeper overview of the regional-level policies. The study will be carried out during 2015–2016 and will focus on barriers to and incentives for implementing green growth initiatives, and differences between different sectors and regions in the Nordic countries. Questions 2–4 relate to the in-depth regional case studies. These empirical case studies provide insight into IS activities in selected Nordic regions, and highlight the key drivers behind IS as well as the factors impeding its development, the key actors involved and the regions' characteristics, policies and institutional arrangements.

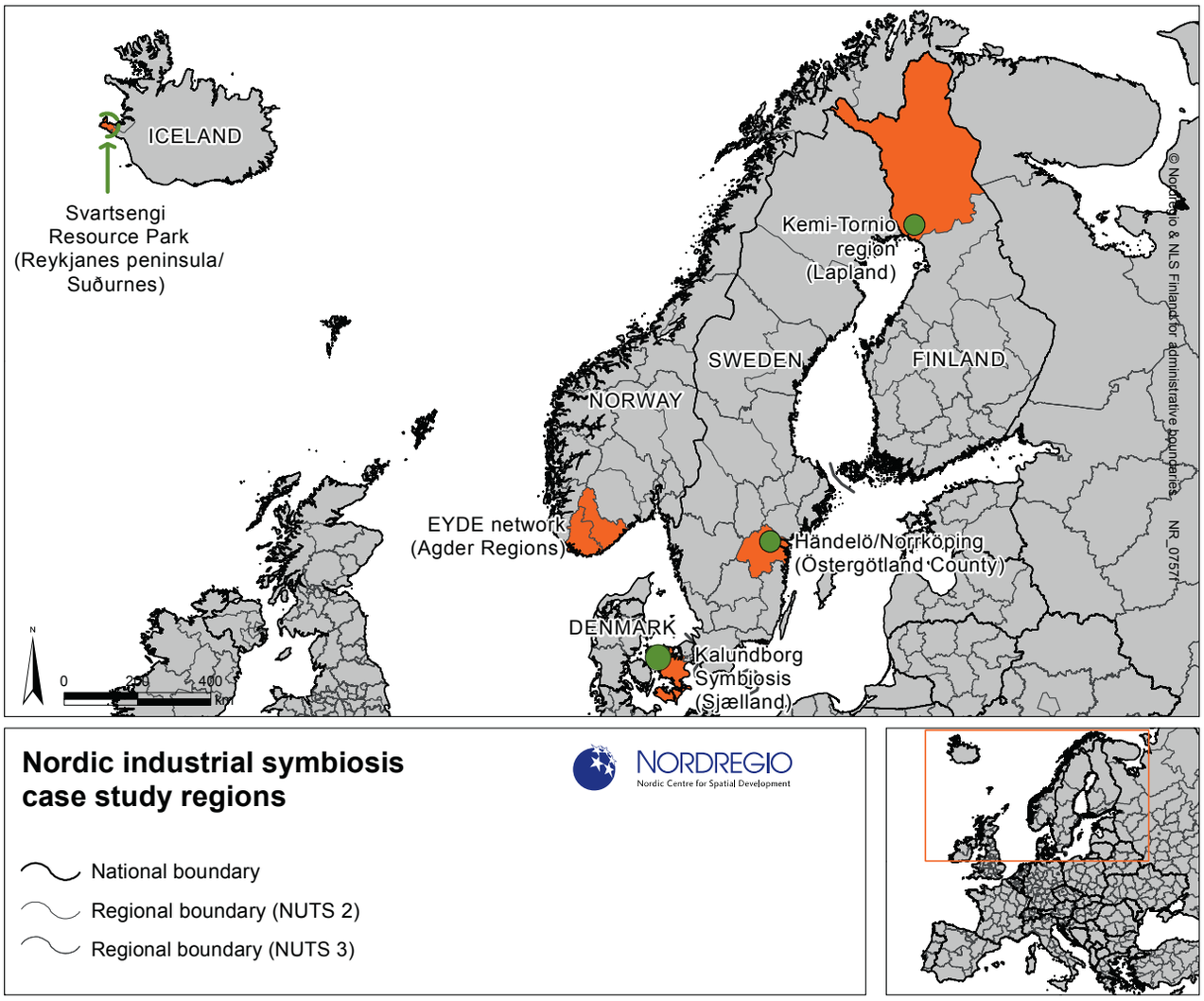
This report aims to provide insights into IS in the Nordic countries by examining national and international policies and trends and by investigating different cases of regional IS activities in the five Nordic countries. The specific regional cases that have been studied are the Kalundborg Symbiosis in the Zealand region, Denmark; the Kemi–Tornio region in Lapland, Finland; the Svartsengi Resource Park on the Reykjanes Peninsula, Iceland; the Eyde Cluster in the Agder region, Norway; and the Händelö IS in Östergötland county, Sweden.

The case studies were chosen in collaboration with the members of the Nordic Working Group on Green Growth – Innovation & Entrepreneurship, and were based on five selection criteria, where the aim was to include a rich selection of Nordic cases related to the following elements.

- Maturity (year of establishment of IS initiative)
- Type of region (predominantly urban; intermediate; predominantly rural[1])
- Type of symbiosis (by-product reuse, utility/infrastructure sharing and/or joint provision of services2 and the main types of by-products shared
- Main industry/industries in the IS network
- Annual turnover (total annual turnover of the companies involved in the IS network or eco-industrial park) and number of employees

1 These region types are part of the typology that was applied to all Europe's NUTS-3 regions. "NUTS" stands for "Nomenclature of Territorial Units for Statistics" and is a standardized, all-European classification for comparable administrative regions. NUTS-3 is the most detailed level. The typology derives from the EC's 5th Cohesion Report (2010). The typology was based on two criteria, population density and population distribution (urban–rural), combined with a distinction between areas located close to city centres and remote areas. This resulted in a classification of Europe's NUTS-3 regions into three main groups: 1) predominantly urban regions, 2) intermediate regions and 3) predominantly rural regions. (In predominantly urban regions, more than half of the region's population make up a city of at least 50,000; however, this only applies to capital areas in the Nordic countries, while all other Nordic regions are either intermediate or predominantly rural.)

2 The type of symbiosis is based on three opportunities for resource exchange defined by Chertow (2007, p. 12).



***Map 1 P**rovides an overview of the geographical locations of the regional in-depth case studies presented in this report. Orange areas on the map correspond to NUTS-3 regions in the Nordic countries, except for Iceland. In Iceland, the Reykjanes Peninsula is one of eight regions. The green circles on the map show the locations of the regional case study sites.*

Annual turnover and number of employees were added as an indicator of the size of the symbiosis initiative studied. However, both indicators are problematic to measure, because of 1) difficulties in determining how many employees are actually involved in activities related to IS as a fraction of all employees in the companies/organizations involved; 2) difficulties in calculating how much economic profit companies are actually gaining by engaging in IS activities; and 3) lack of access to these numbers for all the cases. Thus, annual turnover and number of employees as indicators were not used for the selection and classification of the case studies. Table 1 provides a classification of the selected cases based on the above criteria.

Through desk study and empirical data gathering, we have tried to gain knowledge about the specific context in which CE and IS are promoted in the different Nordic countries, as well as the opportunities and challenges that are specific to each region studied. Based on these insights we have developed specific lessons that have implications for the development of policies in this field. These will feed into the policy debate and contribute to public policy development to support innovation and entrepreneurship for green growth in the Nordic countries.

1.3 Structure of the report

The report has been divided into five main chapters. Following this introduction, Chapter 2 provides a conceptual discussion of IS in relation to CE, including how to measure the potential of IS in the Nordic countries. The chapter also provides a definition of the key terms and concepts in the report.

In Chapter 3, an overview of current trends and policies supporting CE and IS are presented. Although not exhaustive, the overview includes a selection of current IS activities and policy measures at the supra-nation-

Table 1 *Classification of selected in-depth cases*

Case	Year of establishment of IS initiative	Type of region[3]	Type of IS activities	Main industries
Kalundborg Symbiosis, Vestsjælland (DK022), Denmark	1959	Predominantly rural	Utility/infrastructure sharing; symbiotic exchanges, including excess gas, waste water, yeast slurry, steam, heat, straw, sulphur fertilizer, etc.	Pharma/medico, cleantech
Kemi–Tornio region, Lapland (FI1A3), Finland	2001–2003	Predominantly rural (Kemi–Tornio sub-region is an industrial region)	By-product reuse, including ash from forestry products, riffle waste, steel factory by-products, metals and carbon monoxide (CO) from a ferrochrome factory	Forestry, steel, minerals, ferrochrome
Händelö IS, Östergötland (SE123), Sweden	1990s	Intermediate	By-product reuse, including waste water, organic waste, steam, bottom and fly ash, CO_2, raw biogas and sludge	Ethanol and biogas production; combined heat and power (CHP) plant
EYDE network, Vest-Agder (NO042), Norway	2013	Intermediate	By-product reuse, including industrial manganese sludge and Fe(II) sludge	Metals processing (aluminium, nickel, silicon); materials and chemicals
Svartsengi Resource Park, Reykjanes Peninsula, Iceland (IS002)	1976	Predominantly rural	Utility/infrastructure sharing; symbiotic exchanges, including geothermal brine, geothermal steam, geothermal condensate and geothermal CO_2	Geothermal energy production, geothermal spa and clinic, methanol production, molecular farming

al level (EU, OECD and UN) and among the Nordic countries to complement the selected in-depth case studies.

In Chapter 4, the in-depth regional case studies on IS in the Nordic countries are presented. The case studies focus on current activities and policies, as well as opportunities and challenges related to the development of IS activities at the regional level.

Last, Chapter 5 summarizes the key findings and policy recommendations based on the national policy overview and regional case studies presented in the report.

3 Type of region classification is based on ESPON typology for NUTS 3 regions. Typology data: Linus Rispling, Nordregio.

2. Industrial symbiosis as a driver for green growth – a conceptual approach

2.1 Circular economy

The CE concept was developed in response to the need for sustainable growth because of the growing pressure on the world's resources and environment. In a traditional linear economic system, the main focus is on producing consumer and capital goods that stimulate consumption and in turn create welfare. However, this approach is a wasteful one. CE attempt to move from linear to cyclical or closed-loop systems by promoting resource-saving and by driving greater resource productivity at all stages of production, distribution and consumption (European Commission 2014a). Thereby, CE seek to decouple economic growth from resource consumption.

As a generic notion, the CE concept draws from a number of more specific approaches, including cradle-to-cradle design, industrial ecology and the "blue economy".

Central elements of a CE are waste prevention and recycling. The importance of minimizing the use of the environment as a sink for residuals as well as the use of virgin materials in economic activity is emphasized. At the same time, the CE idea does not undermine the importance of economic growth and job creation (Andersen 2007; Su et al. 2013; European Commission 2014a;). As opposed to the market economy, a CE prioritizes setting the right prices on materials and natural resources, to reflect environmental value – and the cost of environmental damage (Andersen 2007).

Different practices contribute to the realization of CE, encompassing production, consumption and waste management, and these are being carried out at the micro (e.g. eco-design), meso (e.g. eco-industrial parks) and macro (e.g. regional IS networks) levels (Su et al. 2013). The EC stresses that "transition to a more circular economy requires changes throughout value chains, from product design to new business and market models, from new ways of turning waste into a resource to new modes of consumer behaviour. This implies full systemic change, and innovation not only in technologies, but also in organisation, society, finance methods and policies" (European Commission 2014a, p. 2). Clever government support is key, whether in the form of the provision of guarantees to reduce risks for investors or via public procurement criteria (European Commission 2014b).

The EC has created a conceptual diagram (Figure 1) that illustrates the main phases of the CE model (European Commission 2014a, p. 5). In each phase, there is an opportunity to reduce costs and dependence on natural resources, and this in turn is meant to boost growth and jobs, as well as limiting waste and harmful emissions to the environment. The overall aim of the CE model is "to minimise the resources escaping from the circle so that the system functions in an optimal way" (European Commission 2014a, p. 5). CE reflect natural systems, in which waste from one process

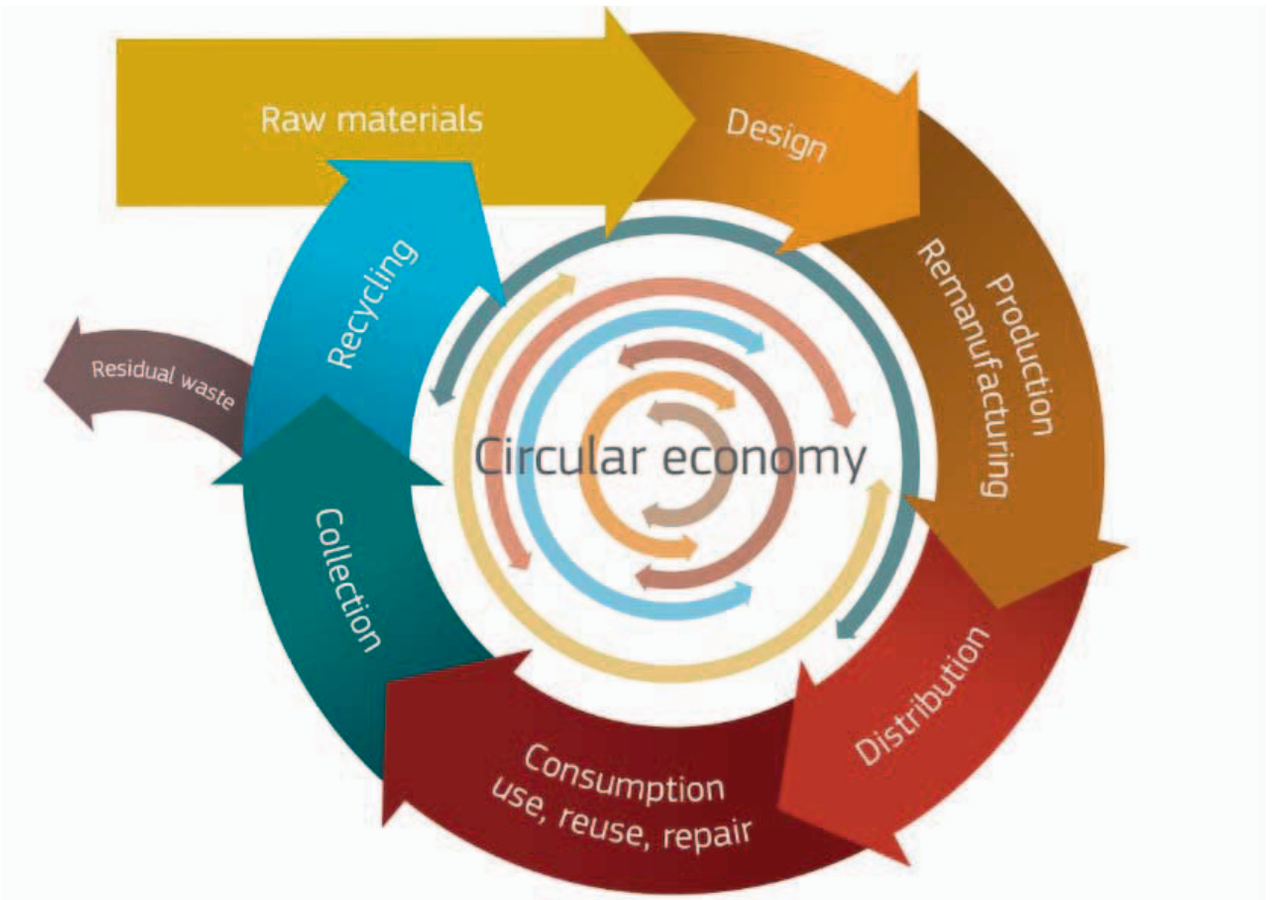
Key concepts related to the circular economy

Cradle-to-cradle philosophy mainly refers to the design of products and systems. It advocates the reuse and extension of the service life of goods through repairing, remanufacturing and upgrading them technologically. Its underlying principle is creating as little waste as possible.

Industrial ecology views industry as a human-made ecosystem that operates in a similar way to natural ecosystems, where the waste or by-product of one process can be used as an input into another process (GDRC 2015).

In a broad sense, the blue economy refers to the use of the sea and its resources in ways that result in sustainable economic development, improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities (WWF 2015).

Figure 1 *European Commission CE diagram*



Source: *European Commission (2014a, p. 5).*

becomes a resource for another. It is important to note that the CE concept not only involves (material) recycling, but also the reuse, repair and remanufacturing of products. Products should thus be designed to fit into material cycles in which they keep their added value for as long as possible, and designed such that the raw materials can eventually return to the biosphere without causing damage. For example, in the CE model, products can be redesigned to be used longer, repaired, upgraded, remanufactured or eventually recycled, instead of being thrown away, and production processes can be based more on the reusability of products and raw materials, and the restorative capacity of natural resources, while innovative business models can create new relationships between companies and consumers (European Commission 2014a, p. 5).

It is important to note that while the benefits of a CE are increasingly recognized, there are a number of barriers impeding its development, including insufficient skills and investment in circular product design and production; current resource prices that do not encourage efficient resource use, pollution mitigation or innovation; limited consumer and business acceptance of potentially more efficient service-oriented business models; challenges in obtaining suitable finance for such investment; and weaknesses in policy coherence at different levels (e.g. bioenergy and waste policies) (European Commission 2014e, pp. v–vi).

2.2 Understanding the context for industrial symbiosis

IS can be viewed as one approach to realizing a CE and achieving green growth. Through symbiotic activities between firms, IS provides many relevant contributions to a CE by promoting sustainable resource use at the inter-firm level, minimizing the input of virgin materials and simultaneously eliminating waste.

IS involves interconnections among industrial processes performed by traditionally separate industries, such as the physical exchange of materials, energy, water and by-products, to create mutual benefits (Boons

et al. 2011; Chertow 2000). Using IS, firms may create competitive advantages and improve their overall environmental and economic performance. IS usually occurs between geographically proximate firms, e.g. firms co-located in clusters or industrial parks, as well as at the regional level (Paquin 2009).

The fundamental principle of IS is the exchange of resources between firms. It is possible to distinguish between three main types of exchanges: by-product reuse (the exchange of firm-specific materials between two or more parties for use as substitutes for commercial products or raw materials); utility/infrastructure sharing (the pooled use and management of commonly used resources such as energy, water, electricity and heat, as well as joint treatment of emissions); and joint provision of services (meeting common needs across firms for ancillary activities such as fire suppression, transportation and food provision) (Chertow 2007; Martin 2013).

Chertow (2007) emphasizes that in order to distinguish IS from other types of exchanges, the "3–2 heuristic" should be used as a minimum criterion. This implies that to be counted as a basic type of IS, at least three different entities, none of which is primarily engaged in a recycling-oriented business, must be involved in exchanging at least two different resources. The 3–2 heuristic is meant to encapsulate the complex relationships that characterize IS, rather than linear, one-way exchanges. An example is a waste water treatment plant that provides cooling water for a power station that in turn supplies steam to an industrial user (Chertow 2007, p. 12).

Recently, the definition of IS has been extended to include other areas that practitioners and other stakeholders regard as important. In the new definition, the importance of geographic proximity for the emergence of IS networks is negated, and exchanges are extended to include personnel and knowledge transfer. Furthermore, competitive advantages from IS are extended beyond resource efficiency to include cost reductions, the addition of value to products and management of risks (Lombardi et al. 2012; Martin 2013). Moreover, IS has been promoted by economic development agencies for its job creation potential rather than for resource efficiency purposes (Lombardi et al. 2012).

A literature search shows that there are many studies aiming to increase our understanding or describe the context of IS. Others aim to uncover IS networks worldwide. There are a handful of studies concerned with quantification of the benefits of IS, whether they be economic, environmental or social. Horizon 2020 (see Section 3.1.1) emphasizes that the realization of IS still requires reliable and harmonized data in order to estimate waste material flows originating from different sectors and to achieve reliable and predictable inputs of secondary raw material for industrial processes (required data include waste composition, patterns of supply and demand and the quantity of waste generated over a period of time).

2.2.1 Industrial symbiosis evolution

IS is not seen as a fixed state, but rather as a dynamic process in which companies move towards increased level of connectedness, or conversely a decline in synergies. It is thus characterized by continuous evolution in terms of the actors involved in the IS network, the flows that connect them and the economic and ecological impacts produced (Boons et al. 2014). In this way, IS interactions are comparable to other industrial patterns whereby firms emerge, disappear or merge together to form new enterprises. Even successful synergies that initially achieve success on the market do not always lead to further synergies, as IS development may face operational, financial or social obstacles (Chertow 2007; Lombardi et al. 2012).

Many authors (Doménech & Davies 2011; Chertow & Ehrenfeld 2012; Baas & Boons 2004) distinguish three main phases of IS evolution: 1) emergence, 2) "uncovering" and 3) embedding and institutionalization. Each consecutive phase involves more in-depth engagement among firms, by which they expand the IS network or strengthen existing collaborations. In the intermediate phase of IS development, there are greater opportunities for more complex exchanges, and the level of "embeddedness" of the network increases (Paquin & Howard-Grenville 2012). In the last phase, the IS network is more mature, and firms develop norms of trust and reciprocity. A co-ordinating body is usually involved to further support firms' actions and develop a strategic vision (Boons et al. 2011; Paquin & Howard-Grenville 2012).

2.2.2 Various forms of industrial symbiosis networks

In the IS literature, scholars use three theoretical categories to describe possible models of IS emergence (although in practice these categories can overlap): 1) self-organization, 2) facilitation by organizations or individuals and 3) top-down planning (Paquin & Howard-Grenville 2012).

In the self-organizing symbiosis model, IS collaboration emerges through the spontaneous action of industrial actors with the purpose of gaining economic benefit. Private sector actors initiate the resource exchanges in order to reduce costs, enhance revenues, expand their business, etc. Such symbioses usually emerge

in an undirected fashion, without an overarching goal or a co-ordinating body. The self-organizing symbiosis model often occurs when there are obvious commercial advantages for firms from forming an IS network, such as value creation. Chertow (2007) and Paquin and Howard-Grenville (2012) emphasize that in the beginning, participating actors might not be conscious that their activities constitute IS, but that this consciousness can develop over time. This model is the most basic, as IS has historically been developed because of the "spontaneous co-location" of businesses in industrial districts. This type of IS network is also referred to as a serendipitous network (Chertow 2007; Paquin & Howard-Grenville 2012).

The development of IS networks through facilitation by organizations or individuals relies on the presence of a brokering organization or leader to bring firms together (Paquin & Howard-Grenville 2012). The broker engages individual firms interested in such collaborations but who otherwise lack some combination of experience, knowledge or contacts with other interested firms (Paquin & Howard-Grenville 2012).

Last, in the planned model of IS, deliberate efforts are made by external actors to identify firms from different industries and co-locate them in order to facilitate resource exchanges among them (Boons et al. 2011). Co-ordinators play a central role in such models by making connections between firms, influencing the network's goals and structure, participating in decision-making on the involvement of particular actors, etc. (Paquin & Howard-Grenville 2012). In some cases, the public authorities are included in the co-ordinating body to facilitate network development, through, for instance, land use planning and/or zoning, or giving grants or long-term financing (Chertow 2007). This type of facilitated network is referred to as a goal-directed network, as it is intentionally created to achieve collective goals (Paquin & Howard-Grenville 2012).

In practice, a combination of the three types of network development may occur. IS may emerge by self-organization and, once uncovered, may come to be managed by a co-ordinating organization (e.g. Kalundborg Symbiosis) (Paquin & Howard-Grenville 2012). Many researchers argue that symbioses that emerge spontaneously (by self-organization) are more durable and functional than ones that emerge through forced planning (Lehtoranta et al. 2011). The reason is that the self-organized networks tend to be resilient and long lasting, as they build upon prior ties and relationships (Paquin & Howard-Grenville 2012). However, it is clear that there is no universal solution that fits all (Chertow 2007).

2.2.3 Enabling and hindering factors for industrial symbiosis development

The major hindrances and key drivers of IS development identified in the literature can be grouped into five main categories: economic, social, technological, information-related and policy-related (Baumgarten & Nilsson 2014) (see Table 2).

Economic barriers arise when synergetic partnerships may be economically unjustified, or may pose a financial risk to the companies. Such hindrances include high investment costs as well as lack of access to (long-term) financing and substantial private (risk) finance, which affect the growth and internationalization potential of SMEs and their capacity to engage in symbiotic ventures. Moreover, it can be difficult for companies to estimate the cost effectiveness of an investment in a symbiotic co-operation. Furthermore, market-related obstacles may hinder the development of an IS partnership; for instance, there is a risk that incentives to use waste products as a resource for other processes may be limited, unless there is a stable market for these flows. Other economic hindrances relate to the fact that the costs associated with environmental damage and climate effects are not reflected in market prices, leading to low investment in new environmentally friendly technology or business initiatives without public support.

Social barriers are classified in the literature into individual, organizational and external types. Such hindrances relate to companies' strong focus on their core business, and their lack of time and resources to work on issues other than their core business. For instance, sustainability work and symbiotic co-operation may not always be consistent with the objectives of the decision-makers in the company. Reluctance to change may also be an organizational hindrance at the company level. Another example is when companies are unable to build trust and are reluctant to share information for competitive reasons. Information-related barriers can hinder new collaborations when there is a lack of knowledge about the opportunities for symbiosis development.

When it comes to drivers of IS development, the major success factors have been identified in the "International survey on eco-innovation parks – Learning from experiences on the spatial dimension of eco-innovation" (FOEN 2014). This study was conducted within the framework of the European Research Area Network on Eco-Innovation (ERA-NET ECO-INNOVERA) with the aim of investigating the characteristics and potential of European collaborative patterns in industrial areas – also known as eco-industrial networks, IS or industrial ecosystems. This large-scale

international survey on eco-innovation from 2014 has analysed the best practices and success factors of 168 eco-innovation parks in 27 countries.

The main economic drivers behind companies' engagement in IS partnerships are related to the possibility for economic gains through, for instance, reduced energy and material use. The economic value added and business interests in reducing expenses and increasing profit are identified as strong motivations for companies to develop eco-industrial parks and eco-innovation strategies (Jacobsen 2006; Karlsson et al. 2008; Massard et al. 2014). Implementing IS is also seen as a way to gain competitive advantage, as IS strengthens the environmental profile of the companies and increases opportunities for innovation and access to new markets.

Furthermore, policies, regulatory frameworks and financial incentives are identified as success factors underpinning the development of eco-industrial parks and eco-innovation strategies in the ERA-NET study. The involvement of governmental authorities in park development and the existence of environmental legislation facilitating eco-innovation projects in industrial zones are also of major importance (Gibbs et al. 2007; Mirata 2004; Massard et al. 2014). Financial incentives, economic tools and access to finance all help to tackle economic barriers and support the planning and implementation of eco-innovation (Massard et al. 2014).

In terms of organizational and institutional designs, the ERA-NET study considers the intensity and quality of the co-operation and co-ordination between economic players and local stakeholders to be a crucial indicator of the potential of IS. Co-operation with science and technology institutions is also identified as important in the ERA-NET analysis. Within the regional framework, access to advanced technologies and knowledge transfer between firms and academia or researchers help to enhance industrial synergies and reduce environmental impacts (Costa et al. 2010a; Costa et al. 2010b; Massard et al., 2014).

Furthermore, geographical factors and regional infrastructure as well as the local diversity of economic activities are identified as success factors in the ERA-NET survey. The physical location of a park close to major conurbations/cities or nearby specific resource extraction or importation sites is an asset (Jensen et al. 2012; Massard et al. 2014). Moreover, a wider spatial scale and a diversity of regional industrial sectors and economic activities increase opportunities to create new sets of circular flows (Fiksel 2003; Korhonen et al. 2005; Massard et al. 2014).

Social factors also play an extremely important role in enabling the implementation of IS. Many authors refer to social concepts of embeddedness and trust when they study IS network stability, evolution and resilience (Boons et al. 2011; Paquin & Howard-Grenville 2012). In the context of IS, embeddedness refers to embeddedness refers to the structural and social/cultural integration of IS into business operations, which will influence the decision-making process in firms and therefore affect the construction and development of IS networks (Doménech & Davies 2011).

There are different dimensions of embeddedness that influence the actions of economic and social agents (Doménech & Davies 2011). Structural embeddedness refers to the interconnection of firms and individuals through particular exchanges, whereas cultural embeddedness is about developing trust and shared norms in support of IS. In serendipitous (self-organizing) networks, trust plays an important role in developing the social relations that constitute the foundation for an IS network and for enabling new exchanges (Doménech & Davies 2011; Paquin & Howard-Grenville 2012).

In non-spontaneous, facilitated networks, such trust may be more difficult to replicate. In such networks, the co-ordinating body plays an important role, as it might facilitate long-term processes of trust-building by establishing some common rules and governance codes to co-ordinate the realization of IS activities (Doménech & Davies 2011).

Three main features of embedded networks are trust, information transfer and joint problem solving. Embedded IS networks in many cases rely on long-term, resilient and close ties, and are characterized by flexibility and high adaptability to changing environments. Therefore, embeddedness often occurs at the later stages of IS evolution (Doménech & Davies 2011; Lehtoranta et al. 2011).

Given that IS often emerges out of spontaneous, self-organizing networks, Chertow (2007) raises the question of what role the government could have, and whether there is any stage at which government intervention might be effective. One example of how to drive symbiosis development at the national level is the UK's National Industrial Symbiosis Programme (NISP). A similar initiative has been launched in Denmark, the programme Green Industrial Symbiosis Denmark, which is further discussed in Section 3.4.1.

Examples of technical, information- and policy-related hindrances and drivers for IS development are presented in Table 2.

Table 2 *Identified hindrances and drivers for IS. The table has been adapted from Baumgarten and Nilsson (2014).*

Category	Sub-category	Hindrances
Economic	Financial	High investment costs Lack of access to (long-term) financing Lack of substantial private (risk) finance Long payback period Uncertainty about the profitability of the partnership
	Between companies	Weak cross-sectoral co-operation
	Market-related	Market failures: costs associated with environmental damage and climate effects are poorly reflected in market prices Availability of raw materials
Social	Individual	Reluctance to change
	Organizational	Companies lack time and resources to work on issues other than their core business Lack of trust; competition among the companies in the network Strong focus on core business; SMEs not actively looking to engage in symbiosis projects with other companies
Technical		Long physical distances between the industries Lack of technical solutions for managing by-products
Information-related		Lack of knowledge about possible side-streams, collaborating partners, etc.
Policy-related		Lack of comprehensive and coherent strategies Strong interest in existing industrial structures Uncertainties in legislation
Category	**Sub-category**	**Drivers**
Economic	Financial	Access to public grants Possibility of economic gains for companies
	Market-related	Companies promoting their “green profile” Gaining competitive advantage Increased access to new markets Increased opportunities for innovation
Social	Relational	Human drivers: strong, enthusiastic and committed leaders New businesses/value chains Building of trust and embeddedness
	Synergy-related	Connecting businesses: local public authorities are crucial Local processes are the most important for greening the economy
Technical		Access to infrastructure Presence of industries from different fields involving different material flows
Information-related		Knowledge and training; capacity building and awareness raising
Policy-related		Overarching strategy for the development of CE/IS Environmental regulations “Green” criteria for public procurement Government intervention

2.3 Measures of industrial symbiosis and its potential

Another question that relates to policy is how to quantitatively measure the output of IS initiatives in terms of economic and environmental gains. IS can have the following three types of measurable impact.

Business gains: minimization of costs (e.g. for waste management and resource purchases) and improvement of a company's bottom line and competitive edge
Environmental gains: improved resource efficiency through reuse, recycling and reduced intake of virgin materials
Innovation and development: improved introduction of and access to new technologies and research and development (R&D); job creation and regional development

Sustainable growth and resource efficiency are important opportunities especially for European industry, which has been identified as a key sector for Europe's economic recovery and competitiveness. The challenge of sustainable industrial growth and the importance of resource efficiency are clearly recognized by the EC and are now at the forefront of strategy and policy. In its communication "For a European Industrial Renaissance" (2014), the Commission notes that industry accounts for over 80% of Europe's exports and 80% of private research and innovation, and that "nearly one in four private sector jobs is in industry, often highly skilled, while each additional job in manufacturing creates 0.5–2 jobs in other sectors" (European Commission 2014d, p.1). The CE model is found to have substantial business potential for industry, and good potential to contribute to improving the European economy. It has been estimated that improving the efficiency of resource use could produce overall savings of 630 billion EUR per year for European industry (European Commission 2014d).

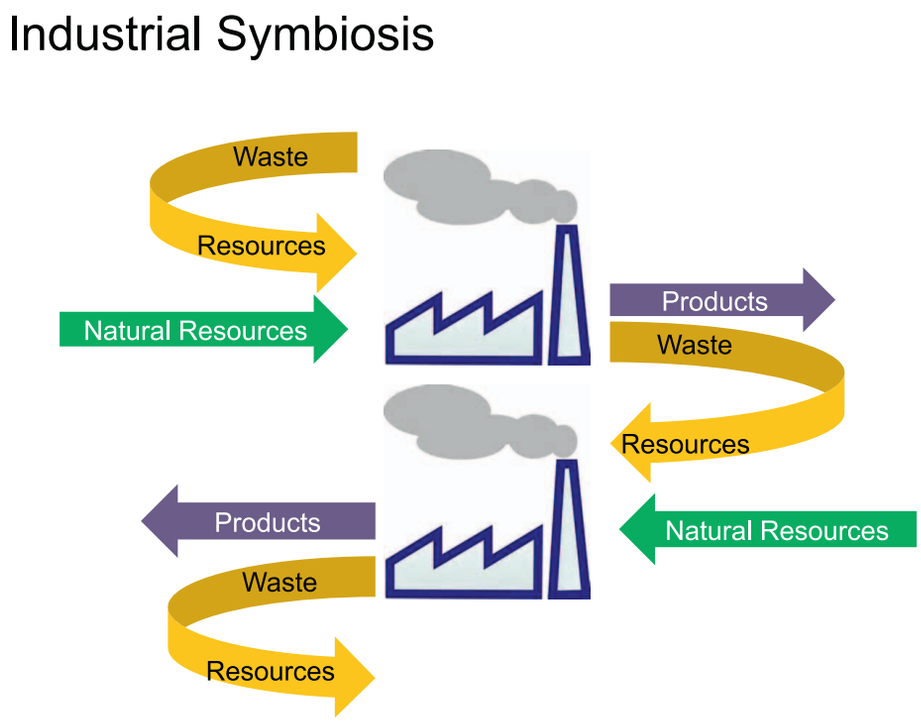
2.4 A working definition of industrial symbiosis

Based on the discussion above, the following definition of IS is used in this study:
IS is a type of business collaboration wherein residuals from one enterprise serve as inputs for another, thereby improving each business partner's bottom line and competiveness and reducing the total impact of the industry on the environment. More specifically, IS involves physical exchanges of resources (materials, energy, water and by-products) among a diversified cluster of firms, involving at least three different business entities and two or more types of exchanged resources that can be used as substitutes for commercial products or raw materials. Physical exchanges of resources can include three main types: by-product reuse, utility/infrastructure sharing and the joint provision of services (e.g. Chertow 2007).

In the selection of the regional case studies presented in Chapter 4, we have tried to include examples of as many of types of exchanges introduced by Chertow as possible. Our cases cover two types of exchange: three of the cases (the Kemi–Tornio region, Finland; the Händelö industrial symbiosis, Sweden; and the Eyde Cluster, Norway) are based on by-product reuse, while two cases (the Kalundborg Symbiosis, Denmark; and the Svartsengi Resource Park, Iceland) cover utility/infrastructure sharing. However, several types of exchanges may take place within the same resource park or cluster, and both the Kalundborg Symbiosis and the Svartsengi Resource Park also have exchanges of by-products.

Figure 2 illustrates a by-product reuse IS model, where the main idea is the exchange of resources (by-products) that can be used as substitutes for commercial products or raw materials. Such a model is based on interconnections among industrial processes performed by traditionally separate industries, involving the physical exchange of by-products to create mutual benefits. A precondition for this model is the geographical proximity of firms, e.g. co-location in clusters or industrial parks in a limited geographical area.

Figure 2 *By-product reuse IS model.*



Source: *Rise (2015).*

3. Industrial symbiosis and circular economy – current trends and policies

This chapter presents an overview of relevant IS activities and policy measures in support of CE and IS at the international (EU, OECD and UN) and national (Nordic countries) levels. With regard to policy measures, we refer to tools that authorities use to encourage green growth through CE thinking. Such tools can be roughly sorted into information and research, laws and regulations, and economic instruments. We have chosen to focus on the latter two.

Although not exhaustive, this overview, which is based on interviews and desk studies, includes a broad selection of current IS-related policy activities that complements the selected in-depth case studies and may provide ideas for further reading.

International review

3.1 European Union

The European Union (EU) has recognized that IS has direct relevance not only to resource efficiency, but also to a broad policy agenda covering innovation, green growth and economic development. Considering that sustainable growth, resource efficiency and enhancing European industry are all high on the EU's agenda, promoting IS and CE at the EU level has progressively gained importance and is considered a way to decouple economic growth from resource consumption. However, the potential benefits of IS were long unrecognized in the EU's policy documents, and explicit references to industrial ecology as a way to promote sustainable consumption and production have appeared only recently (Lehtoranta et al. 2011).

3.1.1 Current European Union policies

In 2012, IS was selected as one of seven "top priority areas" by the European Resource Efficiency Platform (EREP), a high-level stakeholder group with a mandate to deliver concrete policy recommendations for implementation across Europe. By June 2013, EREP had credited IS networks already active in Europe for reducing carbon emissions, preserving resources and improving the competitiveness of European companies, especially SMEs (European Commission 2013).

In December 2012, the EC together with EREP published a document entitled "Manifesto for a Resource-Efficient Europe". The document highlighted the importance of "a systemic change in the use and recovery of resources in the economy" for ensuring future jobs and competitiveness, and outlined potential pathways to CE through innovation and investment, regulation, tackling harmful subsidies, increasing opportunities for new business models and setting clear targets (European Commission 2012).

Following this, recent European policy documents have increasingly supported IS as an integral part of economic and environmental policy. One of the most significant has been the Europe 2020 strategy, the EU's growth strategy, with a vison for a "smart, sustainable and inclusive Europe", and its flagship initiative "A resource-efficient Europe", building on the earlier manifesto by the EC and EREP. Guidelines for this transition were outlined in the form of a "Roadmap to a Resource Efficient Europe" (European Commission 2011), which recognizes resource efficiency gains that can be achieved through IS and calls for member states to prioritize exploitation of the opportunities IS has to provide. According to calculations presented in the roadmap document, "improving the reuse of raw materials through greater IS, the EU could save 1.4bn EUR a year and generate 1.6bn EUR in sales" (European Commission 2011).

The EC also promotes CE through the EU Framework Programme for Research and Innovation, i.e. Horizon 2020, which funds large-scale innovation. In 2013, Horizon 2020 launched an initiative titled "Moving towards a circular economy through industrial symbiosis" with a total budget of 53 million EUR (Horizon 2020, 2013). This is aimed at helping the EU to create a systematic approach to eco-innovation and to facilitate innovation action with a cross-sectoral approach, leading to closed-loop processes. It has already resulted in large-scale, multinational projects that aim to foster a symbiotic approach among European industries.4 However, the outcomes can only be evaluated in the years to come. An initiative for a Europe-wide public–private partnership for innovation in Europe's processing industry was also launched in 2012 in conjunction with the Horizon 2020 programme. Entitled SPIRE (Sustainable Process Industry through Resource and Energy Efficiency), this association was formed to represent the private sector as a partner in making the processing industry sustainable. SPIRE represents around 130 industrial and research stakeholders in the processing industry from several European countries.5

In 2014, the role of CE and IS in EU policy was further strengthened by the establishment of a policy focusing solely on these matters, titled "Towards a circular economy: A zero waste programme for Europe". In

4 See for instance the FISSAC project, which has a budget of 11.5 million EUR and a Europe-wide consortium: http://cordis.europa.eu/project/rcn/196821_en.html

5 Read more at: http://www.spire2030.eu/

this policy document, the EC clearly states that it considers a CE to be an essential element in reaching the most important general objectives of the EU, as stated in the Europe 2020 strategy (European Commission 2014a), among other places.

In this context, the Directorate-General (DG) for Enterprise and Industry released a strategy document titled "Sustainable industry: Going for growth and resource efficiency" (European Commission 2014c), which advocates IS as a policy instrument for realizing the potential of sustainable European industries. Besides being one of the key opportunities for improvement in European industry, this report also notes that IS has added value in encouraging local and regional growth particularly.

These EU-level programmes and roadmaps indicate a likely future policy direction and send an encouraging signal in terms of IS development on an EU scale. Likewise, these documents have important connections to the EU's growth agenda and thus have potential to influence the allocation of budgets in Horizon 2020 and to indicate some priority fields for the Juncker Commission's "Investment Plan for Europe" for 2015–2017. Furthermore, the common time frame that applies to the EU's 7th Environment Action Programme, the EU's Multiannual Financial Framework 2014–2020, the Europe 2020 strategy and Horizon 2020 offers a unique opportunity to harness synergies across policy, investment and research activities in support of the transition to a green economy (EEA 2015).

However, the current Commission has suspended EU enforcement of a CE. In March 2015, the CE package of six laws on waste, packaging, landfill, end-of-life vehicles, batteries and accumulators, and electronic equipment waste was dropped as part of the Commission administration's drive for better regulation. The dropped CE package included legally binding targets of 70% recycling of municipal waste by 2030, 80% recycling of packaging such as glass, paper, metal and plastic by 2030 and a ban on the landfilling of all recyclable and biodegradable waste by 2025. The bill was intended to increase recycling levels and tighten rules on incineration and landfilling, and was predicted to create 600 billion EUR net savings, two million jobs and 1% additional growth in GDP. The current Commission did, however, promise that a "more ambitious" version of the package would be proposed before the end of 2015.

The EC's proposal to move 2.7 billion EUR from the Horizon 2020 programme into the newly launched European Fund for Strategic Investments (EFSI, a part of the Juncker Commission's "Investment Plan for Europe") must also be scrutinized, as this proposal would affect direct funding for European R&D activities that are also important for the development of IS. However, IS-related activities could seek funding from several European financial frameworks and programmes, and IS initiatives also have good capacity to utilize new funding available directly through the European Investment Bank (EIB) and EFSI.

3.1.2 Tackling barriers

The EU has identified several barriers to be overcome when moving towards a CE and IS in Europe. These range from infrastructure, business models and technology to consumer behaviour. This variety implies that a wide range of different kinds of policy measures are needed to promote a CE. In its "Zero waste programme", the EC states that it will respond to these challenges by developing "measures combining smart regulation, market-based instruments, research and innovation incentives, information exchange and support for voluntary approaches". The EC also clearly emphasizes that the transition towards a CE requires changes across value chains and a full, systemic change focusing on innovation not only in technology but also in, for example, organization and policy.[6]

The DG for Enterprise and Industry has further identified possible opportunities to improve resource efficiency, and mentioned the promotion of a CE through increased recycling together with eco-design and a cradle-to-cradle approach (see the info box on p. 14). Components of a CE may include the promotion of IS, cross-sectoral initiatives to identify opportunities for more efficient business interaction across value chains, strengthening the single market for waste and recycling to maximize the reuse of materials, and the development of new business models (European Commission 2014c).

In order to achieve these measures, the DG for Enterprise and Industry has first and foremost called for increased financing options and incentives for resource efficiency projects through the use of market-based instruments and public–private partnerships. Introducing alternative materials, new product designs and more sustainable products requires increased R&D and innovation measures, and in this field EU support for industries is often crucial. Furthermore, EU economy-wide indicators, benchmarks and performance levels for resource efficiency would serve as important tools for self-assessment, productivity evaluation and policymaking, both for companies and for decision-makers (European Commission 2014c).

6 See for instance the "Zero waste programme" (European Commission 2014a).

3.1.3 Practical measures and dynamics between the European Union and member states

In practice, the EC has already in many ways supported the transition towards a CE. For example, the goals of the "Roadmap to a Resource Efficient Europe" (2011) are operationalized in the 7th Environment Action Programme, which envisions the EU as a low-carbon society, based on a CE and resilient ecosystems, simultaneously standing on the front line of science and technology (European Commission 2014c). Furthermore, the EREP functioned as a central instrument for supporting a CE during its working period from 2012 to 2014, bringing together governments, businesses and civil society organizations.

The EU has released a number of new directives aimed at reducing the environmental impact of industries and companies, and promoting innovation and sustainable industries. These ambitions are realized, for example, through the EU's waste legislation, chemical policy and eco-design measures. The EU bioeconomy strategy and climate policy also contribute to the transition towards a CE (European Commission 2014a). With regard to CE and IS promotion, the EC has also noted that EU policy needs to abolish environmentally harmful subsidies and establish the taxation of pollution and natural resource use. Furthermore, voluntary instruments on the EU level, e.g. co-ordination programmes and recommendations, provide information and facilitation assistance for industries to identify economically viable and environmentally sustainable alternatives.

Besides providing the main principles for CE and IS activities at the Union level, the EU directs member countries to develop their own criteria and implementation mechanisms to motivate market demand. While policies at the EU level set strong objectives and incentives for IS, the national level needs to develop strong economic and regulatory instruments, as well as voluntary ones, in response to the supra-national objectives of the EU. A recent study focusing on waste management as a component of IS in EU member states demonstrates that some member states are already actively developing proactive responses to EU challenges in this area, by developing either new regulatory instruments or voluntary ones (Costa et al. 2010b).

As an additional way to support investment in a CE, the EC has integrated CE into EU funding as well as encouraging member states to use available EU funding (especially the European Structural and Investment Funds) to support CE (European Commission 2014c). In this context, policy and legislation at the EU level can positively influence IS development by setting clear objectives and supporting eco-friendly activities. This sends important signals to the market that guide businesses to IS-related actions, without direct governmental intervention in that process (Costa et al. 2010b).

Moreover, the EU has a role as a facilitator for closer and more innovative linkages between different actors, and also a role in forming platforms and networks for the dissemination of good practices. For example, the EU has highlighted the activities of its "pioneer" member states in the field of IS (including the UK, the Netherlands, Austria, Italy, Denmark and Sweden). The UK's NISP has been widely cited by EU institutions as a best-practice example of firm action already being taken by member states (COWI 2011). It is also recommended as an approach that should be replicated across all the member states of the EU (European Commission 2014c). The Kalundborg Symbiosis in Denmark, with its Industrial Symbiosis Institute, is also used as a good example of IS underpinning local and regional growth (DG for Enterprise & Industry 2014).

3.1.4 Financial instruments for supporting industrial symbiosis and a circular economy

The EC has emphasized that the EU and its member states should encourage investment in innovations leading to CE and address the barriers to more private investment. These objectives are partially facilitated by the Juncker Commission's "Investment Plan for Europe", which is based on strategic public–private partnerships and the guaranteeing of high-risk loans by the EIB. It holds potential to increase the prominence of IS and initiate larger-scale ecological industry and CE projects, as these sectors have traditionally been less attractive to private investors. The Commission's commitment to make EU regulation smarter is also welcome news for European IS; as the realization of IS takes place at the regional and local levels, the regulatory framework needs to be flexible and to take into consideration the specific characteristics of each region and symbiosis group, in order to avoid unnecessary constraints on the development of CE.

In terms of investment, CE, IS and ecological industries are some of the key targets of the EC's "Investment Plan for Europe". However, attracting increased private investment requires convincing actions and public support for ecological industrial activities, from both the EU and its member states, as well as credible performance and well-planned projects and R&D activities from industry itself. In the light of the investment plan, access to EU funding and supportive mechanisms is reliant on credible and well-prepared national project pipelines, which require initiative and precision from IS actors at the local, regional and national levels.

3.2 Organisation for Economic Co-operation and Development

The Organisation for Economic Co-operation and Development (OECD) has promoted IS as a key approach to "doing more with less" by creating greater firm-level eco-efficiency outcomes, while also supporting broader policy-level eco-development goals (Paquinet et al. 2013). It has also cited IS as a "systemic innovation vital for future green growth" (OECD 2011a).

In its latest report from 2015, "Material Resources, Productivity and Environment", the OECD states that establishing a resource-efficient economy is central to achieving green growth. Better resource productivity has the potential to improve the environment and to help sustain economic growth. The report calls for putting in place policies that are conducive to the CE approach: improving resource productivity, ensuring sustainable natural resource and material management using the three Rs—reduce, reuse and recycle—and encouraging more sustainable consumption patterns (OECD 2015).

The OECD considers waste management to be a key factor when pursuing CE, and emphasizes the management of material resources after they have been used, especially the recycling of not only high-volume materials such as glass, steel, aluminium, paper and plastics, but also valuable materials such as specialty metals. It has also raised the idea of urban mines, i.e. means to extract materials locked in the economy that could later be reused or recycled (e.g. buildings, cars and electric and electronic equipment) and their potential to become an important future source of raw materials and other inputs to production cycles.

In order to respond to economic and environmental challenges amidst global population growth and increasing consumption and production, the OECD has called for more ambitious policies to increase resource productivity globally. It has highlighted the need for investing in technological change and innovation, integrated life-cycle-oriented management approaches, sustainable materials management and CE initiatives.

In its report "Resource Productivity in the G8 and the OECD" from 2011, the OECD listed the main challenges the global community must tackle in order to implement credible policies that promote sustainable materials management and improve resource productivity in the long term. These include:

- greater coherence of policies relating to resource use and materials management (e.g. economic and trade policies, investment policies, technology and innovation policies, natural resource policies and environment policies);
- enhanced partnerships with the private sector, researchers and civil society;
- a good understanding of the material basis of the economy and international and national flows of materials, and of their relation to productivity and environmental risks;
- shared policy principles and guidelines to overcome barriers to increased resource efficiency, and related framework conditions to secure resource productivity and guide investment choices; and
- an international perspective with a common vision and differentiated solutions at the local, regional and global levels (OECD 2011a).

The OECD also highlights the need to fill the remaining information gaps in terms of analysing material flows and measuring resource productivity as a basis for developing better policies (OECD 2015). Together with the United Nations Environment Programme (UNEP), Eurostat and research institutes, the OECD aims to develop an international knowledge base on material flows and resource productivity (data, indicators, accounts and analytical reports). This work is to be complemented with trade, innovation and sustainable manufacturing research. The OECD will evaluate the progress of this work on a regular basis in country peer reviews (OECD 2015).

3.3 United Nations

Resource efficiency and CE are firmly embedded in the agenda of the United Nations (UN) and in its development goals. Through promoting resource efficiency and sustainable consumption and production (SCP) in both developed and developing countries, the UNEP promotes CE and IS worldwide. Activities and policies in this field fall under the responsibility of UNEP in collaboration with the UN Department of Economic and Social Affairs and are channelled through the UNEP's Resource Efficiency Programme in particular.

The UN has promoted SCP as a key strategy for our times, when increasing economic growth and consumption are coinciding with a resource crunch and environmental degradation. According to the UNEP, responding to this dual challenge will require a combination of new policies, redirected investment, application of environmentally sound technologies, international co-operation, and capacity-building to reshape national economies as well as the global economy. The UNEP has promoted IS, e.g. eco-industrial parks, at the global level since the late 1990s and has suggested that such industrial systems may represent the ulti-

mate integration of the economic, ecological and social dimensions of sustainable industrial development (Lehtoranta et al. 2011).

Given the breadth of the challenges and actions required, UNEP's activities are focused on specific tools encompassing policies, market-based instruments and voluntary approaches, with an emphasis on specific economic sectors. The UNEP's work focuses on four central themes:

- strengthening and communicating the knowledge base for resource efficiency and SCP;
- building governmental capacity;
- consolidating and extending partnerships with business and industry; and
- influencing consumer choice.

To support the international community and individual countries in their efforts to implement and mainstream resource efficiency and green economies, the UNEP has delivered an international policy framework for co-operation in developing resource efficiency, and has served as a platform for information exchange on the adoption of resource-efficient and sustainable production patterns and best-practice technologies and policies. It also provides evidence-based information on CE through studies and analyses of current global trends, and creates capacity-building tools, handbooks, methodologies and policy support documents.

To further its work on resource efficiency and the promotion of life cycle thinking, the UN has established the International Resource Panel (IRP). Officially launched in November 2007, the IRP is expected to provide the scientific impetus for decoupling economic growth and resource use from environmental degradation. The IRP's objectives are to provide independent, coherent and authoritative scientific assessments of policy relevance on the sustainable use of natural resources and their environmental impacts over their full life cycle, and to contribute to a better understanding of how to decouple economic growth from environmental degradation (IRP 2014).

Nordic countries review

3.4 Denmark

3.4.1 Current trends in developing circular economy and industrial symbiosis

In recent years, IS as an approach to enhancing resource efficiency has become part of Denmark's national political agenda. The programme Green Industrial Symbiosis Denmark (henceforth the Green Symbiosis programme) has been run under the auspices of the Danish Business Authority in collaboration with Danish regional authorities since 2013. The programme is managed as part of the Fund for Green Business Development that was launched the same year. The establishment of a fund particularly focused on green business models was new to the Danish Business Authority. The fund is unusual in its focus on supporting projects that are almost market ready. The Danish Environmental Protection Agency and Danish Energy Agency also provide funds for green business ideas, but they typically focus on the earlier phases of R&D and on the testing of environmental technology solutions, rather than commercialization.

In 2015, a report on the economic potential of a CE in Denmark and a toolkit for policymakers were produced by the Ellen MacArthur Foundation, with the Danish Business Authority and the Danish Environmental Protection Agency as key contributors. According to its predictions up to 2035, the transition to a CE in Denmark could contribute to an annual increase in GDP of about 0.8–1.4%, the creation of 7,000–13,000 job equivalents, a 3–7% reduction in Denmark's carbon footprint, and a 5–50% reduction in virgin resource consumption for some materials (Ellen MacArthur Foundation 2015).

The political interest in supporting IS has been generated by its benefits for resource efficiency, which link in to the green growth agenda. Furthermore, knowledge of the IS network in Kalundborg (see Chapter 4) and the idea of broadening the concept across the country have led to increased political interest.

A national strategy for a CE in Denmark is under development and will be completed towards the end of 2015.

3.4.2 Policies in support of circular economy and industrial symbiosis

Under the heading "Green Transition", the Danish Business Authority manages the Fund for Green Business Development. The fund has its own application rounds, and it also supports the Acceleration Programme on Green Business Model Innovation and the Green Symbiosis programme. As part of the state budget negotiations for 2013, 10 million DKK was allocated for a pilot project on the promotion of IS in Denmark. After demonstrating progress in its first year, it was decided that the Green Symbiosis programme would continue for the period 2013–2015, with the intention to further prolong it in 2016.

With the allocation of funds to the Green Symbiosis programme, the Danish Business Authority initiated collaboration with the five Danish regional authorities and with the regional municipality of Bornholm. A national working group was set up, comprising representatives from each region's development department, as well as process consultants and technical consultants. The role of the process consultants is to identify relevant companies in the regions and to bring them into contact with the technical consultants. The role of the technical consultants is to carry out resource checks (i.e. evaluate companies' production residuals and identify possible synergies) and to facilitate matches between companies. The resource checks are offered to the companies free of charge. In collaboration with the companies, the technical consultants identify excess resources from one company that could be utilized by another company, or input materials that could be substituted, e.g. with excess resources from other companies.

The national task force works to bring together companies to develop IS in various ways. A database has been set up, in which technical consultants across the country register the excess resources of the companies they have visited. Other consultants can react immediately if they find a match with another company they have been in contact with. In addition, the task force meets regularly. Often, for part of the meetings, the

process consultants and technical consultants interact in one group to discuss how to match the companies, while the representatives from the Danish Business Authority and the regional authorities form another group to discuss more administrative and policy-related issues on the topic of IS. When possible matches between companies have been found, they are brought together for a matchmaking workshop or a meeting to discuss the potential for developing IS exchanges.

Once companies have met and decided that they wish to develop symbioses, they can apply for a grant from the Green Symbiosis programme. The grants are given to companies for consultation on whether the symbiotic co-operation will be economically advantageous and technically feasible. The grants are for a maximum of 170,000 DKK per symbiosis project. By the end of May 2015, approximately 100 projects had been initiated – 60 supported by grants and another 40 not supported by grants. These are visible on an online map of Denmark that shows the locations and distribution of projects on water, energy and materials.

A survey carried out by the Danish Business Authority demonstrated that two-thirds of the companies that have been involved in the national programme are interested in working with IS in their business. It has become evident, however, that once the projects have been completed and the IS exchanges have been determined to be feasible, the implementation phase (of which the companies themselves are in charge) takes longer. It is therefore currently being discussed whether the task force should also take a more active role in the implementation phase of the projects.

Table 3 *Key economic instruments and regulatory measures in support of CE in Denmark*

Instrument; organization responsible	Main focus	Type of measure
Fund for Green Business Development; Danish Business Authority	Green transformation through business development and the production, sales and marketing of green products	Grants
Acceleration Programme on Green Business Model Innovation; Danish Business Authority	Supporting selected companies to develop and implement new green business models	Programme; grants
Green Symbiosis programme; Danish Business Authority	A national task force to promote IS between companies in Denmark, by conducting resource checks in companies, awarding grants for the evaluation of the business case for IS and providing technical, financial and legal counselling	Programme; grants
Task Force for Enhanced Resource Efficiency; Danish Business Authority in collaboration with the Danish Environmental Protection Agency, Danish Veterinary and Food Administration and Danish Energy Agency	A cross-ministerial task force established to clarify which regulations and taxes have constraining effects on improvements to companies' resource efficiency through IS, and to assess whether there are regulations that could be revised or whether other aspects of administrative practices could be altered	Recommendations for changes to regulations and/or government administrative practices
Environmental Technology Development and Demonstration Programme; Danish Environmental Protection Agency	Water purification, water saving and technologies for adapting to climate change; CE and the recycling of waste; cleaner air and less noise; fewer problematic chemicals; modernization of the manufacturing industry's environmental management	Grants

3.4.3 Identifying drivers and barriers

Key drivers

When the Green Symbiosis programme was initiated in 2013, it was a pilot project to test whether there was any interest from companies in engaging in IS projects. The SMEs that have been involved mainly focus on their core business, and in most cases do not actively look to engage in symbiosis projects with other companies. Thus, the proactive approach of the task force, whereby companies have been approached with the offer of a free resource check, has been a significant driver in terms of developing an interest among companies about the concept of IS. The programme has demonstrated that there is an interest in IS among companies in Denmark. Furthermore, the possibility of applying for a grant for an external consultant to assess the feasibility of potential symbiosis projects has been a driving force. In terms of taking the next step and developing IS, the most significant driver for companies is the existence of a "business case" in favour of IS; i.e. it is essential that the companies can achieve economic gains. An additional benefit for the companies is that IS strengthens their environmental profile. A few companies that have a specific "green" focus have actively been seeking to engage in IS because it complements their green business brand and philosophy.

Major constraints

A key constraint for companies in developing IS involves a lack of time and resources to work on issues other than their core business. Another constraining factor is a lack of knowledge about the opportunities for symbiosis development. Communication efforts to create awareness about IS among companies in Denmark have therefore been an important priority of the national programme.

Other significant barriers to IS development often arise in the phase of planning IS exchanges, in the form of regulations and taxes. In the national programme, such barriers have become evident and have contributed to a political decision to establish the Task Force for Enhanced Resource Efficiency. The task force has been established to enable cross-ministerial collaboration between the Danish Business Authority and the Danish Environmental Protection Agency. It has been set up for a three-year period with a project group based at the Danish Business Authority. A steering group has also been established, with representatives from the four ministries. The purpose of the task force is, first, to clarify across the ministries which regulations and taxes have constraining effects on improvements to the resource efficiency of companies through IS. Next, it will assess whether there are regulations that could be revised or aspects of administrative practice that could be altered. In this regard, it is relevant to clarify whether barriers to resource efficiency are "perceived" or "actual". In some cases, for example, practices to implement regulation may differ between municipalities, and this will influence the extent to which apparently constraining regulations are actually experienced as a barrier by companies. The ongoing work to map barriers to resource efficiency in companies is extensive, and is to a large extent based on dialogue with companies.

3.5 Finland

3.5.1 Current trends in developing circular economy and industrial symbiosis

Finland has already come a long way towards putting in place CE practices in many sectors of the country's economy. Examples include improved energy efficiency in the paper industry, bottle recycling, flea markets and efforts made by forestry sector in the development of new products. Simultaneously, Finnish actors are increasingly considering IS as a means to promote cross-sectoral collaboration and to support local and regional growth, create jobs and foster industrial clusters that share a mutual interest in resource efficiency. In Finland, IS is considered to advance and contribute to the wider goal of a CE as a whole.[7]

According to a survey conducted in 2013 by Sitra – a key Finnish organization advocating green growth (see further below) – CE represent an opportunity for Finland worth 1.5 to 2.5 billion EUR. Despite its small size, Finland is in a good position to thrive in the face of global competition. Advantages such as its high education levels, good technological expertise and strong reputation as a cleantech operator are also fundamental to its success in the field of CE and IS.[8] However, there is still room for the further enhancement of CE activities and IS in the country before the desired extensive, systemic change will be achieved: only 54 per cent of all waste in Finland is recycled or reused in any way, and, similarly, few innovative service concepts concerning the maintenance, reuse or remanufacturing of equipment have emerged.

The potential of CE and IS is also increasingly reflected in the political agenda of Finland, where these topics have gained prominence; for instance, they are on the agenda of the country's newly elected centre–

7 See for example Motiva and Sitra: http://www.motiva.fi/toimialueet/materiaalitehokkuus; http://www.sitra.fi/en/economy/industrial-symbiosis

8 See: http://www.sitra.fi en/ecology/circular-economy

right coalition government.

The key national co-ordinator for CE and IS is Sitra – an independent Finnish fund that reports directly to the Finnish Parliament. Sitra's operations are guided by a vision of Finland as a leader in sustainable well-being. Sitra contributes to CE and IS in Finland by developing a roadmap in collaboration with other players, devising business models for companies operating in a CE and experimenting with operational models within government administration, with the intention of including aspects that would motivate a transition to a CE. In support of this work, in 2013 Sitra reviewed the global market for IS, considering also the international potential of Finnish companies in the field (Sitra 2013).

According to the review, Finnish companies hold great potential in terms of market-driven business activities related to IS. The study also notes that while market-driven business is only now emerging in the IS sector, profitability and market drivers are likely to grow remarkably over the next few years.

Sitra has also identified the IS sectors in which Finnish companies have the most significant opportunities to provide globally competitive solutions. In particular, the following five sectors were discovered (Sitra 2013).

- Sustainable solutions and closed-circulation system built around fish breeding facility
- Optimization and management of IS
- Modular solutions for the reuse of waste and side-streams
- Equipment, management and optimization of biorefinery production
- Production of side-stream-based sugar as a feedstock for biorefineries

Based on these findings, Sitra has started a national collaboration with interested companies in order to utilize the global market opportunities and to develop domestic and international strategies for targeted markets.

To gain an understanding of the volume and scope of IS activities in Finland, the Finnish Industrial Symbiosis System (FISS) has prepared a map showing the locations and distribution of IS activities in Finland. In order to present and disseminate information about good-practice domestic IS activities, FISS has also gathered a selection of successful Finnish cases (FISS 2015a; FISS 2015b).[9]

9 The map is available at: http://www.industrialsymbiosis.fi. Note that this mapping tool is based on voluntary registration by the companies or the IS networks themselves, and thus not all the cases listed in the database necessarily fall under the definition of an IS outlined in this study, or the definitions used by the wider academic community studying IS.

3.5.2 Policies in support of circular economy and industrial symbiosis

Although markets are crucial in bringing about change in the Finnish IS sector, ambitious political goals and legislation also play a key role. Finnish IS is rather well supported from different sides of society. The major guidelines stem from the government's overall strategy and from more precise strategies and policies advocating a transition towards symbiosis-driven industries, including the Material Efficiency Programme released by the Ministry of Employment and the Economy in 2014, the Bioeconomy Strategy released by the Ministry of Environment in 2014 and the "Manifesto for Growth" released by the Confederation of the Finnish Industries in 2014, which call for the reshaping of Finnish industrial strategies and operations.

Following the parliamentary elections in Finland in 2015, a new government programme was prepared. The corresponding document also takes a stance on CE-related issues and has its own chapter dedicated to the bioeconomy and clean solutions. The increasing opportunities provided by CE is set to be one of the key drivers of IS expansion in this context (Finnish Government Programme 2015).

According to the strategic 10-year goals outlined in the government programme, Finland is to become the world leader in terms of the bioeconomy, CE and cleantech. By developing, implementing and exporting sustainable solutions, Finland aims to improve its current accounts, increase its resource independency, create new jobs and achieve its climate goals. The government also intends to reduce the administrative burden currently impeding attempts to move towards greener growth and CE. The Finnish government has promised to provide elaborated indicators to measure the success in fulfilling these goals. However, the concept of IS is not explicitly mentioned in the government's plan.

At a practical level, the commission for the co-ordination of a national operational model for IS has been given (in addition to Sitra) to Motiva, an expert company promoting efficient and sustainable use of energy and materials that also operates as an affiliated government agency. In this role, Motiva manages a national approach promoting IS called the FISS. The system is based on the British NISP methodology adapted to the Finnish operational environment. FISS activities promote the resource efficiency of different actors in the regions, and it serves as an important tool for regional and economic development. The FISS model is based on active facilitation of symbioses and co-development. It aims to promote in particular those symbioses that would not otherwise have materialized. One of the important tasks of FISS is also to bring together

regional actors in a network. FISS also upholds the national SYNERGie database that is used to monitor the progress of the synergies and achieved benefits, as well as to identify new synergy opportunities (FISS 2015a; FISS 2015b).

Promotion of IS in practice falls under the responsibility of regional organizations and actors. Their tasks include business support, exchange of resource-related information and networking and helping with the implementation of the symbiosis. Regional organizers also help companies to identify new synergies and business opportunities, as well as helping them find the necessary partners (SITRA/Arponen 2014).

The Confederation of Finnish Industries has been a key actor in identifying bottlenecks and administrative barriers to IS development in Finland. These hindrances are increasingly taken into consideration at the governmental level and are reflected in the government's ambition to enable a smoother shift towards more ecological industries. Furthermore, regional authorities aim to make their processes more streamlined, and for this purpose the Ministry of Environment has worked together with the regional administrative agencies to speed up procedures related to environmental licensing (SITRA/Arponen 2014).

The national toolkits for IS development are advancing. FISS's web portal serves as a hub for IS actors in Finland and also as a tool for symbiosis development. When it comes to international markets and exporting Finnish know-how, domestic actors are assisted, for instance, by Team Finland, a network that provides state-funded business internationalization services ranging from financing to guidance.

Finnish businesses interested in CE and IS have also created their own networks and collaborations in order to sustain and expand their dialogue and co-operation. One of these private initiatives is called "Mahdoton" (a Finnish word meaning "impossible"), which brings together Finnish actors advocating CE and provides a platform for information exchange and shared events. Simultaneously, companies have established different platforms and living labs for the development of business ecosystems (Mahdoton 2015).

Finland's integration into the international IS community is strong, and Finland was one of the founding members of the European Industrial Symbiosis Association (EUR-ISA), which is a network of Europe's leading experts in the implementation and development of facilitated IS projects and networks. Simultaneously, Finland is engaged in activities with the UN and the Asia–Europe Foundation, and in the Nordic context with the Nordic Life Cycle Association (SITRA/Arponen 2014).

In terms of access to finance and funding, Tekes – the Finnish Funding Agency for Technology and Innovation – provides important public funding for the development of CE, cleantech and IS-related activities. A significant step in favour of CE and IS was taken in early 2015, when Sitra and Tekes strengthened their co-operation in order to advance CE and green growth opportunities in Finland. In the framework of this common strategy, Sitra will focus on the creation of new business models related to green growth and CE, whereas Tekes will further facilitate the development of these models into successful businesses and offer funding schemes.

Finland has also introduced several economic instruments and regulatory measures to support the transition towards more ecological industries and environmentally friendly processes. Many fiscal measures are in place, such as tax exemptions and reductions for biofuels and environmentally friendly technologies, but their impact has been partially diminished because of subsidies and exemptions granted for certain fossil fuel-intensive industries and transport. Therefore, the application of additional incentives and other measures, such as direct subsidies for greener energy and resource efficiency, has become increasingly important. Table 4 provides an overview of the key policy instruments that impact the development of CE initiatives such as IS in Finland.

3.5.3 Identifying drivers and barriers

Key drivers

The drive for the development of IS in Finland is based on both societal and commercial factors. Societal support arises from the need to establish new pillars for the national economy, to create versatile, internationally competitive industries and to use resources in a more efficient manner. Simultaneously, an enhanced system of IS holds potential for extended Finnish business opportunities and commercial gains on the global market (SITRA/Arponen 2014).

Major constraints

However, the Finnish operative environment for CE development contains many challenges to overcome. The existing or prospective symbiosis and CE opportunities generally go unrecognized, and cross-sectoral co-operation is often too weak to generate the preconditions for symbiotic activities. Simultaneously, there is a lack of the demonstration activities and venues required to generate and disseminate IS-related knowledge and good practices. Even though activities and businesses related to IS and CE are increasingly attract-

Table 4 *Key economic instruments and regulatory measures that support CE in Finland*

Instrument	Main characteristics	Type of measure
Premium tariff	The generators of electricity from wind, biogas and biomass receive a variable premium feed-in tariff on top of the wholesale electricity price for a period of 12 years; the generators thus get a fixed (target) price for their electricity	Direct subsidy
Energy support	A state grant for investments in renewable energy production facilities and related research projects; energy support may be granted to companies, municipalities and other communities	Direct subsidy
"Heat bonus" for combined heat and power (CHP) plants	Co-generation of heat and electricity is promoted by giving CHP plants working on biogas and wood fuel the right to an increased fixed "heat bonus"	Direct subsidy
Investment support for farmers	Funds to support farmers' investments in the construction of heating facilities using renewable energy sources	Direct subsidy
Biofuel quota	The Act on the Promotion of Biofuels in Transport obliges vendors of petrol and diesel to fulfil a defined quota of biofuels; the amount of biofuels has to be increased year by year to make up 20% of total sales by the year 2020	Quota obligation
Environmental and energy taxes	Various tax measures in favour of energy transition, e.g. reduced taxation for biofuels	Fiscal
Joint strategy for a circular economy and green growth by Tekes and Sitra	Promotion and funding of new business models in the field of CE and green growth	Funding; strategy
Landfill gate fees	Encouraging recycling and other waste disposal methods by setting lower fees per tonne of waste so disposed than the equivalent landfill gate fees	Economic incentive
Voluntary energy efficiency systems	Supporting energy audits and analyses of buildings and production processes	Economic incentive

ing attention and finance in Finland, there is still a lack of substantial private (risk) finance directed to IS- and resource efficiency-focused activities. This consequently affects the growth and internationalization potential of domestic SMEs and their capacity to engage in symbiotic ventures. Thus, there is a need to produce innovative industrial business models between companies, to support the commercialization of IS- and efficiency-focused activities and to remove barriers currently paralysing the operational environment for IS enhancement (SITRA/Arponen 2014).

In Sitra's IS review of 2013, many future recommendations were provided. These proposals concern first and foremost Sitra and other public actors working for the promotion of IS. According to the review, these actors could, through IS, support the formation of target-market-specific solutions. As a way to promote actual demonstrations of IS (deemed critical for enabling IS solutions and the opening up of markets), Sitra should bring together IS solution providers with potential pilot environments and clients, both in Finland and abroad. Moreover, the efforts of promising SMEs to create IS ideas with good potential for internationalization in response to the global demand for IS should be supported. This type of support could be provided through the use of business development tools, by making capital investments in companies and through sharing ideas on business development and internationalization (Sitra 2013).

3.6 Iceland

3.6.1 Current trends in developing circular economy and industrial symbiosis

The existing IS cases in Iceland are well known and successful but also characterized by private initiatives and individual visionaries, whereas support from the government and municipalities has been largely immaterial, and has arisen mainly to support pre-existing IS networks. There are currently no explicit policies promoting CE and IS in Iceland. Green growth in Iceland has been mainly driven by the business sector, whereas the government is simply encouraging industry and allocating funds competitively to companies.

Despite a lack of concrete policies and action plans in support of green growth, the topic has been on the government's agenda for about a decade. In the aftermath of the financial crisis, the government started rethinking its economic priorities, and has since developed a more strategic approach to green growth. In 2009, R&D and eco-innovation were defined as focus areas, along with education and social development. In 2010, government spending on R&D reached more than 106 million EUR (Nordic Innovation 2012).

Among the important private sector initiatives are CleanTech Iceland and Hafið, which are member-based organizations promoting sustainable tech solutions in Iceland. The latter was founded in 2014 and promotes public–private partnerships in ocean-related operations such as fishing, fish farming and sea freight.

Iceland has two official levels of government, national and local, and no constitutional autonomy is given to the regional level. Thus, regional-level policies and cooperation are mainly based on the competencies of the municipal-level governments, and are supported by the Regional Development Institute of Iceland. Approaches to IS and resource efficiency vary greatly from one municipality and region to another, with the potential of both going mainly unrecognized and references to IS activities lacking.

3.6.2 Policies in support of circular economy and industrial symbiosis

Overall, current Icelandic policies pursue a mixture of aims related to strengthening the country's industrial sector to stimulate new jobs growth and to encouraging innovation and entrepreneurship, while simultaneously opting for sustainable choices and efficiency in terms of resource and energy use.

One of the flagship Icelandic policies has been the Iceland 2020 strategy and its successors, which define eco-innovation as the main growth sector over the next decade and aim to double growth in the eco-innovation sector between 2011 and 2015. This policy, which is in accordance with the Europe 2020 strategy, supports Icelandic actors and municipalities to realize locally the goals set by the policy. As a consequence of Iceland's withdrawal from its EU accession negotiations, the policy was abolished, but its main ideas have been reflected in the new plan, which can be translated as the "Push Ahead Policy".

In 2011, a parliamentary resolution to strengthen the green economy of Iceland was adopted. It contains 50 proposals for action on the strengthening of the green economy, among which is the formation of a green investment fund (Parliament of Iceland 2011). Funding for the implementation of the proposals comes from the "Investment Plan for Iceland 2013–15" (Prime Minister's Office 2012).

The foreign direct investment (FDI) policy in Iceland makes an important contribution to green growth. For a number of years, the emphasis of the FDI policy in Iceland has been on attracting environmentally friendly companies and green technologies. Access to clean energy in Iceland makes it an attractive location for industrial investments and the establishment of data storage centres and high-tech industries. To further promote "green" FDI, the Icelandic government is currently drafting a new policy on FDI, which is even more selective in its environmental focus.

The "Master Plan for Hydro and Geothermal Energy Resources" has also had some impact on the greening of Iceland's economy. It serves as a tool to reconcile the often competing interests of nature conservation and energy utilization on a national scale. This master plan was developed by the Government of Iceland in 1999 and is currently in its third phase, which is due to be completed in 2017, thus far, there have been no references to IS.

According to the "Parliamentary Resolution on a Strategic Regional Plan for 2014–2017", the Icelandic public support systems will continue directing funds to the regions, especially for industrial development, innovation and the economic support system. The ambition is to create a varied range of industrial and employment activities capable of flourishing in economically challenged areas in particular. The emphasis will be on supporting collaborative projects and the encouragement of collaborative ventures, which leaves scope for IS types of initiatives.

No public funding has been earmarked specifically for facilitating IS. The government is supporting the growth of innovative companies through three categories of funding. There is competitive funding available for R&D, which includes the Icelandic Research Fund for basic research and the Technology Development

Fund for innovation and the development of new projects and services (both of which are part of the Icelandic Centre for Research, Rannis). Another category of funding is designed to support genuine development companies. The companies can apply for 20% reimbursement of costs for R&D. The third pillar of funding is still under development. Its purpose is to promote purchases of stock in innovative companies.

Globally, industrial ecology and IS have been considered as possible new solutions to the challenges of sustainable island development. Industries in an island system are embedded in a finite natural environment, characterized by a strictly limited amount of natural resources, by limited access to these resources and by the island's geographical isolation. Thus, well-defined island systems offer a unique opportunity for a new approach to industrial ecology and IS (Deschenes & Chertow 2002). Considering certain successful exemplary cases (e.g. the island of Puerto Rico) and recent academic research and policies adopted by international organizations (e.g. the UN, OECD and EU), Iceland has given relatively little consideration to IS policies.

Iceland could benefit from supporting IS at the national level and more strategically. A focus on IS, cleantech and CE could also help reduce emission levels and contribute to the sustainable extraction of the island's narrow range of domestic materials.

3.6.3 Identifying drivers and barriers

Key drivers

The two main factors that have contributed to putting green growth on the agenda in Iceland are the rising environmental awareness of the population and public realization of the potential for economic growth in the green economy sectors.

Key barriers

General conditions for R&D and start-up companies have been relatively good in Iceland. The major constraints are to be found in Iceland's financial difficulties since 2008. Iceland has currency restrictions, which makes it difficult to invest money abroad and to expand into foreign markets. As a result, many of the fastest-growing small companies in Iceland have been taken over by foreign companies and are more or less being sold out from the country.

Moreover, a lack of concrete policies and regulations with regard to the development of clean technologies is a major challenge for private companies. The private sector would like the government to develop clear and long-term strategies in support of cleantech, which should be accompanied by an action plan and include concrete measures. Another major barrier to green growth is a lack of highly qualified labour within the science and technology sectors.

3.7 Norway

3.7.1 Current trends in developing circular economy and industrial symbiosis

Norway has a plentiful supply of biological resources, both offshore and on land. Utilization of these provides opportunities for new knowledge-based jobs in rural areas. New knowledge and technology, including biotechnology and industrial process technology, makes it possible to exploit the renewable biological resources in new ways. Increased and more comprehensive resource exploitation will both increase added value in existing companies and also create a basis for new ones.

Norway's pure green industries have considerable potential, particularly its industries related to energy,

Table 5 *Key economic instruments and regulatory measures in support of CE in Iceland*

Instrument; organization responsible	Main characteristics	Type of measure
"The Investment Plan for Iceland 2013–2015"; Government of Iceland	Provides investments and projects financed through dividends and asset sales in several areas, including green investments, green investment funds, the greening of companies, eco-procurement and energy system transition in ships	Annual contribution; investment projects
Competitive funding for R&D; Rannis	The Icelandic Research Fund is for basic research, and the Technology Development Fund supports R&D activities that aim towards innovation in Icelandic industries	Grants
Tax Credit Scheme; Rannis	For enterprises, to strengthen R&D activity and improve the competitiveness of innovation	Fiscal

waste systems and environmental consulting services. Clean, green industries will, however, constitute a limited portion (3–5%) of the total Norwegian economy in the near future (Econ Pöyry 2011). Other relevant industries include agriculture and forestry, the marine sector, food processing, timber and wood processing (organic waste products), the processing industry (including the utilization of CO2) and parts of the energy sector.

As a high-cost country, Norway is dependent on being a leader in knowledge-intensive sectors in order to maintain international competitiveness. This will require restructuring in an environmentally friendly and resource-efficient direction, meaning that the future competitiveness of industries such as the Norwegian processing industry will be largely related to the degree to which they become environmentally friendly and effective compared with other countries.

Until recently, there has been a lack of focus on CE in the Norwegian policy debate. This may be because of Norway's very different needs for energy conversion compared with many other countries, as well as its strong oil and gas sectors and access to vast renewable energy sources for electricity generation.

CE have gained more attention since the EC published "Towards a circular economy: A zero waste programme for Europe" as part of the EU's flagship initiative "A Resource Efficient Europe" under the Europe 2020 strategy. From a Norwegian perspective, it is worth noting that the EC does not propose measures to prevent hazardous substances in recycled plastic, which Norway has advocated, and there are no guidelines related to waste incineration. However, the EC strategy could lead to measures that may contribute to Norway becoming a low-carbon society by 2050, and it is argued that the increased focus on recycling should also provide opportunities for the Norwegian recycling industry and recycling technology providers.

The government is also in the process of developing a new White Paper on energy, and there is a possibility that the CE concept will be included.

3.7.2 Policies in support of circular economy and industrial symbiosis

The Norwegian government has expressed great ambitions for developing the green economy. However, it is unclear how they will act in practice, given the increasing pressure on natural resources. It is also unclear how they will ensure a better valuation and integration of natural capital in planning and implementing the transition to a low-carbon society. The Parliament has adopted ambitious climate targets (the "Climate Agreement" White Paper 2008) for 2020, but how these goals will be achieved remains unclear (Econ Pöyry 2011).

The Norwegian government is in the process of developing a bioeconomy strategy in 2016. The strategy will focus on inter-sectoral opportunities and challenges and on exploiting new opportunities arising from research and use of knowledge and technology. The strategy will focus on areas that can contribute to increased value creation and employment and to solving global challenges related to climate change, environment and access to resources.

Substantial funding has been allocated for programmes that promote the development of environmentally friendly technologies in recent years, but few steps have been taken with regard to structural changes towards an economy that has less impact on the natural resource base. The upcoming White Paper ("Climate Report") is expected to set the framework for significant cuts to greenhouse gases nationally.

The report "Klimakur 2020" ("Climate Cure 2020") stresses the measures needed for Norway to reach its climate goals by 2020. The analysis in the report is based on the goal of national emissions reductions embodied in the "Climate Agreement" that a majority of the Parliament signed in 2008 (White Paper No. 21, 2011–2012). According to that White Paper, Norwegian climate policy has the following two main objectives. 1) Norway should cut greenhouse gas emissions to 30% of the emissions level that existed in 1990 by 2020. 2) Norway should become carbon neutral by 2050. According to Statistics Norway, 53.9 million tonnes of CO2 equivalents were discharged from Norwegian areas in 2013. This represents a decrease of 0.3% from 2012 and an increase of 3.7% from 1990 (Sør-Trøndelag Fylkeskommune 2015).

The transition from fossil fuels to renewable energy sources is central to many of the climate measures examined in the "Klimakur 2020" report. Specific measures that can contribute significantly to reduced industry emissions are the transition from fossil fuels to charcoals and biomass, as well as energy efficiency measures and process improvements. As such, this is in line with a broader green growth approach to climate change; however, the report does not mention the CE approach as a solution to the increased need for emissions reductions.

Innovation Norway, the Norwegian Research Council and the Industrial Development Corporation of Norway are national-level funding agencies that aim to facilitate renewal, innovation, competitiveness and value creation in Norwegian businesses. Through its environmental scheme, Innovation Norway supports projects related to purification technology, more environmentally friendly products and production pro-

cesses, more efficient resource management, and technological systems that reduce environmental impact. Innovation Norway's biorefinery programme supports enterprises working with the processing of biomass in the early pilot stage. The aim is to encourage the development of new production processes based on renewable biological raw materials. Such new or modified production processes will lead to market-oriented products, e.g. ingredients, chemicals, materials and energy, and thus trigger the economically profitable adoption of these greener options by corporations, and so lead to wealth and job creation in the country. The program mainly targets SMEs.

The Programme for User-driven Research-based In-

Table 6 *Key economic instruments and regulatory measures in support of CE in Norway*

Instrument; organization responsible	Main characteristics	Type of measure
Miljøteknologiordningen ("Environmental Technology Scheme"); Innovation Norway	Funding for pilot and demonstration projects in Norway. Companies of all sizes from all over the country can apply; the specific focus areas are purification technology, more environmentally friendly products and production processes, more efficient resource management, and technological systems that reduce environmental impact	Grants
Biorefinery programme; Innovation Norway	Funding for the development or optimization of new processes that are past the research phase, but before piloting and upscaling	Grants
BIA; Norwegian Research Council	Funding for projects that will provide high value creation for both the participating companies and society; no specific focus on green growth or CE	Grants
Enova	Company owned by the Ministry of Petroleum and Energy created in 2001 to help with the environmentally friendly restructuring of energy consumption and production, as well as contributing to the development of energy and climate technology	Grants; counselling
CO_2 tax	The CO_2 tax is, in addition to the quota system (see below), one of Norway's most important instruments for reducing greenhouse gas emissions; both schemes involve setting a price on CO_2 emissions, and the fee is determined by the Parliament, while the price of quotas is determined by the market	Regulatory measure
Quota system for manufacturing	Many of Norway's land-based industries and the entire oil and gas industries are included in the Norwegian quota system for manufacturing, which is part of the EU quota system; emissions covered by quotas are generally exempt from the CO_2 tax	Regulatory measure
Reimbursement and handling requirements of fluorinated gases	Companies have to pay duties for the import of fluorinated gases such as HFCs and PFCs, and a corresponding amount is reimbursed when used gas is delivered to an approved disposal facility; in addition to the national tax, Norway has also implemented EU legislation, which sets requirements for the handling and use of HFCs and other fluorinated gases in products (Regulation (EC) No. 842/2006) – the regulation sets control and competency requirements for the use of HFCs, PFCs and SF6 in products, and prohibits certain uses	Regulatory measure

novation (BIA) finances R&D projects that are based on companies' own strategies. BIA is one of the Research Council's largest programmes, and is an important partner of industry. Although the Eyde Cluster in Agder, which is discussed further in Chapter 4, has received funding from the programme for one of its IS projects, the BIA programme is not directed towards green growth or CE in particular.

Another policy instrument is the provision of financial support from the publically owned Enova organization. Its mandate is to support an environmentally friendly restructuring of energy consumption and production, as well as contributing to the development of energy and climate technology.

Although there are no measures directed towards the development of CE as such, several of the existing economic instruments and regulatory measures support the development of environmentally friendly products and production processes. Table 6 provides an overview of the key policy instruments that can be seen to have an impact on the development of CE initiatives such as IS.

3.7.3 Identifying drivers and barriers

Major constraints

Environmental and climate challenges require a major realignment globally towards more sustainable ways to ensure economic value creation, and Norway has advantages that will support its transition towards a greener economy, such as a highly educated population, an adaptable workforce and vast natural resources. At the same time, such a transition may be especially difficult for Norway, which has an economy that is largely dependent on fossil fuels, through its large petroleum revenues and petroleum-related employment and value creation (Econ Pöyry 2011). This, in turn, may contribute to a slower transition towards dependence on environmentally friendly solutions such as IS. Furthermore, measures to promote energy efficiency and renewable energy should be carefully designed. Therefore there is a need for political will and ability to carry out deep structural changes and provide a good framework for a green economy that is built on innovation, CE thinking and co-operation. One example is the increases in spending on R&D in the energy sector and ongoing efforts to develop carbon capture and storage technologies, which are important for future emissions reductions (OECD 2011b).

In their report from 2011, Econ Pöyry highlight the following five barriers to restructuring Norway's economy towards a lower environmental impact and greener industries.

- The risk of path dependence and lock-in: Norway has strong industrial clusters associated with the petroleum and maritime sectors, and might risk becoming locked into a development path on which it is very costly to change direction, and on which alternative technology development (e.g. clean energy) will deteriorate over time because of the continued investment in the petroleum industry. To overcome this barrier, one strategy would be support for demonstration and pilot projects, connected with a long-term framework for gradual commercialization.
- Strong interests in existing structures: a shift to a greener economy means radical changes in some of the present industrial and commercial solutions and to some degree the replacement of traditional technologies. There is thus a risk that new entrants in the market will be undermined by existing dominant players. To overcome this barrier, there is a need for measures such as clear criteria for industrial and R&D support, to prevent established interests from having too strong an influence.
- Restructuring costs: investment in new technology is very costly, and as long as the supplier industry in Norway has improved margins in supplying the petroleum industry, they are less likely to invest in other technology.
- Market failures: costs associated with environmental damage and climate effects are poorly reflected in market prices. Neither the CO_2 tax nor regulations of hazardous substances are currently at a sufficient level to trigger the desired R&D efforts on environmentally friendly technologies. While the quota system (referred to in Table 6 above) is an attempt to put a price on the external effect of greenhouse gas emissions, the market is incomplete and the carbon price on the emissions trading market is lower than what is necessary if global climate goals are to be achieved. This means that the value of green solutions across the economy is not reflected in current market prices. Consequently, investment in new technology is typically low without public support. The market failure can be offset by public initiatives, e.g. public grants and green taxes.
- Strong sectoral divisions: in the policy field, each sector has its own goals and is fighting to optimize the policy environment for its own benefit. This has consequences when it comes to overarching issues for society as a whole that require major changes, because each individual sector fights to avoid paying too much of the bill. The lack of comprehensive and coherent strategies for the sustainable utilization of resources therefore often results in the sum of all sectoral initiatives and commitments not matching the overall levels required.

From a strategic point of view, there is thus a need for climate and environmental goals to become binding.

Regarding the processing of waste, there is still a lack of an appropriate incentive structure for waste minimization and management. There is thus a need for stricter requirements regarding the use of recycled material and recyclability, e.g. in criteria for public procurement or in taxes related to pollution (Econ Pöyry 2011).

Key drivers

However, there are also important drivers that could trigger the transition towards a greener economy. Such drivers are linked to the fact that Norway is rich in resources such as renewable energy (hydro, wind and biomass), food (fish farming) and raw materials (metals and wood). Norway thus has a good resource base for a future green economy in which the petroleum industry plays a smaller role than today. The employment potential is also good within industries related to these resources (Econ Pöyry 2011). When it comes to innovation and job creation in support of green growth, the greatest opportunities for Norwegian actors will be in those industries where Norwegian businesses and knowledge institutions already have relevant skills and experience, such as the industries related to Norway's rich natural resource base.

3.8 Sweden

3.8.1 Current trends in developing circular economy and industrial symbiosis

The concept of IS is gaining increasing attention in Sweden today, and although no national IS programme or strategy exists, relevant work has been underway in business projects, demonstration areas, research projects, etc. for a long time. Dimensions of IS such as energy sharing, resource efficiency, management of residuals, common R&D activities by interlinked industries, etc. have been developed in programmes financed by Swedish resource councils, regional authorities, universities and industries. These are starting to "take off", and there is evidence of increased knowledge-sharing within the Swedish IS sphere.

According to researchers at Linköping University, Sweden is rich in IS networks, but little is known about them. The researchers have started to put together a platform for sharing information on examples of IS in Sweden today, with descriptions about actors, drivers, enablers, etc. The primary purpose of their project is to "share information about industrial symbiosis networks operational in Sweden" and make their insights available to a wider audience. The platform presents known examples of IS and provides short introductory descriptions of the IS sites. It also invites others to share information on developments in Sweden related to IS.

Besides this, the information available in Sweden today about IS largely consists of self-description and self-promotion by industrial parks, and a growing arena of seminars and conferences about IS.

For some time, the concepts of biorefineries and integrated heat/energy production have been important in Sweden. Some of the respondents in this study noted that although these have recently come to be considered examples of IS in European or global contexts, the association of these concepts with IS is still rather rare in the Nordic countries. Hence, whether IS is widespread in Sweden is a question of interpretation. Small-scale examples that would now be labelled IS have been around for decades, including many integrated solutions involving refineries, energy and waste management. In Sweden and other Nordic countries, there are many examples of bioeconomy clusters acting in an IS fashion (see for example "Nordregio Working Paper" 2014, p. 4). In Sweden, examples include the biorefineries and bio-based development clusters supported by VINNOVA (Sweden's innovation agency) development grants, e.g. the Biorefinery of the Future (in Örnsköldsvik) and Paper Province (in Karlstad).

3.8.2 Policies in support of circular economy and industrial symbiosis

Sweden has a long tradition of regulations and incentives in the field of environmental, resource and energy policy. Traditionally, regulations and economic incentive structures (primarily taxes) have been utilized. Over time, market-based measures and certificate schemes (i.e. to enable trades in energy savings) have become ever more common, and today the mix of environmental incentives and regulations also includes support for R&D by bodies such as VINNOVA.

Still, many regulation-centred measures, such as technological restrictions, emissions ceilings and landfill regulations, are among the most effective measures at stimulating reuse and CE. In the Swedish case study, landfill and emissions taxes were mentioned by respondents as important drivers for IS, as well as resource prices.

Although there are no measures directed towards the development of CE as such in Sweden, several of the existing economic and regulatory instruments support the development of environmentally friendly products and production processes. In its 2006 report "Economic instruments in the environmental policy", the Swedish Environmental Protection Agency and Energy Authority discuss all instruments targeting en-

vironmental impacts in Sweden. Although the report is from 2006, it provides an overview of the types of regulations that have had, and continue to have, an impact on the evolution of IS in Sweden. These instruments provide incentives for action related to symbiosis.

Besides these instruments, there are other administrative practices (regulations, etc.) and R&D grants that also impact IS. These latter instruments and financing schemes largely consist of instruments targeting IS more specifically, which have been initiated in recent years. They often follow closely the developments in the European arena, and recent large-scale funding has been targeted towards integrated (often symbiosis-type) biorefinery developments, as well as research funding for developing knowledge about CE. In 2015, collaboration between universities and industry received the equivalent of 4.2 million EUR for research on "Resource-efficient and effective solutions based on CE thinking". This is one way in which "policy" or governmental research funding is stimulating the development of future IS.

The conclusion from the 2006 governmental evaluation of the efficiency of targeted measures to induce environmental improvements is that "multi-sectoral taxes, such as the carbon dioxide tax, are the instruments with the greatest socio-economic potential for influencing behaviour in the interests of sustainability". Considering the evolution of IS in a European context, it is interesting that the authors write that: "it is also essential to take account of international aspects, such as industrial competitiveness and the EU emissions trading system. Internationally co-ordinated or harmonized instruments should be given priority".

Many instruments in the Swedish environmental policy mix are operating horizontally across many sectors and environmental domains; as such, they are suited to stimulating the development of IS on a broad basis. Examples include energy taxes (electricity and fuels), the carbon dioxide tax and KLIMP (the Climate Investment Programme). KLIMP has operated in Händelö (an IS discussed in Chapter 4) and has been one of a few regional driving forces having a substantial impact on the development of specific symbiosis projects.

3.8.3 Identifying drivers and barriers

As there have been few IS initiatives in Sweden, until recently there has been rather limited information about the most important drivers and barriers in the development of IS.

Table 7 *Key economic instruments and regulatory measures in support of CE in Sweden*

Instrument	Main focus	Type of measure
The Climate Investment Programme (KLIMP), 2002–2012	Reducing climate impact and energy system transition	Economic incentive; investment support
Programme for Improved Energy Efficiency	Trade and industry policy and energy system transition	Economic incentive
Tax exemption for biofuels	Reducing climate impact and energy system transition	Fiscal
Landfill tax	Reducing climate impact and the EU waste strategy	Fiscal
Grants for the market launch of energy-efficient technologies	Energy system transition	Grants; investment support
Tax on natural gravel	Reducing gravel extraction and increasing reuse	Fiscal
Tax on cadmium and nitrogen in artificial fertilizers	Stimulating the reuse of fertilizer materials from biogas production, etc.	Fiscal
Grants for energy forestry and the cultivation of energy crops	Energy system transition: stimulating the introduction of energy crops and the interaction between agriculture and biofuel production	Grants
Various taxes on motor fuels, sulphur, CO_2, etc.	Energy system transition	Fiscal

Key drivers

While there are few explicit stimuli towards IS, environmental regulations play a major role in the transition towards resource efficiency and the reuse of materials and "waste". For example, landfill tax regulations and other requirements of the "Waste Framework Directive" contribute by making waste available for energy recovery. In Sweden, there are discussions today of even stronger legislation for waste and waste management; e.g. a tax on the incineration of waste has been suggested in the debate.

Similar regulations for the management of organic waste stimulate the availability of organic waste for biogas production or as bio-fertilizer. The energy and CO_2 taxation policies of the Swedish government, similarly, supported increased updating and uptake of more energy-efficient solutions, such as district heating utilizing or by-product heat utilization, as well as increased use of renewable fuel alternatives.

Major constraints

Barriers seem to be rather site specific, from the planning and localization perspective. For example, in the Östergötland case study in Chapter 4, there is a discussion of physical planning challenges and other challenges linked to local conditions. On a more general note, there are also regional barriers associated with markets, prices, the availability of raw materials and uncertainty. In academic terminology, the barriers seem to be economic (investments, markets, etc.) rather than technological, social or policy- or information-related. The latter dimensions are usually identified as "possible" barriers, but as mentioned before, we have found no national investigations into the most important barriers to developing IS nationwide. On a case-by-case level, a lack of information and platforms to support company interaction around a symbiosis might act as a barrier to developing new products or projects; some examples exist in Östergötland, where interactions are ad hoc.

Finally, a possible barrier in the information domain in Sweden is the lack of a strategy for CE or IS. As described elsewhere in this report, in other Nordic countries (e.g. both Denmark and Finland), CE and/or IS strategies have been clearly defined and marketed. These are accompanied by policies, networks, activities, information and network platforms, etc. Sweden lacks such a positive driving force. It is not clear why this is the case, but similar issues also affect the development of the Swedish bioeconomy.

3.9 The Faroe Islands, Greenland and Åland

Green growth and CE are fairly new topics in the Faroe Islands. The Faroe Islands economy is currently highly dependent on oil, which is also used for electricity production. The main focus is therefore on increasing the use of renewable energy sources. In 2015, a working group established by the Ministry of Trade and Industry published an action plan and recommendations on the future electric energy system of the Faroe Islands. According to the action plan, the development of wind and hydro power has particularly good potential in the Faroe Islands. There has been an increase in the production of wind power over the past three years. The first energy storage system is currently under development. Priority has also been given to the installation of heat pumps in public buildings and private homes, as well as replacing oil-based burners with modern and environmentally friendly ones. However, there is currently no national support programme or earmarked funding for promoting and facilitating a greener economy and IS initiatives in the Faroe Islands (interview; Faroese Ministry of Trade and Industry 2015).

In Greenland, two issues challenging the adoption of green energy production and consumption are the dependency on diesel and petrol for the fishing fleet, and on diesel as a source of power generation in the smaller settlements. Additional greening of the energy supply and energy consumption in Greenland have become important issues both at the municipal and national levels of planning. The Arctic Technology Centre (ARTEK) in Sisimiut, in co-operation with the Danish University of Technology, is an important player in this area. ARTEK has been providing input into the discussion on developing a greener energy supply, not just for population centres but also for the smaller (often diesel-dependent) settlements. Establishing a common electricity grid is extremely difficult because of Greenland's long distances between settlements, deep fiords and inland ice. This means each community has to produce its own electricity and balance it with local consumption. Attempts have been made to establish incineration plants to generate electricity and heat in some of the smaller communities, and small-scale hydropower plants have also been tested. But such communities are challenged by their isolation, and expensive infrastructure and maintenance are problematic. Small communities may benefit from solar heating or photovoltaic systems that supply both heat and power. Work is currently underway on systems that use a combination of solar collectors and heat pumps.

The efficient use of energy becomes a strict require-

ment under relatively extreme weather conditions in countries where fuels are not readily available, such as Greenland. District heating is a well-known type of heating in Greenland, and its source is mainly surplus heat from electricity production, waste incineration and electricity and oil production. The company Nukissiorfiit is the main supplier of energy in 17 cities and a number of smaller settlements and has approximately 30 employees engaged in district heating. More than 70% of the energy produced by Nukissiorfiit in Greenland can be characterized as green. The district's major source of electricity is hydropower, and today five large hydropower plants supply electricity. Geothermal energy supplies are also under development in Greenland. Holes in the mountains are being drilled to approximately 200 meters in depth near the head office of Nukissiorfiit in Nuuk.

On the Åland islands, the transition to a green economy is being driven by both the public and private sectors. Åland has recently adopted a sustainability programme stretching to 2051, which is an overall development strategy with a broad focus. Åland also has a specific programme financed through the European Regional Development Fund (ERDF) designed to support smart and sustainable business development. This programme finances initiatives that promote a green economy and CE. Smart specialization strategies also play an important role in Åland.

Among the largest private sector investments recently that have contributed to the greening of the economy in Åland was the construction of a ferry that runs on liquefied natural gas (LNG) in 2013. The Viking Line service is operated from the Åland islands, and Viking Grace is the world's first and largest LNG-fuelled passenger ferry. The industrial sector in Åland has provided financial support for the development of wind power. Electricity generated from wind power is expected to increase from today's 20% to 70% in about 10 years. There are also some good examples of applying CE thinking in Åland, such as co-operation between the dairy producer ÅCA mejeri and the municipality. ÅCA mejeri produces biogas from whey, and the process water and some of the surplus heat is supplied to the municipal district heating network. Moreover, sewage sludge from the biogas production is used as a nutrient-rich organic fertilizer in agriculture.

4. Nordic regional case studies

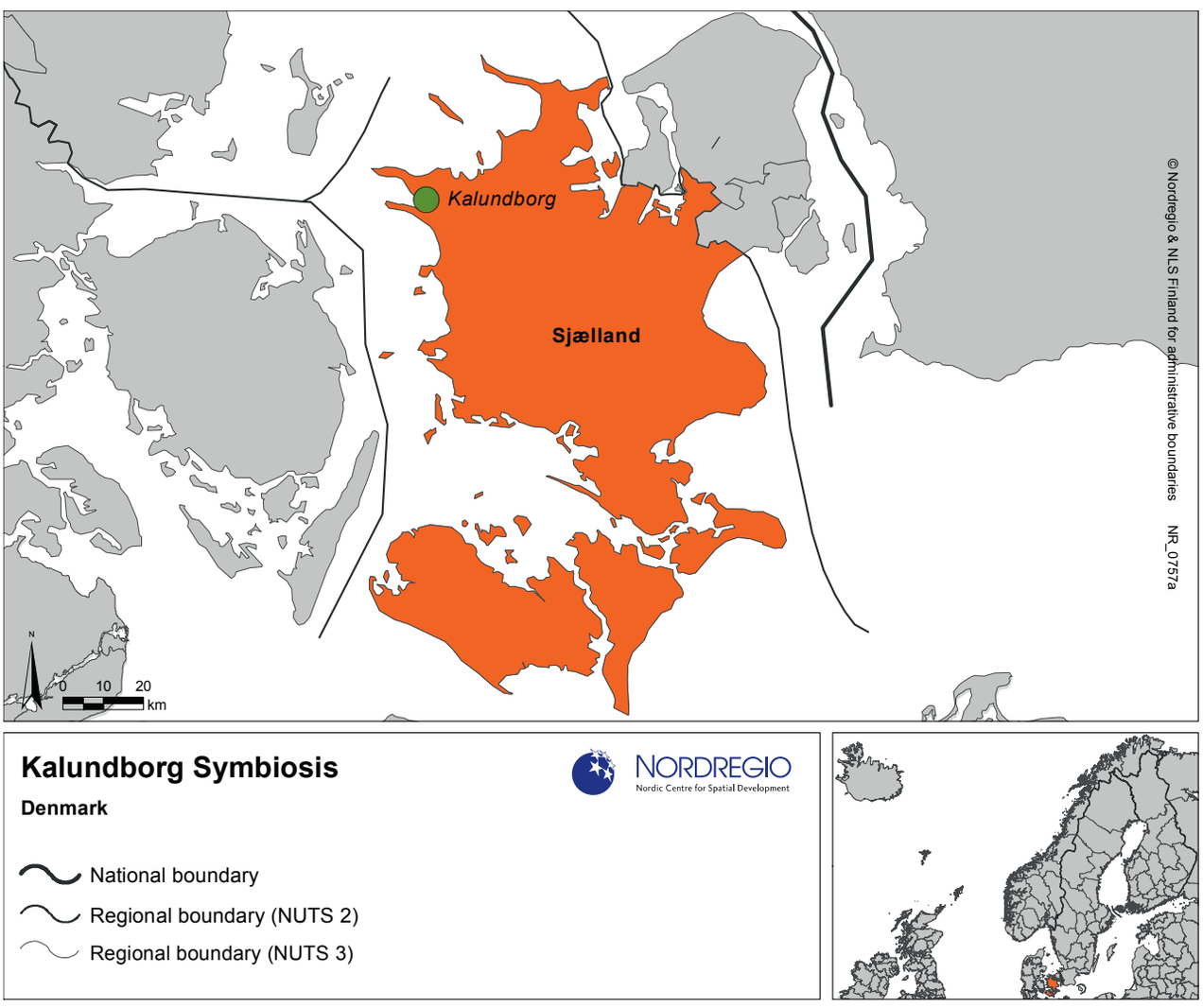
This chapter presents the findings from the five regional in-depth case studies. Each case study provides a short introduction to the region, an overview of the regional policy settings for supporting CE development, and a description of the specific IS activities in the region. The main aim of the case studies is to gain insight into the main actors driving/supporting IS development at the regional/local level, the type of regional/local policy instruments in place to stimulate IS activities, and the potential for economic growth to arise from IS. These insights will provide a basis for learning and feedback on the general policy debate on how to foster green growth through IS in the Nordic countries.

4.1 Kalundborg, Zealand region, Denmark

4.1.1 Brief description of the region

The administrative region of Zealand covers an area of 7,273 km² and has 816,460 inhabitants. The unemployment rate in the region in 2013 was 7.1%, which was slightly above the national average of 6.9% (Region Zealand 2015a). The municipality of Kalundborg cov-

Map 2 *The Zealand region*



ers an area of 604 km² and has a coastline of 160 km. It has approximately 49,000 inhabitants and 21,000 jobs. Two-thirds of the inhabitants have a job within the municipal borders, approximately 8,000 inhabitants commute to work outside the municipality and approximately 5,000 people living in other municipalities commute to work in Kalundborg. One of Denmark's largest concentrations of industrial companies outside of Copenhagen is located in Kalundborg. Large energy and processing industry companies, including pharma/medico and cleantech companies, are based in the industrial area, and some of these are participants in the internationally well known Kalundborg Symbiosis industrial ecosystem. The harbour of Kalundborg is the third largest in the country measured by goods turnover, which also suggests that there is a large transport industry in the municipality. Other significant business areas include smaller companies active in services and crafts (Kalundborg Municipality 2011, p. 4).

4.1.2 Regional support for green growth

The "Regional Growth and Development Strategy 2015–2018" for the Zealand region has 10 objectives, of which one is concerned with the development of IS. The objective states: "Sustainable development with a particular focus on resource efficiency will enhance the competitiveness of companies", and the sub-targets are as follows (Growth Forum for Zealand and Region Zealand 2015, p. 8 and p. 30).

- In 2020, more than 200 companies with more than 10 employees in the region will be working with IS and resource efficiency (65 companies were working with IS in 2014).
- These companies will achieve an annual reduction in energy and material consumption.

The Regional Council and the Growth Forum for Zealand further demonstrated support for the development of IS by granting 12 million DKK of regional development funds for the establishment of the information centre called "Symbiosis Center Denmark" in Kalundborg in December 2014. This decision should be seen in relation to the national Green Symbiosis programme recently initiated at the time (see Section 3.4.1), and the recognition of the significance of the IS in Kalundborg to the region.

The "Common Regional Climate Strategy 2015–2018" was developed by the region in collaboration with the 17 municipalities that are responsible for environmental management. One of the objectives of the strategy is "More renewable energy and better use of resources", and one of the ways in which this should be implemented is through "enhancing the development of industrial symbiosis between companies in the region" (Region Zealand 2015b). Municipalities in the region are showing an increasing interest in this area, in that some have started to employ "symbiosis employees" in the municipal environmental departments.

Kalundborg has built its local development strategy on being the "Green Manufacturing Municipality". This is because Kalundborg is one of the few places in the country that has managed to maintain its manufacturing industry, which is the most important industry for the local economy. Kalundborg's broad objective of green technology development therefore underpins its ambition to broaden the potential of IS.

Projects supported by the European Structural and Investment Funds – the ERDF programme (Danish Business Authority 2014a) and the European Social Fund (ESF) programme (Danish Business Authority 2014b) – are important instruments for implementing regional and local strategies in the region.

4.1.3 The Kalundborg Symbiosis and its activities

The IS network

The IS network in Kalundborg has developed over the course of five decades. It began in 1961, when Statoil (then Esso) needed water for its refinery near Kalundborg. The first conduit pipes in the Kalundborg Symbiosis were laid between Statoil and the nearby lake, Tissø. In 1972, Statoil entered into an agreement with Gyproc, a local gypsum production enterprise, for the supply of excess gas from Statoil's production to Gyproc. Gyproc used the gas (today, natural gas) to dry the plasterboard produced in their ovens. The following year, 1973, Dong Energy (then the Asnæs Plant) was connected to the Statoil water pipe, and so what would later come to be known as the Kalundborg Symbiosis then had three partners. Over the years, more businesses were linked into the Kalundborg Symbiosis, and in 1989 the term "industrial symbiosis" was used to describe the collaboration for the first time. Today it has eight private and public partners and involves approximately 50 symbiotic exchanges (Symbiosis Center Denmark 2015). Many studies have been carried out on the development and effects of the IS in Kalundborg, and some of them can be found through the website http://www.symbiosis.dk/en/bibliotek. Figure 3 shows the most recent illustration of the symbiotic exchanges in Kalundborg.

Table 8 *Existing regional instruments in support of CE/green growth in Zealand*

Instrument	Duration	Type of instrument	Policy priorities	Authorities/organizations responsible
"Regional Growth and Development Strategy 2015–2018"	2015–2018	Strategy	Ten objectives Four business areas where the initiatives should primarily have an effect: food construction logistics and transport bioeconomy	The Growth Forum for Zealand; Region Zealand
"Common Regional Climate Strategy 2015–2018"	2015–2018	Strategy	More renewable energy and better use of resources Sustainable and commuter-friendly transport and infrastructure Climate change adaptation in rural, urban and coastal areas	Region Zealand, in collaboration with the 17 municipalities
Kalundborg Municipality's "Business and Development Policy 2011–2014: The Green Manufacturing Municipality"	2011–2014 (under revision at the time of writing)	Strategy	Infrastructure and transport Commerce, construction and environment Settlement, culture, leisure and tourism Green technology development Business services, labour and education	Kalundborg Municipality
National Programme for the European Regional Development Fund 2014–2020: Denmark (ERDF)	2014–2020	Operational programme	Increase the number of innovative SMEs Increase the number of growth companies Improve the energy and resource efficiency of SMEs Reduce energy consumption in cities with over 30,000 inhabitants	Managing authority: the Danish Business Authority Intermediate body: the Growth Forum for Zealand
National Programme for the European Social Fund 2014–2020: Denmark (ESF)	2014–2020	Operational programme	Six objectives with a focus on growth through education and entrepreneurship	Managing authority: the Danish Business Authority Intermediate body: the Growth Forum for Zealand

The development of an IS centre

During the 1990s, the IS in Kalundborg gained international attention from academia (especially Yale University) and practitioners wishing to work with IS. In order to manage the increasing number of international delegations wishing to visit the IS network in Kalundborg, a visitor service was established in 1996 by the partners of the symbiosis. This involved financing a part-time position for a visitation service manager. In 2010, the companies involved in the IS established an association. The companies pay membership fees to the association, which has a board of directors that meets regularly. The head of the development department at Kalundborg municipality is involved as the secretary of the association, and the administrative work for the association is managed by the municipality. The visitation service also became an integrated part of the development department, with funding from the association.

In 2010, the development department of the Kalundborg municipality began developing an ERDF application in collaboration with the neighbouring Holbæk and Odsherred municipalities. The application was successful and resulted in the initiation in 2011 of the Regional Symbiosis Centre, co-located and integrated with the development department of the Kalundborg municipality. The purpose of the project was to work towards the objective of the "Regional Development Strategy" of Region Zealand at the time, which was to be Denmark's leading centre of competence for the establishment of IS. In January 2013, the regional project became highly integrated with the national Green Symbiosis programme (introduced in Section 3.4.1). Thus, the project manager of the ERDF project was working with the staff of the Danish Business Authority to design and co-ordinate the national programme. The work initiated in 2012 to develop approaches to support new IS exchanges based on the Kalundborg experience was continued in collaboration with the Danish Business Authority.

During the period 2012–2014, the Symbiosis Center Denmark supported more than 20 IS projects across the region of Zealand, of which 16 resulted from applications to the national programme (Viegand Maagøe 2014). There was increasing political backing for the Symbiosis Center Denmark, and from 2015 onwards it will have the mandate to engage in initiatives across the country to support the development of IS. The national centre will work strategically in four key areas: developing symbioses between companies, training and education, branding and investment promotion, and collaboration with universities.

Key tasks of the Symbiosis Center Denmark

Development of symbioses between companies

The IS network in Kalundborg has developed based on commercial agreements between the partners. The early development of the network was based on the initiatives of the companies themselves, especially Statoil's steps to find a solution the water supply to its refinery. The economic benefits have been vital incentives for the partners in the IS network. Several other factors underpin the success of IS development in Kalundborg. There are several industries located within a limited physical distance, which has made feasible the installation of pipes for water and energy exchanges. The companies are not key competitors, and mutual trust has been essential in the development of the network. These experiences have been integrated into the development of the national Green Symbiosis programme. The Symbiosis Center Denmark employs process consultants that are part of the national task force to promote symbioses for the region of Zealand and the capital region. The centre is thereby actively involved in IS projects in the two regions, and maintains close contact with the technical consultants. In the near future, the centre plans to focus on developing business models for the implementation of IS projects, and municipalities will be important collaboration partners in this regard.

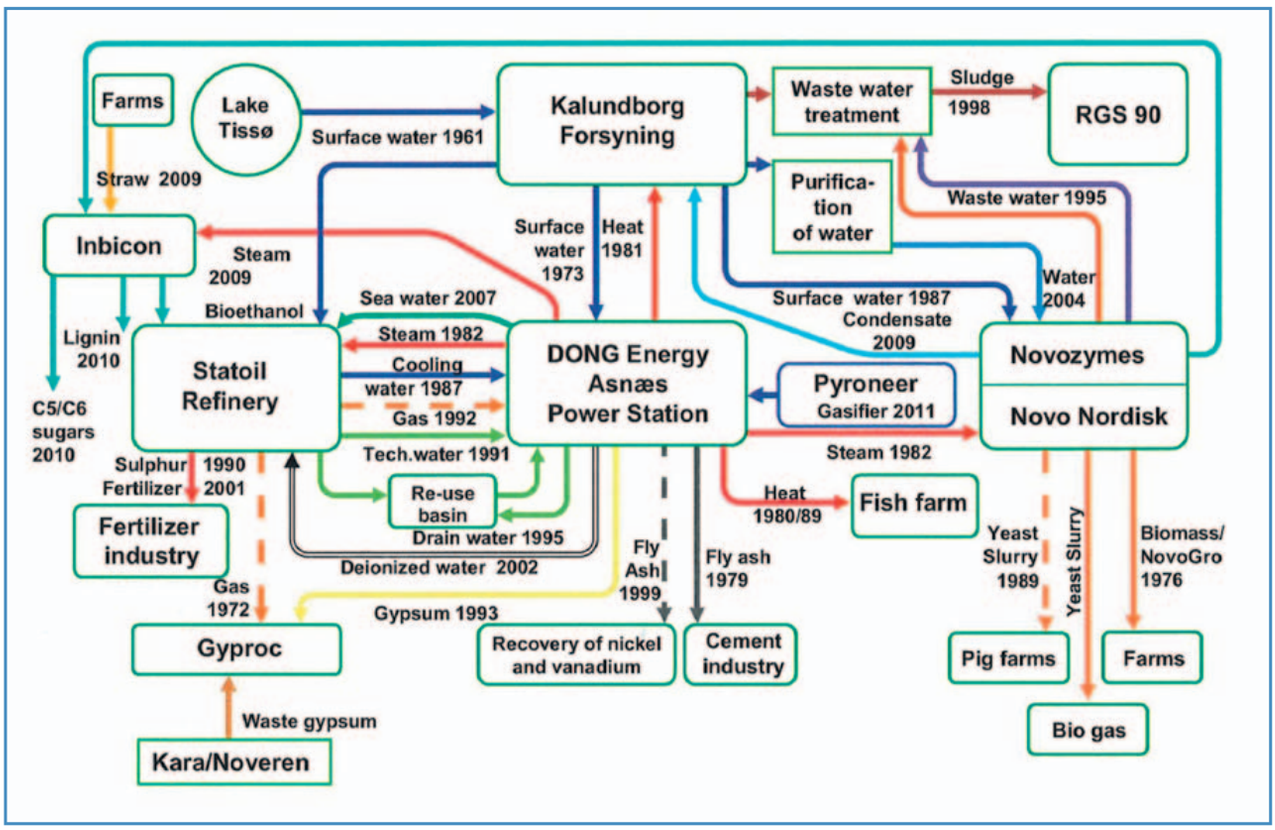
Training and education

As part of the ERDF project during the period 2011–2014, a number of two-day training courses were run by the Symbiosis Center Denmark in the region, which included companies (including local utility companies) and municipalities. The courses brought together these local parties to explain the IS concept, and allowed the actors to discuss possible opportunities among themselves. In the project evaluation report, such symbiosis education was highlighted as an important tool that has contributed to establishing contact with companies and also the initiation of IS projects (Viegand Maagøe 2014). The Symbiosis Center Denmark intends to continue to develop and provide courses.

Branding and investment promotion

Branding and investment promotion is taking place in collaboration with the investment promotion agencies State of Green, Copenhagen Capacity and Invest in Denmark, which are interested in the potential for attracting investments based on Danish IS know-how. This involves attracting investments from the delegations that come to the Symbiosis Center Denmark to learn about the IS initiatives in Kalundborg. The development of this concept was in its early stages in spring

Figure 3 *Kalundborg IS overview in 2010. Source: www.symbiosis.dk*



2015, but a first attempt was made during a visit by a delegation from Malaysia that was interested in integrating IS in the development of a new industrial area. The consultancy organization that provided the technical consultants for the Danish national project was invited to present its services. The concept of branding and investment promotion can be expanded to include companies across the country, so that they will be given the opportunity to sell their services and products to foreign delegations. Another branding and investment promotion priority involves branding Kalundborg as an attractive place to locate companies. For example, the surface water used in production is comparatively cheap in Kalundborg, which can be promoted to interested stakeholders. Furthermore, the municipality is highly experienced in supporting manufacturing companies that may wish to join the IS network.

Collaboration with universities

Since the 1990s, the IS in Kalundborg has been the topic of research by universities abroad, particularly Yale University. However, in Denmark, it has only received limited attention. It is the intention of the Symbiosis Center Denmark to establish collaborative agreements with Danish universities to generate more research in the field of IS. Another purpose of strengthening collaboration with universities involves attracting Master's degree students for internships in the companies within the IS network, and making it attractive for recent graduates to work in Kalundborg. It is difficult for Kalundborg to attract recent graduates, and today the average length of employment of workers in Kalundborg is less than two years. Collaboration agreements with universities are also part of the broader local development initiatives to enhance the attractiveness of living and working in the area.

Impact on economic growth and CO_2 emissions

It is not possible to establish quantitatively whether the IS network has generated new jobs in Kalundborg. However, respondents emphasized that the IS network has made a difference in terms of maintaining manufacturing industries and thereby jobs in Kalundborg. The IS network has helped develop close ties between the companies and the municipality of Kalundborg over the years. The IS exchanges between the companies and their membership in a common association ensure that the directors and site managers meet to discuss IS-related and other development issues, and contribute to an ongoing dialogue between public and private actors. In general, respondents indicated a preference for collaborating to find solutions to problems. Another benefit of being part of the IS network

involves the strengthened green Corporate Social Responsibility profiles and environmental strategies of the larger manufacturing companies based in the area.

In 2008, a study estimated the resource savings from the IS exchanges in Kalundborg compared with a "non-symbiosis situation". Examples of resource savings include the following.

- Ground water: ~2,000,000 m^3/year
- Surface water: ~1,000,000 m^3/year
- Natural gypsum: ~100,000 tonnes/year
- Oil: ~20,000 tonnes/year

The total reduction in CO_2 emissions in 2008 was estimated to be 275,000 tonnes, and now it is approximately 300,000 tonnes (Symbiosis Center Denmark 2015).

4.1.4 Key opportunities and challenges for developing industrial symbiosis

The key drivers and barriers of IS development were described in Section 3.4.3, which covered the experiences of the national Green Symbiosis programme. These are also valid for the initiatives in the region of Zealand facilitated by the Symbiosis Center Denmark in Kalundborg.

Danish public policy is ambitious in the sense that IS development is prioritized at the national level, with the national Green Symbiosis programme, the regional development strategy for Zealand and the local development strategy for Kalundborg all being focused on the development of IS. Furthermore, the European Structural and Investment Funds programmes provide good opportunities to apply for funding for IS projects focused on promoting resource efficiency and innovation.

Respondents stress that, in the case of Kalundborg, the IS network has been significant in supporting the manufacturing companies in the area. The importance of partnerships was also highlighted, as was the role of IS as a tool in the urban–rural discussion that supports manufacturing industries in rural areas such as Kalundborg.

Respondents also highlighted the importance of having a facilitator in the public system working to support symbioses. In Kalundborg, the development department at the municipality has the important role of managing the Symbiosis Center Denmark and operating as the secretariat for the IS network association, through which close contact is maintained with directors and site managers of the companies.

It is important that the national symbiosis programme is managed by the Danish Business Authority (and not by an environmental authority). This has given more credibility to the Symbiosis Center Denmark and to the technical consultants who identify business opportunities.

It has proven useful that companies can apply for counselling on the feasibility of initiating concrete IS exchanges.

In terms of making IS attractive to decision makers, a challenge is to determine the impacts of IS development initiatives in terms of both job creation and reduction of CO_2 emissions. A key issue in this regard is the large case-by-case variation in IS exchanges, which means job creation and emissions reductions will vary depending on which companies exchange which resources. Increasingly, there is a focus on monitoring such effects, e.g. the European Structural and Investment Funds have required the Symbiosis Center Denmark to define the CO2 emissions reduction objectives of IS development projects. The centre has estimated that when there are two to three partners in a given symbiosis project, the annual reduction in CO2 emissions is approximately 1,000 to 1,500 tonnes. However, especially when projects involve different types of materials, it is difficult to make such calculations. There-

Table 9 *Key opportunities and challenges for developing IS in the region of Zealand*

Key opportunities	+ Maintaining manufacturing industries through the development of IS partnerships + The current political prioritization of IS and resource efficiency at local, regional and national levels, including opportunities to apply for funding + Symbiosis Center Denmark as a knowledge centre for IS: company support, education, investment promotion and strengthened collaboration with universities + Strengthened knowledge and interest among companies and municipalities about working with IS
Key challenges	– Lack of time and resources of SMEs to implement new business models such as IS – Regulatory barriers (perceived and actual) – The implementation phase of IS exchanges between companies takes time and often loses speed after the consultation phase – A lack of public policy support for the implementation phase of IS exchanges

fore the objectives will only be estimates, and making such calculations nationwide is problematic.

4.2 The Kemi–Tornio region, Lapland, Finland

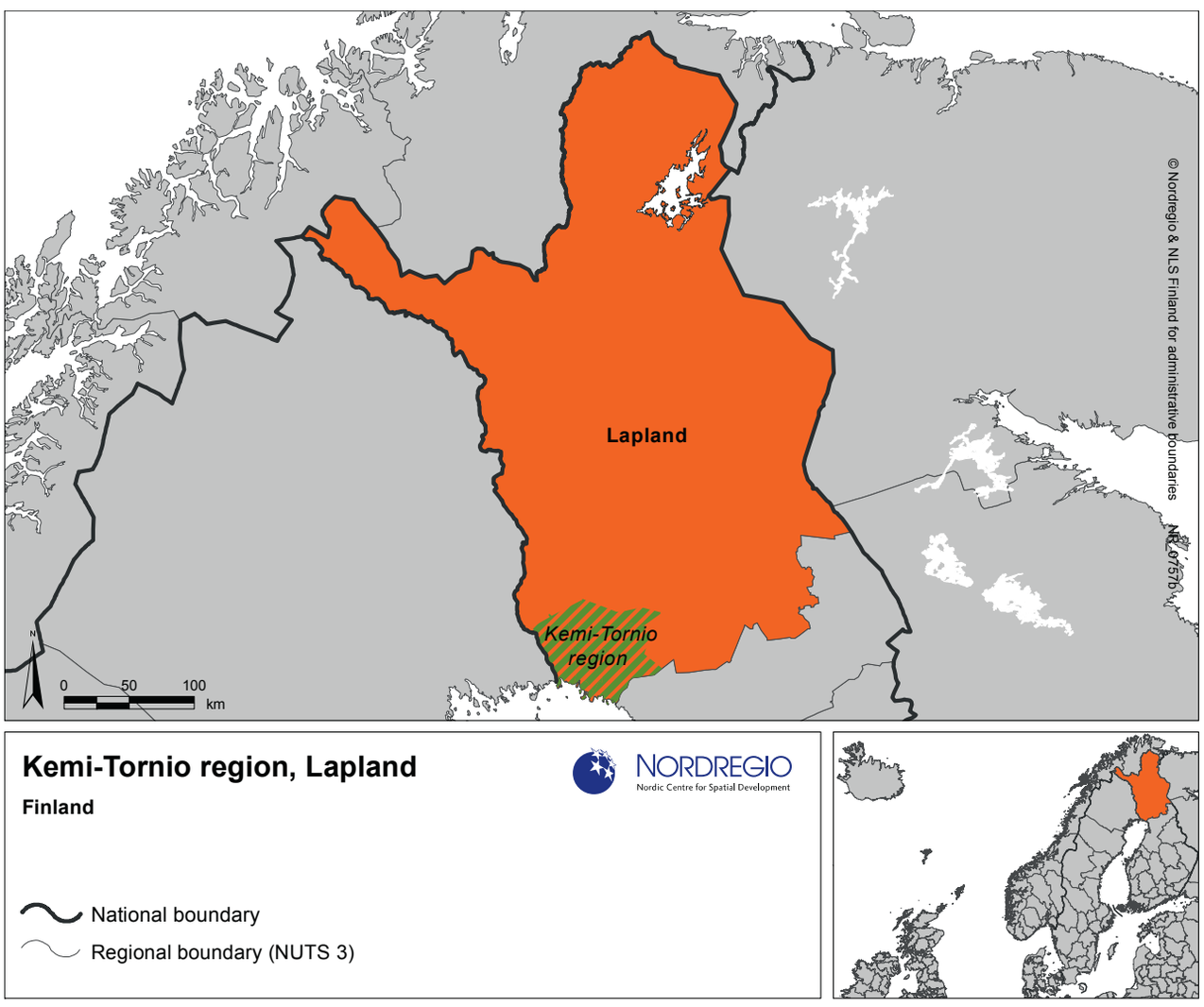
4.2.1 Brief description of the region

The Kemi–Tornio region in north Finland comprises the cities of Kemi and Tornio, as well as the municipalities of Keminmaa, Simo and Tervola. In 2012, the total population of the Kemi–Tornio region was 60,099 residents, which represents 1.1% of the total population of Finland. The region is important for industrial refinement and exports. It is responsible for 80% of Lapland's industrial production and creates more than 5 billion EUR of exports annually, which amounts to 7–8% of the total export value of Finland's products.

The Kemi–Tornio region represents a junction where two regions in different countries, Finland and Sweden, operate together in close co-operation, as the Tornio municipality borders the Swedish municipality of Haparanda and is its cross-border "twin" city. The region is part of the Bothnian Arc around the northern gulf of the Baltic Sea between Finland and Sweden. Its industrial system has a large number of mines and metal producers, paper and pulp mills, cardboard factories and also fertilizer and fine chemicals producers. The primary metal-based and forestry industries have an important role to play in the environmental quality of the area. Watkins (2014) states that new policies and technologies need to be designed to minimize the ecological impact of these industries, without losing the economic incentive to support the livelihood of communities in the Kemi–Tornio area. The companies in the processing industry in the region make active attempts to minimize their wastes and increase material efficiency by developing new products from their production residuals and wastes.

The industrial ecosystem in the Kemi–Tornio region is dominated by large-scale industrial operations, such as the Outokumpu stainless steel plant, Metsä Group

Map 3 *The Kemi–Tornio region*



forestry industry plant, StoraEnso forestry industry plant and Outokumpu Kemi chrome mine.

The Kemi unit of the Lapland University of Applied Sciences is the major educational and public-sector applied research institute in the Kemi–Tornio region. The vast majority of the R&D work takes place within Kemi–Tornio Industrial ecosystem companies. Extra-regional R&D partners include Aalto University, among others.

4.2.2 Regional support for green growth

Climate considerations are among the main priorities in political decisions in the Kemi–Tornio region, at both the regional and local levels. The ERDF programme for Lapland 2007–2013 has been the key operational programme in regional development in recent years.

In 2012–2013, Lapland prepared the Arctic Specialisation Programme, following the major guidelines of the European Smart Specialisation Platform concept (Regional Council of Lapland 2013). According to the vision of Lapland's Arctic Specialisation Programme, in 2030 Lapland will enjoy a leading position in exploiting and commercializing Arctic natural resources and conditions. Lapland will also be the centre of international arctic transport, information and telecommunications. From the point of view of Lapland's future, the aspects to be highlighted are the sustainable utilization of natural resources and natural conditions and the addition of value to Lapland's exports. The most important Arctic spearhead sectors in Lapland are the mining and metal industries, tourism and the bioeconomy.

Table 10 highlights some of the policy priorities in Lapland to promote green growth.

4.2.3 The Kemi–Tornio region and its industrial symbiosis programme and activities

The Kemi–Tornio region provides a platform for the piloting of IS products and services and for creating and strengthening an industrial ecosystem in Arctic conditions. The key elements of the IS in the Kemi–Tornio region include forestry, mining and steel industry companies, industrial service companies, research and educational organizations and intermediaries, especially Digipolis, the Kemi Technology Park.

It is a challenging task to estimate the volume of IS activities in the Kemi–Tornio region. Based on the interviews in 2015, a rough estimate would be in the range of 200 million EUR annually.

The Kemi–Tornio industrial region could be described as an ecosystem of Arctic industries; see Figure 4.

Based on the interviews included in the study, the basic concepts of IS have been present in the Kemi–Tornio region for decades. The more systematic efforts to strengthen IS in the region commenced in the early 2000s. Examples include the transportation of ash from the StoraEnso industrial site to the Outokumpu Elijärvi chrome mine, in which waste from one site became a resource for another. The terms IS or CE were not used frequently; rather, these activities were referred to as "the utilization of waste". An important event in the development of IS was the mapping of the by-product flows of industries in the Kemi–Tornio region, which was implemented in 2013–2014 as part of the By-product Flows of Arctic Industries project in 2013–2015. Digipolis invited representatives of industrial actors and public sector interest groups in late 2014 to an Arctic industrial by-products workshop, in order to further catalyse and co-ordinate the IS efforts

Table 10 *Existing regional instruments in support of CE/green growth in Lapland*

Instrument	Duration	Type of instrument	Policy priorities/action points	Authority/organization responsible
ERDF 2007–2013 Programme for Lapland	2007–2013	Operational programme	Promotion of business and innovation	Regional Council of Lapland
Lapland's Arctic Specialisation Programme	2014-	Strategies; suggestions for operational programmes	Sustainable utilization of natural resources and natural conditions	Regional Council of Lapland
ERDF 2014–2020	2012–2016	Strategy	Strengthening the country's ambitions related to climate and energy through the development of a new regional plan for climate and energy	Regional Council of Lapland

Figure 4 *Arctic industrial ecosystem in Kemi–Tornio.*

Source: *Poikela (2014).*

in the Kemi–Tornio region. It should also be noted that national actors in IS, e.g. the Finnish innovation fund Sitra (see Section 3.5.1), have been closely involved in the development talks and the planning of the Kemi–Tornio industrial ecosystem. The Kemi–Tornio industrial by-products project has co-operated intensively with the national industrial symbiosis programme coordinated by Sitra.

The following examples describe some of the main IS ideas and activities in the Kemi–Tornio region.

- Utilization of wastes from Metsä Fibre's Kemi mill: "Riffler waste is created in the wood room. This can be used as mulch in landscaping and, after screening, as fuel. Ashes from the bark-burning boiler can be used in earth construction. Ash and ash-mixtures can replace soil in certain earth structures such as in earth filling, protective layers and road structures" (Marika Alapoikela, the environmental manager for Metsä Fibre's Kemi mill, 2014).
- Utilization of wastes at the StoraEnso Veitsiluoto mill: The ash from StoraEnso processes has been used to fill the open pits of the Outokumpu chrome mine after metal extraction has concluded.
- Remediation of contaminated soil using the thermal method by Savaterra: At the Savaterra receptory site in Kemi, the versatility of the thermal method allows high variation in the contamination levels and

compounds in the input materials.

- Slag treatment by Tapojärvi: The valorization plant of the Tapojärvi company in Tornio that was built in 2010 turns steel factory by-products into valuable products without any disposable waste. By concentrating slag, Tapojärvi is able to separate a significant amount of valuable metals and return them to the steel factory. Of what is left, Tapojärvi produces, among other things, first-class rock material.
- Reducing CO_2 emissions through co-operation between the SMA Mineral factory and the Outokumpu ferrochrome factory: SMA Mineral, a full-range supplier of lime and dolomite products, uses carbon monoxide (CO) as a fuel, thus replacing the use of 17,000 m3 of oil annually. The CO is a surplus from the Outokumpu ferrochrome factory in Tornio. The SMA Mineral factory in Tornio had considered the use of CO for years, but because of limited availability, the investment decision was not made earlier. The investment by Outokumpu in an additional ferrochrome oven increased its surplus of CO, which enabled SMA Mineral to switch to CO as a fuel, based on both economic and environmental arguments (Yle Uutiset 2014).

4.2.4 Key opportunities and challenges for developing industrial symbiosis

The future potential of IS activities in the Kemi–Tornio region is considered significant. The recent mapping of by-product resources together with the positive mindset in the region regarding IS pave the way for future activities. Based on the interviews, the future business potential of Kemi–Tornio IS lies especially in symbiotic products from side-streams and waste streams, recovery of materials, innovations related to drying and excess heat utilization, and increased brokerage of side-streams and waste streams.

Based on the interviews, additional work is needed in order to unravel the needs and ideas of companies in the region regarding IS and to catalyse further activities. The key challenges include the need to guarantee the long-term, systematic role of a competent and trustworthy intermediator to build bridges between producers of waste and potential users of waste as a resource.

The Kemi–Tornio IS activities received an additional development boost in 2014 when the Unit for SMEs, Clusters and Emerging Industries at the EC's DG for Enterprise and Industry selected Lapland as a European model demonstrator region for "new or better ways of designing and implementing modern cluster policies". The Lapland proposal is largely based on cross-sectoral co-operation on resource efficiency, sustainability and the natural resources of Lapland. The Kemi–Tornio industrial ecosystem plays a key role in the proposal.

What is, then, the role and importance of public sector funding in promoting IS activities in the Kemi–Tornio region? On the one hand, according to some informants, numerous business-to-business IS activities take place constantly, independently of public funding. On the other hand, many IS initiatives in Kemi–Tornio need feasibility studies, pilot activities, etc. that would not take place without public co-funding and/or catalytic work by intermediaries such as Digipolis. One example is the regional project for mapping industrial side-streams.

MAPPING OF INDUSTRIAL SIDE-STREAMS IN THE KEMI–TORNIO REGION 2014

Digipolis technology park in Kemi co-ordinated a project on the mapping of industrial side-streams in the Kemi–Tornio region in 2014. The main purpose of the mapping project was to create a regional actor network and encourage matchmaking, in order to utilize more efficiently the industrial side-streams in the region. Moreover, the project aimed to reveal new business opportunities in utilizing the industrial side-streams. Documentation of relevant side-streams included recording their chemical and physical properties, analysis of the utilization grade of the side-streams and studies on markets, technology and logistics related to the side-streams. IS played a key role in the project, which included an analysis of combinations of industrial side-streams between the actors.

Based on the analysis, a total of more than 1.3 million tonnes of annual by-products and waste streams were identified (excluding the veinstone of mining activities). The Digipolis project resulted in a databank of industrial side-streams in the Kemi–Tornio region. The databank includes real-time information on actors, references and potential new applications. The databank will soon be opened to large companies and SMEs in the Kemi–Tornio region.

4.3 Svartsengi Resource Park, Reykjanes Peninsula, Iceland

4.3.1 Brief description of the region

The Resource Park is located within the Grindavík jurisdiction on the Reykjanes Peninsula and is located 50 km from Reykjavik. The municipality of Grindavík has 3 058 inhabitants (June 2015) and covers a total area of 425 km^2. The area is characterized by barren lava fields. There is a lack of grazing areas, which means

Table 11 *Key opportunities and challenges for developing IS in Kemi–Tornio*

Key opportunities	+ The IS activities are based on actual demand for relevant inputs (i.e. the resources nominated for exchange) in the industries involved + Business potential has been identified + Trends in resource efficiency and a positive mind-set regarding IS among decision-makers + Multidisciplinary approach involving private and public sector actors
Key challenges	– Lack of IS expertise in the region – The need to make a transition from managing individual waste flows to creating and strengthening more holistic CE systems

a lack of agricultural activity (Valsson 2003). The key natural resources in the region are geothermal energy and fisheries. The region is also characterized by an abundance of hot and cold fresh and salt water, fresh air, unspoiled nature, a wide variety of wildlife, ocean minerals and wave power.

The area has significant geothermal sources in Svartsengi, where the Blue Lagoon is located. Grindavík does not have heavy industries, and relies on the seafood sector and tourism. It is known as one of Iceland's largest fishing centres and has some of its strongest seafood companies. There are around 700 jobs in the largest fishing and seafood companies in Grindavík, in both fishing and seafood processing. The export value of the catch landed in Grindavík is about 20 billion ISK (approximately 139 million EUR) a year, which is about 4% of the total export value of Icelandic products (Pitea Municipality 2014). Tourism is another of the largest industries in Grindavík and is a major growth sector in the area. The Blue Lagoon spa and clinic is Grindavík's premiere attraction and an important employer in the municipality.

Grindavík municipality is located close to Keflavík Airport and a former US naval and air force base. Many businesses in the greater Reykjanes region are connected to the airport and harbour, and logistics is an important industry. In the mid-2000s, the population and employment rate dropped in the area because the base was closed. Since the base was deactivated, several initiatives driven by the Keflavik Airport Development Agency have been launched in the area aimed at fostering regional development. The Keilir Atlantic Center of Excellence offers academic programmes in the fields of green energy and technology, health, aviation and various entrepreneurial studies. The area hosts the largest university campus in Iceland, several start-up companies and the Ásbrú Enterprise Park, which includes a business incubator, the Eldey entrepreneur centre and the first green data centre in Iceland (Ásbrú 2015). In recent years, the growth has primarily been within innovative SMEs in Reykjanes. According to the Grindavík local administration, not only Grindavík but also the whole Reykjanes Peninsula is a resource park, where power plants are the basis and their side streams are utilized by other companies.

4.3.2 Regional support for green growth

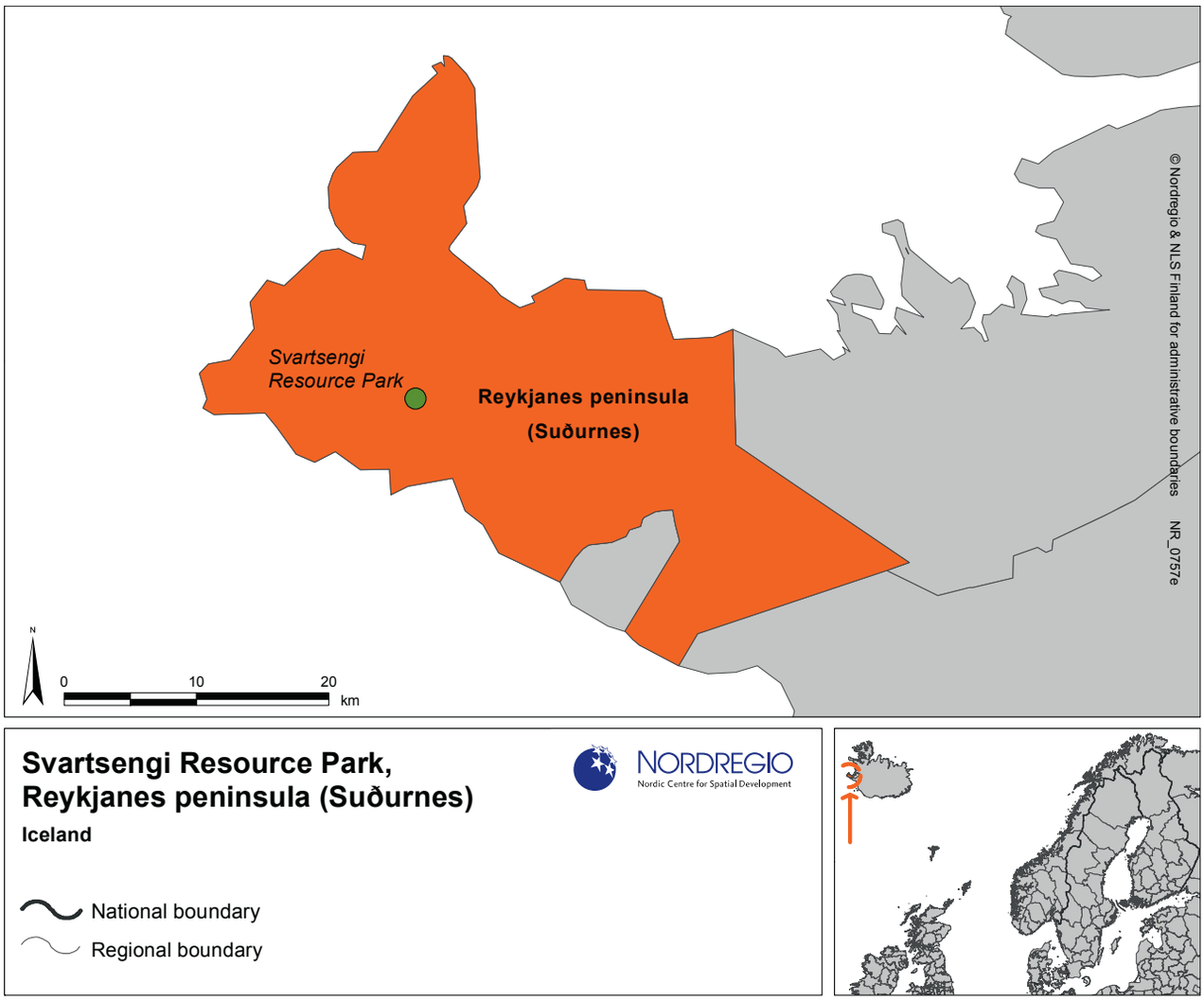
There is no regional governance in Iceland. The regions in Iceland do not have any administrative function and are mainly used for statistical purposes and strategic co-operation. The municipalities in Iceland have full autonomy in terms of planning and zoning, decisions on the use of resources and initiating voluntary co-operation regarding regional development.

In 2008, the Grindavík municipality started working on resource development and management, and carried out a mapping of Grindavík's most valuable natural resources, which resulted in the development of a a green growth policy for natural resources utilization in 2010. The policy is not confined to energy production, but comprehensively addresses all available resources in Grindavík (EFLA 2015). Its key focus areas are geothermal energy and sustainable fishing. The Grindavík local administration prioritizes the development of small-scale activities and projects within the focus areas and opposes the development of large-scale industries in the municipality.

Among the other policies supporting green growth at the local level are the regional development plan for the five municipalities on the Reykjanes Peninsula regarding planning and zoning, and Iceland's national "Master Plan for Hydro and Geothermal Energy Resources".

The Grindavík local administration co-operates extensively with the power plants and local industries in the area. It provides backing for their ideas and projects to support green growth in the area. Grindavík has an incentive system aimed at encouraging entrepreneurs to work on new projects in the area that complement local policy. The local administration also applies for grants from the state (e.g. the Reykjanes Geopark project received start-up funding). Within the Regional

Map 4 *Reykjanes Peninsula (Suðurnes)*



Development Agency, funding is available for entrepreneurs in the Reykjanes region under the framework of so-called "growth contracts". These grants support initiatives that complement Grindavík's natural resources utilization policy and the Svartsengi Resource Park philosophy (which is explained below in Section 4.3.3).

The decision to focus on green growth came naturally for the local administration, as the economy of Grindavík relies to a large extent on the responsible exploitation of green energy and natural resources (through fisheries).

4.3.3 The Svartsengi Resource Park and its industrial symbiosis activities

HS Orka owns and runs geothermal power plants at Reykjanes and Svartsengi that produce electricity, heat for district heating and distil water from subterranean steam. For over three decades, the company has been a role model for the Resource Park's philosophy in its operations at the Svartsengi plant.

Since the establishment of the power plant in 1976, the company has focused on "reading" nature and incorporating sustainability principles in its operations. The first IS activities emerged unintentionally. In 1976, as a result of condensing outlet water from the power plant, a blue lagoon was formed. A few years later, the brine's healing properties for skin diseases were discovered, which led to further scientific studies on its healing powers and the establishment of the Blue Lagoon spa facilities. Further development of IS activities eventuated from a "snowball effect". The spin-offs of the power plant and the Blue Lagoon led to the development of the Resource Park philosophy, which was defined and instituted in 1988–1989.

At the core of this philosophy is a holistic approach to multiple uses of a variety of subjective and objective resources of different natures, and the goal of creating a society without waste. The key principles behind the philosophy have been maximizing the utilization of every resource, and wasting as little as possible. The overall goals of the Resource Park are to "equally" pursue ecological balance, economic prosperity and so-

Table 12 *Existing regional instruments in support of CE/green growth*

Instrument	Duration	Policy priorities/action points	Authority/organization responsible
Policy for natural resources utilization	Since 2010	Geothermal resources, sustainable fisheries	Grindavík local administration
Regional development plan regarding planning and zoning on the Reykjanes Peninsula	Since 2013	Natural resources use	The five municipalities on the Reykjanes Peninsula
Incentive system – encouraging business activities in the municipality	Ongoing	Geothermal resources, sustainable fisheries; small-scale projects	Grindavík local administration
Growth contracts for entrepreneurs (grants)	Annually	Financial support to business development	Regional Development Agency

cial progress. Bridging different social and technical cultures and interconnecting various disciplines have been central elements in the Resource Park approach. The Resource Park philosophy is consistent with today's popular concept of a CE. Although Albert Albertsson, the main visionary behind the development of the Resource Park concept, refers to it as nothing more than common sense, such thinking was new in the late 1980s, and HS Orka faced considerable scepticism at first.

The companies within the Resource Park are founded on sustainability, as they use green electricity and side-streams from the Svartsengi power plant (geothermal steam, geothermal brine, geothermal condensate and geothermal CO_2) as resources in their operations. The Resource Park model shows that geothermal fluid has more uses than simply as a source of energy. The Resource Park companies utilize geothermal resources for a methanol production plant, a molecular farming facility, a geothermal spa and clinic, an algae farm and more; the geothermal resources are used for fish farming, at fish drying facilities and for the production of protein, enzymes, cod liver oil, sea vegetation and algae. Thus, in contrast to a conventional power plant that only earns revenue from the sale of electricity, the Resource Park has multiple revenue streams, resulting in diversified financial risk (Albertsson & Jónsson 2010). The companies at the Resource Park are dependent on the resources provided by the power plant, which makes the symbiotic relationship quite unique and strong.

The Svartsengi Resource Park consists of the HS Orka power plant, Blue Lagoon bathing facility, Blue Lagoon treatment centre/health facilities, Blue Lagoon R&D centre, Carbon Recycling International (CRI) and ORF Genetics.

HS Orka has been a lead investor in the Blue Lagoon since the company's foundation in 1992. In 1994, the Blue Lagoon opened a treatment centre for psoriasis patients in co-operation with the Icelandic health authorities. Gradually, new activities have been developed within the Resource Park. The Blue Lagoon Dermatology Clinic was established in 2005, followed by the Blue Lagoon R&D centre, which specializes in bio-technology, dermatology and marine cosmetology and produces salt, algae and silica as well as undertaking specific research. Various skin care products that use active ingredients (silica and two types of algae) are manufactured at the R&D centre (Gudmundsdóttir et al. 2010). The Blue Lagoon facilities use waste water (cold and warm sea water) and electricity from the power plant, purchase geothermal brine from HS Orka and now also use CO_2 for algae growth (as of two years ago).

CRI is driven entirely by emissions and waste streams from the geothermal power plant. The power plant produces gas containing CO_2. CRI takes about 10% of the plant's gas, separates the CO2 from the hydrogen sulphide and converts it into methanol. CRI is currently focusing on the production of renewable vehicle fuels of non-biological origin. CRI is also looking into possibilities for re-utilizing sulphur.

ORF Genetics uses hot water, ground water and electricity from the power plant to produce specific human proteins by cultivating barley in greenhouses located a short distance from the power plant. CRI and ORF Genetics obtained their own financing but received some financial support from HS Orka during the ini-

tial phase of development.

The Resource Park has been working continuously on increasing productivity, process improvements and the development of new, specialized products through interdisciplinary research and innovation. The Resource Park depends heavily on uninterrupted R&D and applying innovative thinking. The expenditure on interdisciplinary R&D amounts to over 4 million USD annually.

The Blue Lagoon facilities employ 300 people, of which 250 are full-time employees. The Resource Park companies combined employ around 600 people. If related service and spin-off companies are included, the total number employed in Resource Park activities reaches 2,500. The Resource Park's activities are also central to regional development and growth in other ways: the Blue Lagoon spa facility has about 400,000 visitors annually, which boosts the local economy substantially.

There is no formal co-operation and co-ordination among the different types of actors within the Resource Park, and there is no official network co-ordinator. Dialogue and communication takes place on a daily basis in informal meeting places, such as canteens, as well as through HS Orka's visits to Resource Park companies at least once per year. The companies within the Resource Park emphasize that being flexible, open to co-operation and understanding of each other's needs is crucial for collaboration in the framework of IS.

4.3.4 Key opportunities and challenges for developing industrial symbiosis

IS activities have played a central role in the development of the Reykjanes region for over 20 years. The driving forces behind the successful development of the Resource Park are innovative thinking, commitment and the visionary mind-set of the leadership of HS Orka since the 1970s. The Resource Park is a unique example of how a single enterprise (a power company) can shape regional development and promote sustainability and innovation.

Interdisciplinary co-operation has proved to work well in the context of the Resource Park and has been among the enabling factors for its development. The Resource Park brings together geologists, different kind of engineers, geo- and biochemists, seismologists, builders, medical specialists and other professionals, who co-operate to develop projects and innovative products. Building up trust and understanding among the actors within the Resource Park has been a crucial element for this successful co-operation.

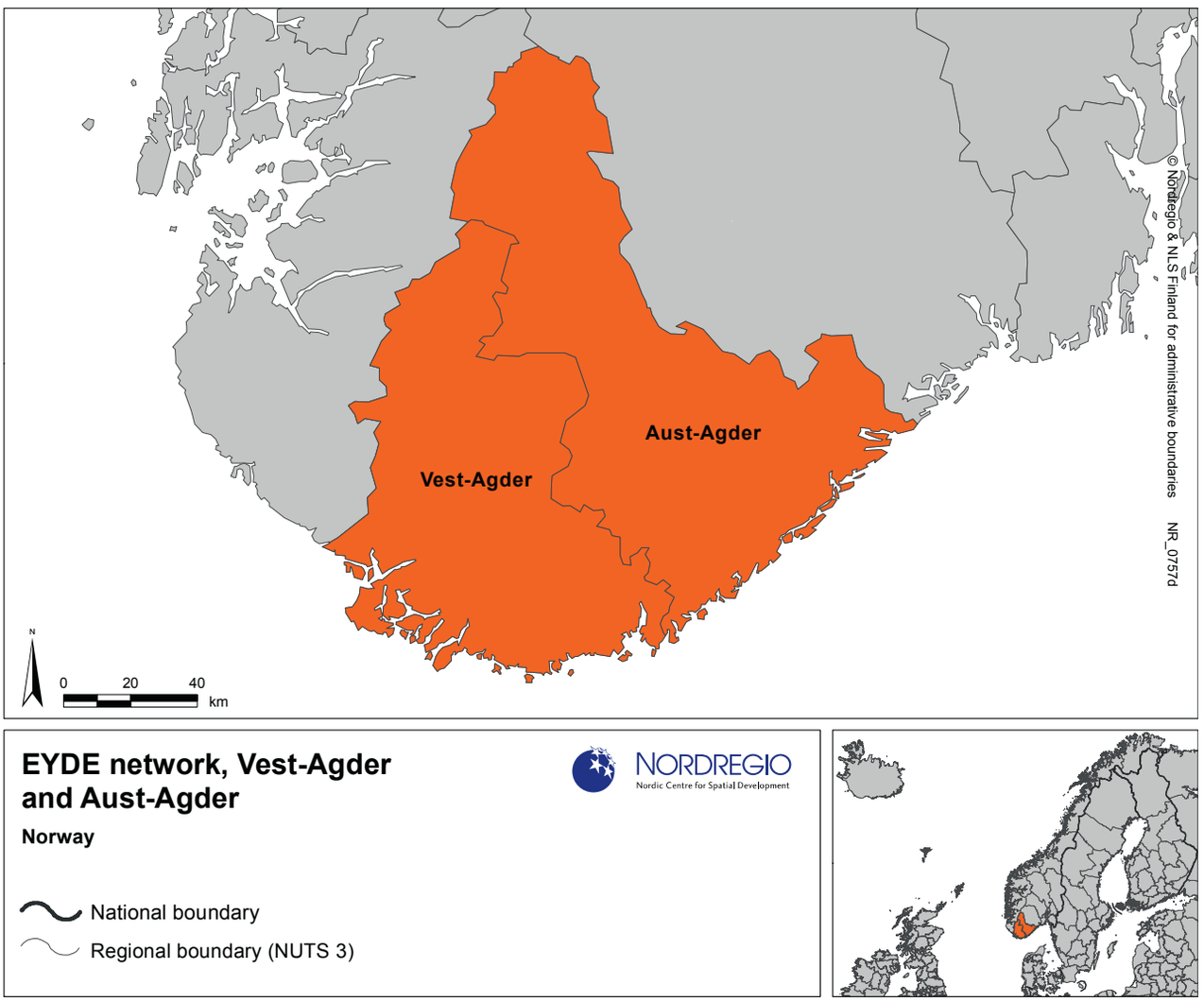
From a business perspective, there have not been any major challenges in developing IS activities here. Lack of communication has been identified as the main challenge that can affect network functionality, and the main business challenge is difficulty attracting investors, though the Resource Park has overcome this barrier. However, governmental support would be appreciated by businesses in this regard.

From a local administration perspective, the single most important factor that can challenge co-operation in the framework of the Resource Park is a failure to build consensus among the municipalities and the key actors in the area. All previous project failures were caused by a lack of consensus. Today, regional co-operation in Reykjanes is flourishing, which is due to synchronized activities and a consensus on the development priorities among the key actors, including the municipalities, infrastructure companies and power companies. The results of this co-operation are visible in the region today, and there is an understanding that this co-operation benefits the region as a whole.

Table 13 *Key opportunities and challenges for developing IS in Grindavík*

Key opportunities	+ Commitment to the Resource Park philosophy and the visionary mind-set of the leadership of HS Orka + Strong culture of co-operation in Iceland + Interdisciplinary co-operation at the Resource Park has enabled the development of new businesses and innovative products within the IS partnership + Businesses in the Resource Park were founded and have operated as IS partnerships from the commencement of their operations, which makes the IS network strong and co-dependent + Synchronized activities and consensus on the regional development priorities among the key actors in the area, including the local administration and HS Orka + Low energy prices and access to renewable energy in the region
Key challenges	– Lack of national and local support schemes for IS activities – Inadequate focus on and support for CE/IS initiatives at the national level – Lack of communication and a failure to build consensus may affect network functionality – Difficulty attracting investors

Map 5 *The Agder region*



So far, there have not been any conflicts of interest or competing claims over the use of resources. The Resource Park and its companies have received considerable support from the local municipality and from politicians at the national level, although this has been predominantly "emotional" support and backing only, because no public funding has been provided for Resource Park activities. The businesses within the Resource Park are entirely privately funded and are economically sustainable. However, some public funding has been available for research activities. For instance, the Blue Lagoon received funding from the National Energy Fund to test different algae types for lipid production and utilization in cosmetics, nutritional supplements, fish feed and possible future biofuels (Gudmundsdóttir et al. 2010).

When it comes to possibilities for future growth, HS Orka is investigating further opportunities for the expansion of its network to include companies with business ideas that are consistent with the Resource Park concept. There is a high potential for algae production using geothermal energy, as well as the production of sustainable fish feed. As for development of the Blue Lagoon, the bathing facility is to be extended and a new hotel and spa built in the area. It is expected to provide 100 new ongoing jobs in 2017 and 450 new temporary jobs during the building phase.

4.4 Eyde Cluster, Agder, Norway

4.4.1 Brief description of the region

The Agder region comprises the two counties Aust- and Vest-Agder, situated in southern Norway. Aust-Agder county, covering 9,212 km^2, is divided into 15 municipalities with a total of 113,747 inhabitants (2015) (Statistics Norway 2015). Vest-Agder covers 7,281 km2 and is divided into 15 municipalities, with a total of 178,478 inhabitants (2015) (Statistics Norway 2015). The population in the two Agder counties makes up 5.7% of the total population of Norway. Around 51% of the inhabitants live in the three biggest towns in the region: Kristiansand, Arendal and Grimstad. The two

administrative centres are Kristiansand (approximately 82,000 inhabitants) and Arendal (approximately 42,000 inhabitants) ("Regional Development Plan Agder 2020").

The majority of the Agder region's population and businesses are concentrated along the coastline. Vest-Agder is the biggest export county (per capita) in Norway and a leading region in terms of entrepreneurship and exports of processed goods. Industries in Agder are heavily based on energy-intensive raw materials processing (e.g. aluminium, nickel and silicon. The region is also host to world-leading producers of offshore equipment (e.g. for drilling and mooring), and has strong maritime industry clusters ("Regional Development Plan Agder 2020"). The region's considerable hydropower resources and proximity to the European continent make it an important provider of climate-friendly power to Europe. Agder also has numerous industries that are advancing the field of energy production, as well as leading research organizations in the field of energy and climate issues.

Universities, research institutes and industry in Agder generally have a lower than average R&D expenditure compared with the rest of the country, with the exception of three industries: the oil and gas supply, processing and chemical industries. The region also has a higher share of manufacturing employment than the rest of the country.

4.4.2 Regional support for green growth

Climate considerations are a key priority in all political decisions in Agder, both at the regional and local levels. In the "Regional Development Plan Agder 2020", which is a strategy document for the Agder region, one of the main priorities is for Agder to become a leading international region for the climate-friendly production and distribution of renewable energy by 2020. Creating a sustainable processing industry is mentioned as a key motivation in this regard. In the strategy, there is also a focus on developing renewable energy and facilitating energy exchange, to increase the delivery of green energy to the European mainland.

Table 14 summarizes some of the policy priorities in the regional development plan that promote green growth. Important measures aim to stimulate cross-sectoral co-operation between actors working on renewable energy solutions and energy efficiency improvements; to prioritize projects directed towards climate challenges through the allocation of regional development funding or other public intervention; and to support projects that contribute to process improvements in energy-intensive industries (such as the processing industry).

The regional planning strategies for Aust- and Vest-Agder also have the reduction of emissions as a key priority. Vest-Agder county has set priorities to develop green energy, while Aust-Agder county has an ambition to develop a new regional plan for climate and energy, in order to strengthen the region's focus on climate.

Both the county councils and the municipalities are important collaborating partners to cluster organizations (such as the Eyde Cluster) in the region. Available regional support instruments include the Regional Development Funds (RDF) and Regional Research Funds Agder. The aim of the RDF is to contribute to raising the level of competence in the county in order to secure jobs and good living conditions. Public or private research/educational institutions, local authorities and public or private enterprises can apply for funding through the RDF. Regional Research Funds Agder works to strengthen research on regional innovation and development by supporting the region's priority areas and mobilizing increased R&D efforts. The funds are granted to projects that provide benefits in the form of the increased competitiveness of businesses, commercial growth and the securing of jobs.

4.4.3 The Eyde Cluster and its industrial symbiosis activities

Despite Norway being a high-cost country for industry compared with competing manufacturing locations, its processing industry (including the production of metals, chemicals, materials, wood and paper) produces Norway's most important non-maritime exports to the EU (Menon 2013). This industry is also an important provider of jobs in rural regions in Norway.

The Eyde Cluster was established in 2007 by CEOs in the processing industry in the two Agder counties. The network is built on a strategy that follows the "Vision 2050" report of the World Business Council for Sustainable Development (WBCSD), which focuses on how companies in the process industry can work together to improve resource efficiency. The Eyde member companies produce specialized products (metals, materials and chemicals) for the global market, and although they are involved in different value chains, they have a common denominator in the manufacturing process. The motivation for forming the network was based on increasing demands for cost reductions from international investors and the tightening of environmental standards. The goal was to increase the member companies' competitiveness through internal and external collaboration.

The 13 member companies have 3,000 employees and a total annual turnover of about 10 billion NOK (approximately 1.15 billion EUR). The core member firms export approximately 90% of their production

Table 14 *Existing regional instruments in support of CE/green growth in Agder*

Instrument	Duration	Type of instrument	Policy priorities/action points	Authority/organization responsible
"Regional Development Plan Agder 2020"	2010–2020	Strategy	Establish co-operative measures with businesses specializing in renewable energy and energy efficiency in the processing industry and the petroleum-supply industry Give high priority to projects, measures and business concepts addressing climate challenges when allocating regional development funding and engaging in other public intervention with regard to framework conditions and business development Stimulate the regional development of climate-friendly technology by funding projects and initiatives emphasizing energy efficiency and the development of renewable energy through joint ventures between the academic sector, industry and the public sector Support projects that contribute to process improvements in energy-intensive industries	Aust- and Vest-Agder county councils
Regional planning strategy for Vest-Agder	2012–2016	Strategy	Developments that facilitate the region's function as a green battery for Europe through - expansions of the power grid and hydropower, - development of wind power, and - continued work on energy efficiency in industry	Vest-Agder County Council
Regional planning strategy for Aust-Agder	2012–2016	Strategy	Strengthening the county's ambitions related to climate and energy through the development of a new regional plan for climate and energy	Aust-Agder County Council
Regional Development Funds (RDF)	2014–	Funding	Grants for projects/initiatives that - are consistent with the county council's goals and strategies for rural and regional policy, and - can demonstrate substantial rural and regional political benefits	Competence Development Fund of Southern Norway
Regional Research Funds Agder	2015 (yearly announcements)	Funding	Grants for projects that can demonstrate practical benefit for the region	

and are all part of global value chains through foreign ownership. The Eyde companies spend considerable resources on R&D; total annual expenditure on R&D is 270 million NOK (approximately 31 million EUR), and approximately 12% of their employees are participating in R&D activities (Oxford Research 2014). The network has also triggered 20 R&I cluster projects for a total of 32 million NOK (approximately 3.7 million EUR), with different regional, national and international partners, and with co-funding from regional and national sources (Dale Strategi 2013; Oxford Research 2014).

The Eyde Cluster has evolved incrementally over several years since its establishment in 2007. During the initial years, the network focused on establishing connections and projects between the member companies. In 2010, it entered Innovation Norway's Arena programme (as Arena Eyde), which is one of three cluster programmes in Norway that offer financial and technical support for the long-term development of regional clusters. Since then, the network has gradually developed from being solely a platform for knowledge sharing to being an important arena for and facilitator of technology development projects. The Eyde companies are currently working to increase productivity, improve processes and develop new, specialized products for new markets through joint research and innovation projects. Through its activities, the network has also managed to achieve strong political visibility through the establishment of a national platform for research-based innovation in processing industries (PROSIN). The Eyde Innovation Center is the driving force behind the network's innovation and research projects.

A number of institutions are central R&D partners to the Eyde companies. At the regional level, the University of Agder and other R&D institutions and innovation agencies are important partners through participation in relevant fora, workshops and strategy processes. NCE NODE, which is a leading global technology cluster in Agder, comprising more than 60 companies, is the most important cluster partner. At the national level, the network has developed PROSIN in partnership with the Federation of Norwegian Industries (Norsk Industri), SINTEF, Tel-Tek, Hydro and the Norwegian Research Council. The firms in the network also have several international R&D partners, including Oxford University (UK), the Fraunhofer Institutes (Germany) and Kungliga Tekniske Högskulan (Sweden).

The Eyde companies are involved in a number of different projects related to resource efficiency and sustainability, which are gathered under the umbrella of the Eyde Environment Program. Two of the projects that were initiated in 2012, Eyde 0 Waste and Eyde Biocarbon, are based on CE/IS principles.

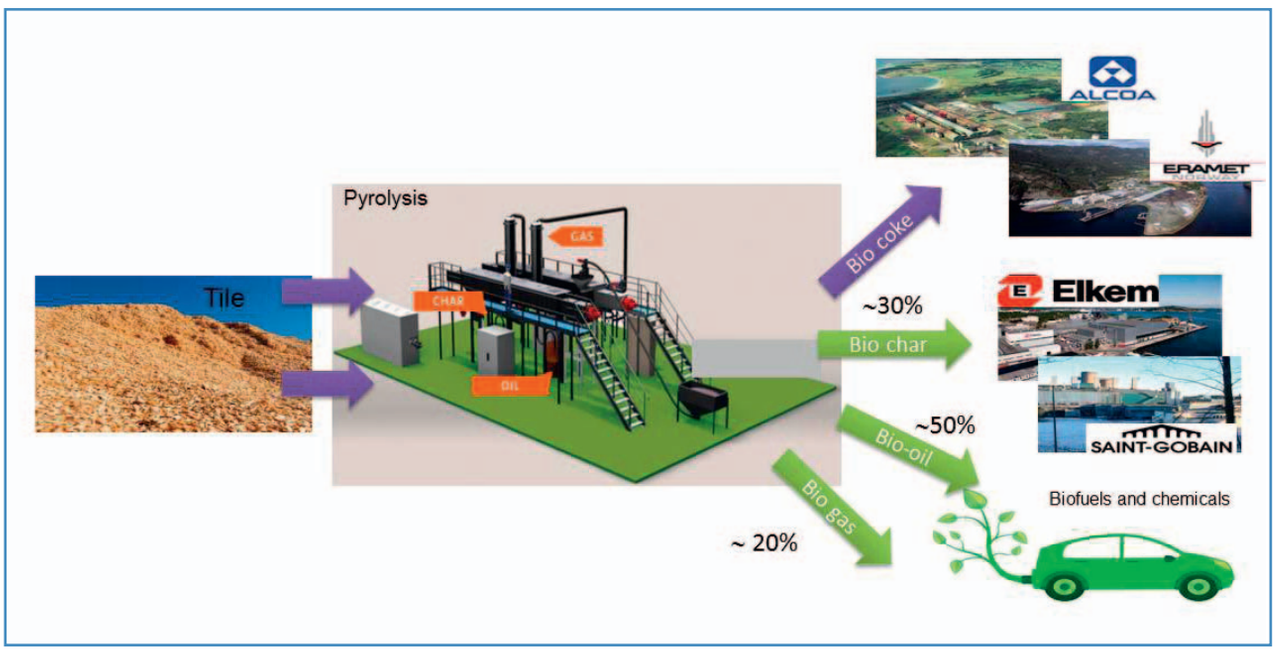
EYDE 0 Waste

Many of the companies in the network have side-streams of various volumes that are often dealt with through sales to external clients, emissions into air/water, landfilling or incineration at external facilities. Stricter regulation of landfill use and recycling means that the participating companies have the goal of reducing "waste" (i.e. usable material) to a minimum, and the Eyde 0 Waste project has a common goal of reducing participants' use of landfill to zero by 2030. This will be achieved through new, environmentally friendly and cost-effective ways to deal with side-streams through the recycling of side-streams, better utilization of raw materials and/or alternative uses of side-streams. The companies have already worked internally for many years on issues related to side-streams; however, through Eyde 0 Waste they have the possibility to exploit the expertise available in the other companies participating in the network.

Nine companies are participating in Eyde 0 Waste (Eramet, Alcoa Carbothermic, Alcoa Lista, FAC Benteler, GE Healthcare, Elkem Solar, Glencore Nikkelverk AS, Saint Gobain and Elkem Technology). The Eyde Cluster is the project owner, and the project is led by a project co-ordinator, with each sub-project having its own project leader. It is funded through cash contributions and time investments from member companies. The companies have also received external funding from the Norwegian Research Council, Innovation Norway, Regional Research Funds, Enova and the EU association SPIRE. In 2014, the project received two million NOK (approximately 232,000 EUR) from the Competence Development Fund of Southern Norway. In February 2015, the Eyde Cluster received an additional 600,000 NOK (approximately 70,000 EUR) from the Aust-Agder Competence Development Fund, which granted a total of 10.2 million NOK (approximately 1.2 million EUR) to different R&D projects in the region in 2015.

The project is still in an early phase: the companies have identified side-streams that can be used, and based on this identification, possible collaborative projects have been identified. The Eyde Cluster is currently in dialogue with Innovation Norway regarding the possibility of applying for funding from the Environmental Technology Scheme. The funding would cover costs related to the planning and construction of a pilot plant to test the identified side-stream exchanges and explore whether these could be developed commercially.

Figure 5 *Eyde Biocarbon – possible value chain*



Source: *Eyde Cluster.*

Eyde Biocarbon

Eyde Biocarbon aims to find sustainable economic solutions to replace petroleum coke and coal with locally sourced and produced biochar/biocoal that can be used in the production of silicon and silicon carbide. The overall goal is in line with the national strategy "Klimakur 2020", which stresses the need to reduce emissions of greenhouse gases by 15–17 million tonnes by 2020. The alternative to locally produced biochar/biocoal is to import it from other regions of the world – typically Central and South America, or Asia. This raises ethical issues such as the de-forestation of tropical forests, displacement of indigenous populations, etc. Furthermore, these solutions involve long transport routes, and the production processes are often inefficient, leaving bio-oil and biogas unused. However, the Agder region has vast forest resources, which implies that there is considerable potential for increasing the use of timber for bioenergy.

The Eyde companies Alcoa Carbothermic, Eramet, Elkem and Saint Gobain all use large amounts of fossil fuel carbon in their processes. Together they wanted to explore the possibility of replacing this with biocarbon. As a first step, the companies started mapping the available biomass from wood in the region. The conclusions from the mapping were that sufficient biomass is available in the region and that there is potential to increase the biomass feedstock use. As a next step, the companies intend to start the test production of biochar. Profitable production of biochar implies that all products generated in the production process, i.e. bio-oil and biogas, will be sold and used for other purposes: the biochar will be used as a carbon source in melting processes at Elkem and Saint-Gobain; the biogas may be used as a substitute for natural gas, e.g. for melting recycled aluminium at Alcoa; and the bio-oil can be upgraded to fuel oil or used as feedstock for biodiesel production (Figure 5). A key goal is to start using regionally sourced Norwegian wood to produce biochar that will entirely or partially replace coke and coal, as well as the biochar currently derived from tropical wood. This could result in new industrial activity in the region, focusing on converting biomass to metallurgical biochar. Furthermore, as charcoal production is a sub-process and charcoal a sub-product resulting from the production of biofuels and biochemicals, it is likely that it can be produced more competitively if it is integrated into the metallurgical processing industry.

Eyde Biocarbon is in the early stages of testing the qualities of different processes and simultaneously assessing production methods that could reduce costs. In January 2015, the project received 4.4 million NOK (approximately 514,000 EUR) in support from the Norwegian Research Council's BIA programme to start the laboratory testing of biocarbon in industrial processes. The grant from the Research Council is estimated to cover 40% of the total project costs. The remaining 60% (6.6 million NOK, approximately 767,000 EUR) will be covered by the companies themselves. The laboratory testing will start in 2015 and is planned to continue

until 2018. The next phase will be the establishment of a pilot plant in 2018, and commencement of full-scale industrial production is planned for 2020. Important questions to be answered during the laboratory testing are whether the predicted net carbon emissions reductions from substituting biochar/coke for fossil fuel can be achieved in practice, and whether it is possible to recapture and reuse the gases on a scale that makes it profitable. Table 15 presents the predicted potential for CO_2 reductions in Norway by substituting biochar/coke for fossil fuel in the metalworking industry.

4.4.4 Key opportunities and challenges for developing industrial symbiosis

Although the Eyde Cluster's IS projects are in an early phase, it is expected that they will provide possibilities for future growth and jobs in the region. The Eyde 0 Waste project has already seen spin-off effects through the creation of a new company, and it has created new opportunities for other companies in the region working with waste processing (e.g. Returkraft, Høst, Agro-Plas and ReSiTec). Eyde Biocarbon has the potential to contribute to growth in the regional forestry industry and increase the added value of the industry as a whole by upgrading knowledge-intensive activities and skilled jobs. The survival of the Eyde companies depends on their resource efficiency because of strict international requirements, and collaboration through IS – leading to reductions in costs and emissions – can be regarded as one means of retaining the companies in the region.

There is generally strong support for the Eyde Cluster's activities from the regional administration; the processing industry is prioritized in local and regional strategies, the county councils grant basic funding to the network on a yearly basis and Aust-Agder County Council has been directly involved in the launch of one of the network's projects, Eyde Biocarbon, in an effort to find collaborating partners in the private sector. The cluster, acting as a facilitator for collaborations and projects across companies, plays a crucial role in developing CE/IS initiatives in the region.

There are multiple opportunities for the network to apply for short-term project funding from regional and national actors. However, there are challenges when it comes to long-term support schemes for innovative projects such as Eyde 0 Waste and Eyde Biocarbon, as most long-term funding schemes, such as Innovation Norway's Environmental Technology Scheme, do not apply to projects in an early phase focused on concept development and laboratory testing. Such projects to a large extent rely on large investments from the companies themselves as well as short-term project funding from various public support schemes, until they are at a stage where the technology is close to commercialization. This means that the development of IS in the processing industry in Agder to a large extent depends on the interests of the companies themselves, which are mainly a desire to minimize costs and comply with environmental standards and regulations.

There is generally a need at the national level for stronger support for and more awareness of CE/IS and their potential to solve future challenges relating to green growth. As a step in this direction, the interviewees requested that the government develop a strategy for the processing industry, similar to the one for the oil and gas industries in Norway (White Paper No. 28, 2010–2011), focusing on future frameworks for the industry and how it can become greener, e.g. through investment in new technology.

4.5 The Händelö industrial symbiosis, Norrköping, Sweden

4.5.1 Brief description of the region

The Händelö IS (or "Händelö energikombinat", as they call themselves) is located in the municipality of Norrköping, where it is situated physically on an island close to the city and harbour. Norrköping is a coastal municipality in the north-east of the NUTS-3 region of

Table 15 *Potential for CO_2 reductions*

	% Biochar/coke	Saved CO_2 (Mt per year)2
Eyde companies (total in Norway)	20%	~650,000
	40%	~1,300,000
Total metalworking industry in Norway	20%	~1,400,000
	40%	~2,800,000

Source: *Eyde Cluster.*

Table 16 *Key opportunities and challenges for developing IS in Agder*

Key opportunities	+ Strong interest from processing industry companies to develop environmentally friendly solutions as a means to reduce costs (e.g. through IS) + Collaboration through the Eyde network helps strengthen the industry and its competitiveness through a focus on resource efficiency + Low energy prices and access to renewable energy in the region + Strong focus on the development of renewable energy and energy efficiency in local and regional strategy documents
Key challenges	– Lack of coherent and long-term support schemes for innovative projects – Insufficient focus on and support for CE/IS initiatives at the national level – Lack of a long-term strategy for the development of the processing industry in Norway – High demands for productivity and sustainable production in the processing industry

Östergötland county, in the south-east of Sweden. In terms of population, Östergötland is the fourth-largest county in Sweden, with close to 416,000 inhabitants, or 4.6% of the population of Sweden. Norrköping municipality is home to the second-largest city in this region (the city has the same name as the municipality). Around 125,000 people live in and around Norrköping, with approximately 110,000 of those in predominantly urban areas.

The landscape of central Östergötland is dominated by an agricultural plain, whereas the northern and southern parts are characterized by forested areas and inland lakes. The infrastructure in Östergötland is rather well developed, with roads, railways, airports, harbours and information technology. The most important road and rail networks in Sweden, connecting Copenhagen and Stockholm, intersect the county from the southwest to the northeast, offering good opportunities for the transportation of goods and people within the region. The harbour in Norrköping is one of the most important harbours in the Baltic Sea, and more than four million tonnes of goods are shipped from it yearly – mostly wood and petroleum products, but also a large amount of agricultural products. The harbour hosts the Djurön Grain Terminal, which is one of Europe's largest grain terminals and is run by the Swedish Farmers Supply and Crop Marketing Association (Svenska Lantmännen) as their main gateway for exports.

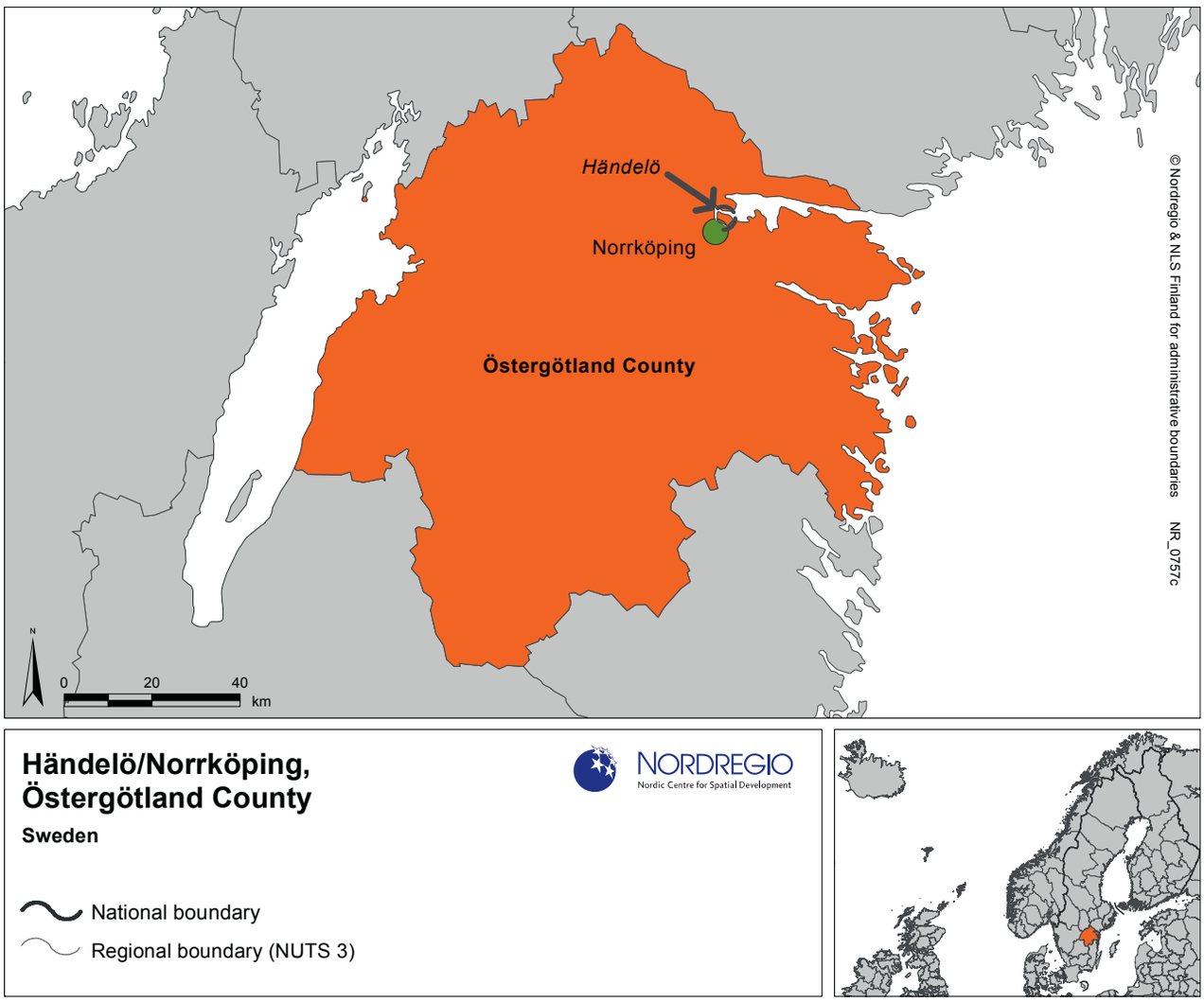
The regional GDP in real terms for Östergötland is around the fourth or fifth highest among the 21 Swedish counties. In terms of GDP per capita, however, the region is only ranked around 15th, and in terms of GDP per worker it is among the last five counties. Examining the municipal origins of the regional GDP, Linköping and Norrköping stand out as the top contributors by far, generating 37% and 31% of the total GDP, respectively. Roughly 40% of the regional GDP for Östergötland comes from agriculture, manufacturing, energy production and construction, 31% from services, 18% from public administration and households and, finally, 12% from other sources (Statistics Sweden 2014). The unemployment level in Östergötland in 2014 was 9.1%, compared with 7.9% for Sweden overall. The highest unemployment rate is in the municipality of Norrköping (12.6%), followed by Motala (11.1%) and Finspång (10.3%). Norrköping has been struggling with industries closing down because of an economic downturn for some years now, and is struggling to reinvent its economy and create new jobs.

Firms in manufacturing dominate the region's trade and industries. There are traditional manufacturing plants in the smaller municipalities, whereas in Linköping and Norrköping there is also the development and production of technically more advanced products. The largest public employers in the region are the county council in Östergötland and the municipalities of Norrköping, Linköping and Motala. The fifth-largest public employer is the University of Linköping. The 10 largest private employees include international firms such as Siemens and Ericsson. Some large national corporations in the food processing and forest products industries (e.g. Swedish Meats and Holmen Paper, respectively) are also among the largest employers in the region (Östsam 2007).

4.5.2 Regional support for green growth

The municipality has stated that environmental technology, green businesses and the Händelö IS are crucial dimensions of the development of the regional economy. Händelö is seen as a very good example of environmentally sound business practices supporting regional development, and it attracts interest both nationally and internationally. The municipality recognizes the possibility of building on such activities through the

Map 6 *The Östergötland region*



growth of service industries around Händelö, as well as companies that develop adjacent technologies and service solutions (and the possibility of exporting such solutions). The municipality recognizes that there is a triple helix structure around Händelö – comprising Händelö, the municipality and universities – but agrees that it could (and should) be much more developed. But this is a question of resources, and there are many other issues requiring the municipality's attention in the business environment of Norrköping.

Although IS and CE are not explicitly mentioned in the regional and municipal development strategies today, the issues of sustainability, renewable fuels, biorefineries and smart specialization in cleantech are visible and definitely do not deliminate IS. Recently, the abolished municipal cleantech company was re-established (as a supported NGO) to continue its work, and there is an ambition to establish the region as a strong actor in different dimensions of cleantech, and IS is one part of this. Also taking into consideration the ecosystem of the Cleantech Park in Linköping, there seems to be a rich "flora" of businesses in this field. However, as mentioned before, IS has been adopted in some larger, established firms.

The municipality and region seem to have been active in some aspects of developing the IS in Händelö. For instance, the policy position of the municipality and their environmentally motivated actions have been key drivers of IS in Norrköping. The establishment of a district heating system, development of a combined heat and power (CHP) plant and support for the use of waste and biomass as fuels are among such actions. The municipality has also been a key actor in the development of a biogas market in transportation. Furthermore, the business development department of the municipality has been active in persuading firms to locate their plants in Händelö, e.g. it persuaded Lantmännen to locate its "Agroetanol" ethanol plant there, in order to take advantage of the available steam.

But at the same time, there seems to be no real momentum towards developing Händelö from a regional development perspective, or in branding the Händelö

Table 17 *Existing regional instruments in support of CE/green growth in Östergötland*

Instrument	Duration	Type of instrument	Policy priorities/action points	Authority/organization responsible
Regional development programme for Östergötland >2030	2012–	Regional development strategy document	Recommendations and strategies, e.g. "turning Östergötland into a robust and resource-efficient region" and "strategic focus on environmental technology firms"	Östergötland County
Cleantech Östergötland	2008–2013; 2015–	Municipal company until 2013; from 2015, an association supported by municipalities	Supports the development of cleantech companies in Östergötland; closely connected to the development of IS through the creation of networks and interaction	NGO; supported by the two largest municipalities
KLIMP	2002–2012	Economic incentive; investment support	Investments in support of reduced climate impact and energy system transitions	National EPA
"Waste to Energy"	2010–2012	Interreg IVC project	Improving the sustainable management of waste in Europe's regions, and producing energy from waste	County Board

IS as a regional success story. Even though the municipality is part of the IS through its links to waste, water, heat and fuel exchanges, there do not seem to be any long-term development projects that incorporate innovation, entrepreneurship, regional smart specialization, etc. into this IS initiative.

The support from the municipality and regional authorities has not been strong when it comes to financial support for developing a formal cluster around the IS. However, in this case, the firms have been sufficiently strong to invest in and develop their IS activities despite the lack of public assistance. But it is possible that more regional support and formalized cluster coordination could have led to the creation or participation of more small firms and entrepreneurial start-ups, and a stronger research platform supporting IS in Norrköping, with greater inclusion of the universities. This has been the case for the two VINNOVA Vinnväxt projects in Karlstad and Örnsköldsvik, where the triple helix is extremely well developed.

The LIP (Local Investment Programme) and subsequent KLIMP (Climate Investment Programme; see Section 3.8.2), with funding administered by the municipality, were mentioned by respondents as mechanisms that brought the actors together. In this policy area, the municipality worked with the large firms from the IS. These programmes – most recently KLIMP – have been utilized nationwide and seem to have given great support for energy system transitions.

There seems to be some consensus that the work of the regional development actors has not been effective in further developing the promising IS of Händelö. This is illustrated by the quote below (from "Ten challenges for a sustainable Norrköping", Eklund and Gustafsson 2015; translated from Swedish):

"The municipal business development work has mainly been focused on the creation of new businesses, and less on networking and development between existing companies. The municipality has expressed interest in further development of Händelö IS towards green innovation, but they probably don't quite know how it should be done."

Support specifically targeted at the development of IS seems to have been scarce, although support has been available for related areas (e.g. entrepreneurship, sustainable development, research and innovation, etc.). Table 17 lists some of the regional support mechanisms and strategies in Östergötland. Besides these, the general stimuli mentioned in the chapter on national policies and drivers (see Section 3.8) have also played a crucial role in Östergötland (e.g. landfill and waste regulation, etc.).

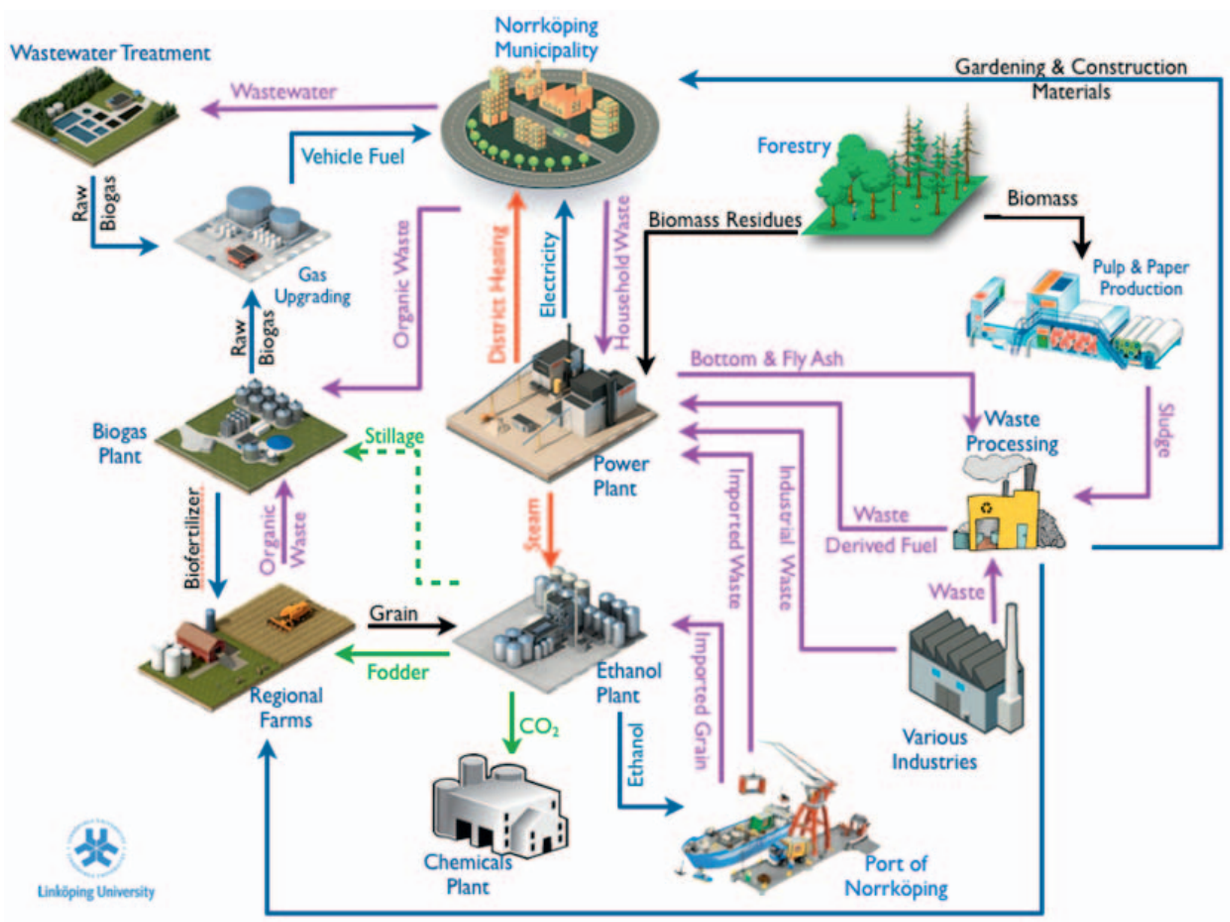
4.5.3 The Händelö/Norrköping region and its industrial symbiosis activities

The history of Händelö business collaborations or IS is centred primarily on the development of the CHP plant, which was sold by the municipality to EON in the early 1990s. The development of this plant has involved a shift from fossil fuels towards primarily renewable resources, and utilization of the waste streams associated with power production. One interviewee pointed out that a CHP plant is not innovative from a Swedish perspective, but in a European context this might still be considered IS. The development of this power plant, and of the Lantmännen Agroetanol plant in 2001, is the strongest evidence of IS. This was most likely when the description of Händelö as an IS started. Together with a biogas plant owned by Svensk Biogas (installed in 2007), these businesses constitute an IS. Lately, other activities have been linked to the IS of Händelö; one of these is a chemical factory (operated by AGA) that is upgrading CO_2 from the ethanol plant. The plant is actually owned by both Agroetanol and AGA and operated through a joint venture business. This is a new "set-up" in this symbiosis network when it comes to organizational structures – previously there have been no such joint ventures.

It is difficult to delimit the geographical boundaries of an IS. In Östergötland, there are many activities linked to Händelö that take place outside its immediate area. Furthermore, the on-site plants utilize scientific processes and innovations developed by their larger parent firms off site. Hence, any attempt to delimit and describe an IS is very difficult.

Outside the immediate geographical region in which there are direct physical symbioses, there are many other firms that could be included in the IS. One of these is Econova, which specializes in processing waste from a multitude of activities and selling this as landfill, soil and transformed plastics. Furthermore, farmers and foresters in the region can be included in the IS: farms, for instance, supply grain and organic waste for ethanol and biogas production, and use fodder and fertilizers in return. The municipality supplies

Figure 6 *The IS in Händelö*



Source: *www.industriellekologi.se*

household waste and waste water, and receives district heating as well as fuel (biogas) for vehicles. The picture below illustrates some of the most important linkages.

Business opportunities seem to have been the driving force behind the development of the Händelö IS, rather than any regional support or development agenda. Access to steam, heat, feed crops, etc. was an important motivation behind the location of the above plants, as well as the proximity to the Norrköping harbour and other infrastructure. However, returns from IS in the form of environmental advantages and improvements in the firms' environmental profiles seem to have been as important as the gains from business opportunities. Both power production and fuel production are activities with great scope to reduce their environmental footprint. Furthermore, having a CHP plant that is primarily fed by waste and biomass provides significant reductions in CO_2 emissions. The CHP plant is able to use waste and biomass, replacing coal or other fossil fuels, which would have been difficult to realize in individual boilers. Additional CO2 reductions are enabled by the production of bio-ethanol and biogas and their use as a transport fuel, replacing diesel and gasoline. The environmental profile of ethanol production benefits substantially from having an outlet for the CO2 (the AGA-operated chemical factory), which means that the comparison with fossil fuels on a life cycle basis becomes more favourable.

The IS in Händelö operates without any formalized cluster co-ordination, and the interaction is primarily on a business-to-business level. This is rather different to some other Nordic IS clusters. Maybe as a consequence, this IS is rather static today. Compared with some other cluster set-ups, the Händelö IS can be seen in simplified form as an interaction between three equally strong firms (EON, Agroetanol and Svensk Biogas) but with obvious links to other regional firms and input streams.

The municipal company "Cleantech Östergötland" operated for some time, but this business focused on much broader aspects of establishing cleantech in the region, and was not responsible for running the Händelö IS. The creation of this company represented an attempt to develop and work with Händelö firms. There is also some perception that the establishment of Cleantech Östergötland may have hampered internal IS development at Händelö, because it led to a perception (perhaps a misperception) that this company would help organize more of the common interaction and activities, and so these may have been neglected somewhat by the private sector actors. It is thus possible that a central actor can actually slow down other forms of interaction and development, when the mandate and ambitions of this actor are unclear.

On the other hand, municipal representatives believe that Cleantech Östergötland was working actively with the firms at Händelö, and that the abolition of this actor is the cause of the slowdown in the future-oriented development of the IS. Their perception is that the new organization, which is now a municipally owned company, can fill many of the gaps when it comes to having a platform for interaction and development at the Händelö IS. And as one interviewee pointed out, further development of the IS as it stands today would require organization and co-ordination at the industrial level and place-specific measures for the Händelö IS. This development would also require consideration of the challenges faced by the actors and their interaction in the long run.

Activities/co-operation

The interaction in this IS seems to be primarily about side-stream utilization. This was described briefly above, and is evident from the schematic figure of the IS network and streams. There seems to be less interaction in the fields of innovation and common research compared with some other places with stronger cluster co-ordination (such as in the SP Processum in Örnsköldsvik).

This was verified by respondents, who stated that there is a long-term commitment when it comes to management and interaction around "streams", but no formal interaction on a day-to-day basis and no interaction in R&D.

Respondents mentioned that a more formalized cluster organization could indeed work on more long-term development topics and research – as well as facilitating links to other activities in the area, such as those at large paper mills (e.g. Holmen, Billerud-Korsnäs).

However, there have been some other forms of collaboration. The Linköping University started a project involving research into biofuels, in which Agroetanol and Svensk Biogas participated. These firms did not seem to have been collaborating on this issue previously, and the project established an arena for such collaboration at least temporarily.

From the narrow perspective of direct job creation at participating sites, it is difficult to argue that substantial new employment is being created from such IS activity. One reason is that much of the IS activity at Händelö today is within the processing industry, and the factories and plants are highly automated. However, from a wider perspective, these activities obviously demand services, transport, infrastructure development, etc. and thus have a multiplier impact on the regional economy. But it is hard to dismiss arguments

that a more integrated IS strategy supporting innovation, the development of small firms, demonstration facilities and so on would stimulate the regional economy further.

4.5.4 Key opportunities and challenges for developing industrial symbiosis

Some challenges relate to the limited resources available. At present, the biogas plant is not operational because it does not receive any deliveries from the ethanol plant. This is due to there being more profitable alternative uses for the residuals from ethanol production, and this is a clear sensitivity in such an IS. The need for sufficient input resources for primary processes and the risk of the emergence of new (potentially competing) markets for residuals are limiting factors in any IS collaboration.

Another very important challenge is uncertainty around the future of renewable energy, such as ethanol and biogas. This is similar to the concerns reported in other places: questions over the long-term stability of these markets and concerns with their current fluctuations hamper investment and long-term capacity build-up.

Some interactions with the local surroundings have acted as limiting, or at least disturbing, factors. Like all such factories, those operating within an IS still sometimes produce odours as well as other unpleasant emissions. There are residential areas rather close to Händelö, which limits current production and could limit the development of new activities in the future, e.g. intensive animal husbandry, more transport, etc.

On the other hand, the fact that there is a high intensity of farming activities in the region acts as a key enabler for some of the synergies. Farms provide inputs to ethanol production and also absorb some products, such as fertilizers.

The business opportunities offered by the Händelö IS seem to be underexploited, both in the proximity of the large plants and in the region in general. This holds for both utilization of waste streams and for possible future R&D activities, and perhaps demonstration facilities. One interesting topic mentioned was "power-to-gas", which is a way to produce gas from electricity (i.e. a way to store electricity in the form of gas). Another natural step would seem to be to increase activities related to biorefineries, although this is somewhat covered already by other large plants, e.g. in Linköping.

One possible future path mentioned in the interviews is to focus on food production and processing. There could be many avenues to follow in this regard, such as greenhouses, aquaculture, animal husbandry utilizing fresh feed, heating for stables, etc. This could be a way to develop Händelö IS in future.

Eklund and Gustafsson (2015) write in their "Ten challenges for a sustainable Norrköping"

Our proposal is to consider and develop Händelöverket area as an eco-industrial park. To strengthen this further, a new organizational structure is necessary that will work on the industrial level. The municipality, the port company and the large companies should take special responsibility to create a forum or arena where common concerns can be addressed. With this as a base, the actors themselves can identify further synergies and develop their businesses. From this base there will likely emerge new businesses and innovations. Some key factors necessary for this to succeed are: i) that there be at least one actor who is prepared to act for the good of the area, and this ought to be the municipality; ii) endurance, as such a process takes time; and iii) external input from academia and international initiatives. In addition, national and international marketing of Händelöverket eco-industrial park as a model for sustainable industry is necessary.

The firms of the IS are doing extensive work to develop new products both from traditional inputs in current use and from waste streams, e.g. new proteins, materials and energy, and as in many other places, new types of feed (such as fish feed) are being explored.

As mentioned above, the development has been rather static lately. One respondent called for more branding (nationally and internationally) so that the firms realize more of the benefits of collaborating, including R&D and test-beds for ideas (e.g. demonstration sites). Demonstration activities are performed within the individual firms today, but could add a vital dimension if scaled up to the IS level. Furthermore, there is a call for more "systems solutions" involving the municipality and county.

Table 18 *Key opportunities and challenges for developing IS in Östergötland*

Key opportunities	+ In the absence of formal co-operation, but nonetheless successful symbiosis, the possible future establishment of a platform for product development, finding new areas of co-operation, etc. appears to be a tremendous opportunity for development + Regional trust in cleantech, recycling and sustainable development provides a favourable environment for developing the symbiosis + Local proximity to large firms in related industries (e.g. paper and pulp) provides opportunities to develop a large cluster comprising bioeconomy firms, refineries and the existing Händelö IS around Norrköping + Interested stakeholders (e.g. universities, Cleantech Östergötland and the municipality) as well as a proven track-record and endurance in developing the symbiosis
Key challenges	– Mobilizing the municipality and county in the development of the symbiosis, possibly in combination with developing new "systems solutions" with the city and municipality in order to take the next step in symbiosis – Finding common ground for developing a platform for co-operation in order to strengthen the symbiosis and include new firms; the fact that the core members of the symbiosis today consist of large (and to some extent global) firms, with their own internal R&D activities, might be a challenge because the mutual benefits might not be as obvious – Sensitivity when it comes to the interaction around waste streams: this is obviously a vulnerability in the symbiosis, as one activity is presently not operational because of a lack of input material

5. Key findings and policy recommendations

In this report, we have attempted to shed light on to what extent and how industrial symbiosis can be a driver of green growth in Nordic regions. The aims of the study were: 1) to provide an overview of i) the potential for growth in industrial symbiosis at the national, regional and local levels, and ii) industrial symbiosis-relevant policies in the different Nordic countries; and 2) to present in-depth regional case studies of industrial symbiosis.

The specific regional cases studied were Kalundborg in the Zealand region, Denmark; Kemi–Tornio region in Lapland, Finland; Svartsengi Resource Park on the Reykjanes Peninsula, Iceland; the Eyde Cluster in the Agder region in Norway; and the Händelö industrial symbiosis in Östergötland county, Sweden.

This aims of the study are consistent with the ambition stated in the 2013–2014 work programme for the Nordic Working Group on Green Growth – Innovation & Entrepreneurship commissioned by the Nordic Council of Ministers, which is "to identify 'good practice' of regional (and local) governance in the Nordic countries to support innovation and entrepreneurship for green growth".

In the context of this report, we understand industrial symbiosis as one approach to realizing a CE and achieving green growth at the inter-firm level. It involves the physical exchange of resources (materials, energy, water and by-products) among a diversified cluster of firms, involving at least three different entities exchanging two or more resources (e.g. by-products) that can be used as substitutes for commercial products or raw materials. Through the symbiotic activities between firms, industrial symbiosis provides many relevant contributions to CE by promoting sustainable resource use, minimizing the input of virgin materials and simultaneously eliminating waste.

In the following, we summarize the key findings, based on the research questions introduced in the introductory chapter.

5.1 The Nordic "big picture": What characterizes industrial symbiosis activities in the Nordic countries?

One of the research questions presented in Chapter 1 relates to the characteristics of CE/industrial symbiosis activities and policies in the different Nordic countries. This section summarizes some of the main trends in the different Nordic countries.

In Finland, there is generally a strong top-down approach to industrial symbiosis, led by the national industrial symbiosis initiative by the Ministry of Trade and Industry, which is supporting the industrial symbiosis development by Sitra (the key national co-ordinator and facilitator of CE and industrial symbiosis) and by Tekes (which provides public funding for the development of CE, cleantech and industrial symbiosis-related activities). In addition, the Finnish Confederation of Industries is a strong actor, as well as the national government programme for 2015 promoting CE.

Similar to Finland, Denmark has a national approach to industrial symbiosis. However, rather than a strong top-down approach, the state-level support programme in Denmark was inspired by the well-known case of Kalundborg. The programme for industrial symbiosis initiated by the Danish Business Authority started as a pilot project involving regional actors. Through the programme, a cross-ministerial task force was established to reduce regulatory barriers by clarifying which regulations and taxes constrain the improvement of the resource efficiency of companies.

The Danish and Finnish approaches have similarities to the UK's NISP by actively facilitating symbioses and co-development, promoting the resource efficiency of different actors within the target regions and serving as an important tool in regional development and the economy. Furthermore, the Danish and Finnish industrial symbiosis programmes bring together regional actors in networks and identify new synergy opportunities. However, one difference is that while the UK's NISP has been criticized for having too strong an environmental focus, the Danish and Finnish programmes

have a stronger focus on business opportunities and supporting industrial symbiosis business models.

Although the CE concept gained more attention after the EC published the paper "Towards a circular economy: A zero waste program for Europe", there are no national support programmes directly related to CE or industrial symbiosis in Norway, Sweden or Iceland. Rather, industrial symbiosis initiatives are often characterized by a bottom-up approach, in which private initiatives and business parks are driving industrial symbiosis development. In Sweden and Norway, industrial symbiosis development has been occurring through business projects, demonstration areas, research projects, etc. for a long time, and industrial symbiosis activities such as energy sharing, resource efficiency improvements, residual management, common R&D by interlinked industries, etc. have been developed in programmes financed by research councils, regional authorities, universities and industry. Sweden has a number of industrial symbiosis networks, but little is known about these; to address this knowledge gap, Linköping University has started to map industrial symbiosis in Sweden. In Norway, there are some well-known examples of industrial symbiosis (e.g. the Borregaard biorefinery), but there is still a long way to go to reach the level of activity and attention that the concept has seen in Denmark and Finland. The lack of interest at the national level in Norway might be partially explained by its strong oil and gas sector and access to vast renewable energy sources for electricity generation. In Iceland, industrial symbiosis activities are driven solely by the private sector, whereas at the national level there is a stronger focus on promoting innovation and cleantech solutions. The government is supporting the growth of innovative companies by allocating competitive funds for R&D activities.

It should also be noted that there are considerable differences within Nordic regions when it comes to adoption of the term "industrial symbiosis". Both Denmark and Finland use the term more frequently than the other Nordic countries. Danish authorities use "green symbiosis" to describe green business models and symbiotic relationships between firms, while in Finland, Sitra has identified the industrial symbiosis sectors in which Finnish companies have the most significant opportunities to provide globally competitive solutions. In Norway, Sweden and Iceland there is, by contrast, no direct use of the term industrial symbiosis at the national level. For instance, in Norway the focus is rather on the "green economy" as a means to support the transition to a low-carbon society. A green economy is also the main concept used at the national level in

Table 19 *Hindrances to the development of IS identified in the Nordic regional case studies*

Category	Sub-category	Hindrances
Economic	Financial	Lack of time and resources to develop IS partnerships, in particular among SMEs Challenges in estimating the impact of IS projects on job creation and CO_2 emissions reductions Lack of local and national support schemes for IS and CE
	Synergy-related	Weak cross-sectoral co-operation
	Market-related	Lack of materials (input resources)
Social	Organizational	Failure to build consensus among the key actors in the area, including the local administration and private companies Involving municipal and regional key players in the development of IS
	Local community-related	Disturbances such as odours and other unpleasant emissions
Information-related		Lack of knowledge about possible side-streams, collaborating partners, etc. Lack of communication within the IS network
Policy-related		Lack of comprehensive public policy support for the implementation of IS activities Regulatory barriers Uncertain regulations and an unstable market for renewable energy, such as ethanol and biogas

Table 20 *Identified drivers for developing IS in the Nordic regional case studies*

Category	Sub-category	Drivers
Economic	Financial	Access to public grants Use of the European Structural and Investment Funds Possibility of economic gains for companies Possibility of product innovation and new business development
	Market-related	Companies promoting their "green profile"
Social	Relational	Human drivers: strong, enthusiastic and committed leaders and visionaries Trust among the companies in the network
	Organizational	Interdisciplinary co-operation enables the development of new businesses and innovative products in IS partnerships Presence of a network facilitator/intermediary Municipal/regional involvement in co-operation with private companies Possibility of applying for counselling on the feasibility of initiating concrete IS exchanges
	Local community-related	Regional trust and a long-term focus on cleantech and sustainable development provide a favourable environment for developing IS
Information-related		Knowledge and training; capacity building and awareness raising; provision of company support and education; investment promotion
Policy-related		Political prioritization of IS at local, regional and national levels Overarching strategy for the development of CE/IS Environmental regulations "Green" criteria for public procurement

Iceland. Industries in Iceland, however, have adopted the resource park concept, which is based on industrial ecology principles. Besides the environmental focus, the resource park philosophy has strong economic and social dimensions, and promotes the interdisciplinary co-operation of different entities and business models.

5.1.1 Enabling and hindering factors for developing industrial symbiosis and circular economy in Nordic regions

A broader theoretical discussion on enabling and hindering factors for developing industrial symbiosis was presented in Section 2.2. This section focuses on the major hindrances and drivers in the development of industrial symbiosis identified in the Nordic regional case studies.

Economic hindrances to industrial symbiosis development identified in the Nordic regional case studies are primarily related to a lack of time and resources to implement new business models such as industrial symbiosis. This is particularly true in the case of SMEs.

In the policy field, one important hindrance is the lack of a comprehensive and coherent strategy with binding objectives for CE or industrial symbiosis. A general observation is that there is a clear difference in how far the different Nordic countries have progressed with regard to developing strategies for CE/industrial symbiosis, with Denmark and Finland as clear forerunners in this context. In both Denmark and Finland, such strategies have been clearly defined and marketed. These are accompanied by policies, networks, activities, information, network platforms, etc. However, in Sweden, Norway and Iceland, the lack of such strategies is a barrier. In addition, unstable markets for biogas and ethanol and uncertainties regarding the future framework for renewable energy hamper investment, and are limiting factors for industrial symbiosis partnerships.

When it comes to information-related barriers, a lack of knowledge about the opportunities for symbiosis development can hinder new collaborations. In addition to the role of cluster organizations and networks, communication and co-ordination initiatives at the national level can play an important role in creating awareness about potential partner companies (e.g. Denmark and Finland).

If we look at the drivers of industrial symbiosis development in the Nordic countries, it is evident that a key motivation for companies to engage in indus-

trial symbiosis activities is the possibility of economic gains, e.g. through reduced emissions. For instance, Kalundborg Symbiosis is an example of self-organized industrial symbiosis emergence, initiated in the private sector mainly to achieve cost reductions. A similar driver is found in the Eyde Cluster in Norway and Händelö industrial symbiosis in Sweden, where companies engage in symbiotic exchanges in order to reduce costs, and in the former case also to comply with the strict environmental standards imposed by their international investors. This implies that the exchanges emerged from the market rather than direct government policy or involvement.

An additional benefit for companies is that industrial symbiosis strengthens their environmental profiles, which can increase their competitive advantage. However, there is further potential to encourage such engagement, for instance through green public procurement or taxes related to emissions. Environmental regulations also play a crucial role in the transition towards resource efficiency and the reuse of materials and waste. For example, in Sweden, landfill tax regulations contribute by making waste available for energy recovery, and energy and CO2 taxation policies have supported increased updating and uptake of more energy-efficient solutions – such as district heating (using CHP plants) or other by-product heat utilization solutions – as well as increased use of renewable fuel alternatives.

In Denmark, the proactive approach of the task force, i.e. offering free resource checks to companies, has been a significant driver in terms of creating an interest among companies in the concept of industrial symbiosis. In Iceland, the presence of an enthusiastic and committed private sector visionary has been an important precondition for the development of the symbiotic collaboration at Svartsengi Resource Park. Moreover, because of a high level of trust between the companies in the park, it has been possible to manage this industrial symbiosis network informally, without an official network co-ordinator.

Another key driver is the presence of a co-ordinating body such as a formal cluster organization to catalyse the industrial symbiosis activities, help organize the exchanges across companies and facilitate collaboration. In Kalundborg in Denmark, the Kemi–Tornio region in Finland and the Eyde Cluster in Norway, the presence of clusters or networks to ensure the co-ordinated organization of pilot projects and give other types of support has been decisive for the development of industrial symbiosis activities.

Another driving force has been the possibility for companies to apply for a grant for an external consultant to assess the feasibility of potential symbiosis projects (e.g. the Kalundborg industrial symbiosis). In Sweden, VINNOVA is a strong partner because of the promotion of long-term funding for projects, e.g. through the Vinnväxt programme. The European Structural and Investment Funds have been used in the Finnish and Danish case study regions for promoting industrial symbiosis projects.

Local and regional authorities can support and facilitate the development of industrial symbiosis, for instance by developing networks/clusters based on local and regional strengths and helping to identify industrial symbiosis exchanges for which there is a good business case. Partnership between private companies and the public sector has been crucial in facilitating the emergence of industrial symbiosis exchanges in the Danish and Finnish case studies.

5.2 Main findings from the case studies – actors, policy instruments and potential for future growth

Our case study analysis provides interesting insights into how regions can be drivers for industrial symbiosis activities. The findings can shed light on the following questions presented in Chapter 1. Who are the main actors driving/supporting industrial symbiosis development at the regional/local level? What type of regional/local policy instruments are in place to stimulate industrial symbiosis activities? And what is the potential for new businesses and jobs to arise from industrial symbiosis in the regions studied? In the following subsection, we present the main case study findings related to these questions.

5.2.1 Actors driving/supporting industrial symbiosis development at the regional/local level

In the Finnish case study (the Kemi–Tornio region), the key actors supporting industrial symbiosis development at the regional level are a combination of key private companies and the regional development company, which is municipally owned.

In the Agder region in Norway, private firms are driving the industrial symbiosis projects, but with strong involvement from the regional cluster organisation, which is funded partly by the companies and partly by the municipality/region, as well as through the national Arena programme. Concrete industrial symbiosis projects have also been funded through national-level grants.

In the Swedish case study (Händelö, Östergötland),

it is mainly private firms that support the industrial symbiosis activities. There seems to be no real momentum to work on developing Händelö from a regional development perspective, and the support from the municipality and regional authorities has been weak when it comes to financial support for developing a cluster around the industrial symbiosis. But in this case, the firms have been strong and active enough to invest in and develop their activities despite this lack of support. Linköping University has strong interest and expertise in industrial symbiosis, and is developing a platform for industrial symbiosis in Sweden, so some of the support/push comes from the academic sector as well.

In the Icelandic case, there is also strong privately driven industrial symbiosis development, with non-financial and "emotional" support from the local authorities. The local authorities and private businesses share a common vision for the development of the area. There are thus synchronized activities and a consensus on the development priorities among the key actors, including the municipalities, infrastructure companies and power companies.

In the Danish case study (Kalundborg industrial symbiosis), the industrial symbiosis information centre in Kalundborg is now integrated in the municipal development department. It runs development projects and a visitor centre. Industrial symbiosis is also highly prioritized by the regional council, which has provided some grants in recent years. The Kalundborg industrial symbiosis was initially a private initiative, but over the years it has developed into a close collaboration between companies and public authorities in Kalundborg municipality.

5.2.2 Types of regional/local policy instruments in place to stimulate industrial symbiosis activities

In both the Finnish and Danish case study regions, structural funds are frequently used for promoting industrial symbiosis projects, mapping side-streams, etc. In the case of Kalundborg, projects supported by the European Structural and Investment Funds – the ERDF and ESF programmes – are important instruments in implementing regional and local strategies, and the 2007–2013 ERDF programme for Lapland has been the key operational programme in regional development in recent years. In Kalundborg, the regional development strategy focuses on industrial symbiosis and the provision of direct support to industrial symbiosis projects, and this influences the way structural funds are spent in the region. At the local level, the Symbiosis Center Denmark is working on industrial symbiosis education, involving other municipalities and providing training. The centre is also raising awareness about industrial symbiosis opportunities, and is transferring knowledge and experience to other municipalities in Denmark.

In the Swedish, Norwegian and Icelandic case study regions, there are no local policy instruments that directly support CE/industrial symbiosis, and these activities are not explicitly a part of the regional and municipal development strategies. However, the issues of sustainability, renewable energy, biorefineries and smart specialization in cleantech are visible. The municipality and region seem to have been active in some respects in developing the industrial symbiosis in Händelö, e.g. through environmentally motivated actions such as the establishment of a district heating system and a CHP plant, and supporting the use of waste and biomass as fuels. In the Agder region in Norway, there is also strong support for a green economy/sustainability, and climate considerations are a key priority in all political decisions at both the regional and local levels. The strong focus on renewable energy, which involves the development of a sustainable processing industry, can be seen to indirectly support initiatives such as industrial symbiosis projects. In the Icelandic case study, it is also evident that there is no specific focus on industrial symbiosis; however, in a broader sense there is some support for entrepreneurship development, particularly in the field of green growth and resource efficiency. For instance, in Grindavík the local administration prioritizes the development of small-scale activities and projects that are in accordance with the Resource Park philosophy.

In the Danish and Finnish case study regions, the support system is more advanced when it comes to directly promoting industrial symbiosis activities. In the Danish case, this is strongly linked to the longstanding position of Kalundborg industrial symbiosis in the region, and the fact that industrial symbiosis is on the national-level policy agenda as well. In the Finnish case, the regional development company has taken the role of promoting and co-ordinating industrial symbiosis activities. In Norway, Sweden and Iceland, however, there is clearly a lack of CE/industrial symbiosis thinking from the regional/local governments.

5.2.3 Potential for new businesses and jobs to arise from industrial symbiosis

An important question relates to the potential for new businesses and jobs to arise from industrial symbiosis activities. However, in most of the case studies, exact numbers have been difficult to obtain.

In the case of Agder, Norway, it has been argued that industrial symbiosis contributes to retaining jobs and

business activities in the region by helping companies become more resource efficient. The focus is on CO2 and cost savings that help companies remain competitive in the global market. However, there is no doubt that there is potential for new types of activities to arise from industrial symbiosis, especially in relation to new value chains linked to the regional forestry industry.

In the case of Kalundborg, Denmark, attracting and retaining recent graduates and high-level academic personnel has been identified as a general challenge. From the perspective of maintaining jobs, the partnership between the municipality and the industrial symbiosis network has been significant. Regarding future potential, there are opportunities for private consultancies in technical and green business fields to service the industrial symbiosis in Kalundborg.

In Finland, the current estimate for annual industrial symbiosis activities in the Kemi–Tornio region is 200 million EUR. According to the present analysis, the future business potential of industrial symbiosis in the Kemi–Tornio region lies mainly in the symbiotic exchanges of side-streams and waste streams, recovery of materials, innovations related to drying and excess heat utilization, and increased brokerage of side-streams and waste streams.

The Resource Park in Iceland is continuously investigating opportunities for the expansion of industrial symbiosis activities, for instance by approaching companies with business ideas that align with the Resource Park concept. Moreover, the Resource Park invests over 4 million USD annually in interdisciplinary R&D. The Resource Park is currently working on developing new niche businesses in the fields of algae production, fish farming, sustainable fish feed production and enzymes production. In addition, an extension of the Blue Lagoon facilities is under development, which is expected to create many new jobs. Attracting investors is seen as a challenge in the case of the Resource Park.

In the Swedish case study region, one future potential of industrial symbiosis activities lies in knowledge-intensive activities related closely to the current activities of actors at the site; more specifically, research on new product development in fields related to biorefinery activities, and a shift in focus from working with "core" products to new products and solutions that can be used elsewhere (globally). This is one way in which closer collaboration between actors at the site could be beneficial. A challenge identified in the Swedish case study is that industrial symbiosis activities are presently rather static, and thus not many new jobs have been created. In order to attract new businesses and create more dynamic development, there is a need for regional support for cluster development. In relation to ending the development paralysis, some "less traditional" ideas have been mentioned, e.g. utilizing waste heat for agriculture or horticulture. Regardless of the path chosen, it is clear that in order to utilize the full dynamic and regional potential of industrial symbiosis, a common vision and roadmap will need to be developed.

5.3 Policy recommendations – how to support industrial symbiosis development in Nordic regions

Based on our analysis, some policy recommendations regarding industrial symbiosis as a key driver for green growth in Nordic regions can be given.

- In order to utilize the full dynamic and regional potential of industrial symbiosis, there is a need for a long-term public support framework for CE and industrial symbiosis, including comprehensive and coherent strategies and binding objectives.
- Development companies, regional clusters or similar organizations can play an important role in facilitating and promoting industrial symbiosis in Nordic regions. They can support industrial symbiosis activities by helping companies identify relevant partners for collaborations and new synergy opportunities, as well as developing business plans.
- Local and regional authorities can and should support and facilitate the development of industrial symbiosis, for instance by promoting the development of networks/clusters based on local and regional strengths and helping to identify industrial symbiosis exchanges for which there is a good business case.
- Industrial symbiosis development should be based on private sector needs and actual demand for relevant inputs (i.e. the resources nominated for exchange) in the industries involved. Business opportunities should be the driving force behind the development of industrial symbiosis, meaning that it is essential that companies can achieve economic gains from industrial symbiosis activities. From this base, there will likely emerge new businesses and innovations.
- The European Structural and Investment Funds provide good opportunities to apply for industrial symbiosis projects focused on resource efficiency and innovation, and could be more widely used to support industrial symbiosis activities in Nordic regions.
- The leading cases of industrial symbiosis show that both individual companies and regional clusters can play an important role in facilitating industrial symbiosis development. An example of a good practice that could be transferred to other Nordic regions is the

mapping of industrial side-streams in the Kemi–Tornio region in 2014. The mapping included documentation of relevant side-streams (including their chemical and physical properties and utilization grade, and studies on the related markets, technology and logistics). A total of more than 1.3 million tonnes annually of by-products and waste streams were identified. In Denmark, the proactive approach of the task force, offering free resource checks to companies, has been a significant driver in terms of generating an interest in industrial symbiosis among companies.

- The industrial symbiosis concept and designation are insufficiently familiar in Nordic regions, although examples of industrial symbiosis-like phenomena can clearly be found (albeit often under other names). There is a need for further clarification and for raising awareness of the industrial symbiosis concept in the Nordic countries. In this regard, it is crucial to overcome information-related barriers. Thus, dissemination of knowledge about the opportunities related to industrial symbiosis development is extremely important.

Although an attempt has been made to highlight some successful industrial symbiosis initiatives in Nordic regions, there is still a long way to go when it comes to mapping the current industrial symbiosis activities. Key challenges are thus to obtain an overview of what is really going on in the Nordic countries and different regions within them, as well as to further assess the types of support that the private sector needs and to transfer knowledge from successful industrial symbiosis cases, in order to expand the number of industrial symbiosis activities.

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Footnotes:
1 The type of region classification is based on the ESPON typology for NUTS-3 regions. Typology data: Linus Rispling, Nordregio.

2 Saved CO_2 includes savings from the switch to biofuels from biochar and coke production. Around 60% of the saved CO_2 comes from the switch to biochar/coke in metal production, while the rest comes from the switch to biogas/bio-oil.

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