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FRAMEWORK CONDITIONS AND POLICY RECOMMENDATIONS FOR INDUSTRIAL SYMBIOSIS

Framework conditions and policy recommendations for industrial symbiosis

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Abstract

This report provides policy recommendations for the development of industrial symbiosis in European regions. Industrial symbiosis is a process in which industrial biproducts, such as excess energy, are utilized by surrounding actors. The focus of this report is on a specific type of industrial symbioses, namely the process of excess heat/cold recovery and utilization called 'energy cascade'. The foundation for the recommendations is a study of five European industrial regions: Agder (Norway), Barcelona (Spain), Humber (UK), Dunkirk (France), and Brunsbüttel (Germany). The regions were studied through interviews and document analysis and analysed according to a framework based on a theory on industrial symbiosis, innovation, and industrial development. The analysis identifies several factors that enable or hinder the development of industrial symbiosis, including a need for a facilitating and coordinating actor in each region and the clarification and integration of industrial symbiosis in the regulatory framework. The policy recommendations involve forging links between entities on the production side with those on the market side through a facilitating and coordinating actor on the ground, as well as opening for policy experimentation through financial stimulus and experimentation clauses across levels of governance, such as in regulatory sandboxes.

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Introduction

Our societies confront grand challenges such as climate change, ageing populations, and persistent, and in some places growing, social inequalities. In this situation, innovation policy that not only promotes technological innovation and economic competitiveness but also enhances capacities to tackle such societal challenges are required. Thus, there is increasing interest in mission-oriented, challenge-driven, and transformative innovation policies (Mazzucato, 2018; Schot & Steinmueller, 2018). Rather than aiming purely at economic growth, the focus of these policies is on tackling grand societal challenges through wide-ranging transformation of production, innovation, and consumption systems.

Societal challenges have led to calls for broad socio-technical (and sustainable) transitions. Such transitions are conceptualized as shifts from present socio-technical regimes towards emerging and often more sustainable alternatives. The transitions include long-term, multi-dimensional, and fundamental transformations of large socio-technical systems (e.g., in energy and transport) towards more environmentally sustainable modes of production and consumption (Markard et al., 2012). Transitions are set in 'a wider field of social, institutional and economic change' (Coenen et al., 2021, p. 2020). They often build on technological innovations but are affected by the agency of multi-level actors and by knowledge and institutional contexts.

While mission-oriented policy and technological innovations to tackle grand societal challenges are often linked to large industrial sectors (energy, mobility, food), this report examines the confined but still important case of industrial symbiosis: how excess energy can be utilized locally by other firms and organizations. The report presents aspects of the development of industrial symbiosis in five very different European regions: Agder (Norway), Barcelona (Spain), Brunsbüttel (Germany), Dunkirk (France), and Humber (UK).

In industrial symbiosis, it is essential to explore the institutional framework and changes in it, as institutions promote or inhibit industrial symbiosis in different ways in the five case regions. In addition, the agency of actors becomes important for the success of industrial symbiosis.

This report presents a theoretically based analysis of key aspects of the development and implementation of industrial symbiosis, complemented with practitioner-based interviews from the five regions and extracts key lessons for policy promoting industrial symbiosis at the regional level. The research questions for the study reported here were as follows:

- What are important institutional drivers and barriers for the development of industrial symbiosis in the five regions?
- What type of actors and agency stimulates and hampers industrial symbiosis in the regions?
- What policy lessons can be learned from the study of industrial symbiosis in the regions?

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The next part of the report presents the analytical framework used in analysing industrial symbiosis at the regional level. Descriptions of key information about industrial symbiosis in the regions follow before a summary analysis and extraction of general policy lessons.

Chapter 1 Theoretical approaches to energy efficiency through industrial symbiosis

The theoretical framework provides the basis for analysis (chapter 3) and policy recommendations (chapter 4). This chapter provides a theoretical foundation for factors and dynamics that need to be in place for the development of industrial symbiosis and energy efficiency.
Section 1.1 defines the need for industrial symbiosis alongside related theoretical terms. Section 1.2 provides theoretical clarification on the types of actors and actions needed to promote and develop industrial symbiosis.
Section 1.3 reviews research on stimulating and hampering conditions for industrial symbiosis, as well as illustrates the overall theoretical framework for the report.

1.1 Industrial symbiosis and energy cascade

During the last 50 years, global energy consumption has more than doubled as a result of a growing population and increased energy consumption per capita; it is expected to increase in the future (Ganivet, 2020; Smil, 2016). With the greater part of energy produced by fossil fuels, states find themselves with an amplified challenge to produce and distribute enough energy while doing so in a sustainable way and cutting emissions. However, this energy transition requires change not only in how energy is produced but also in how energy is utilized (for greater energy efficiency). Societies overall need to streamline energy utilization beyond just individual organizations and towards increased holistic utilization of energy at the societal level.

The last few decades have seen increased interest in the concept of industrial symbiosis and how it influences the economy, society, and the environment (Branca et al., 2021). The term “symbiosis” recalls symbiotic relationships in nature, where unrelated species exchange information, material, or energy (Chertow, 2000). Likewise, industrial symbiosis involves place-based exchanges of material and immaterial assets between different entities. It is now recognized as an inevitable strategy to support transitions toward a more circular economy (Fraccascia et al., 2020). At the European level, this has been recognised through increased funding and the concept of Hubs4Circularity[1] in the Process4Planet partnership[2] as well as the Circular Cities and Regions Initiative[3].

[1] https://www.h4c-community.eu

[2] https://www.aspire2050.eu/p4planet/about-p4planet

[3] https://circular-cities-and-regions.ec.europa.eu

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Coenen et al. (2021) argue that energy transition (from fossil-based to renewal energy) and related system changes should not be separated from regional contexts and that "a place-based perspective is critical to understand the multifaceted nature of contemporary energy transitions (and instrumental to the development of effective policies)" (2021, p. 220). Despite not being recognised as the main item in specific energy transitions, energy symbiosis potential is significant (279TWh ref. Bianchi et al. 2019) and could complement and support such transitions by focusing on energy collaboration and increased efficiency. This will reduce the need to develop new primary energy sources. As processes concerning symbiosis largely build on the utilization of resources found in a geographically restricted area (e.g. excess energy in different forms, physical infrastructure, and regional knowledge and competence), a place-based perspective is appropriate for understanding it.

This report is focused on a specific type of industrial symbioses, namely excess energy (heat/cold) recovery. The development of such symbiosis can take place and demand coherent policy at different levels – global, national, and regional levels, as well as at the interfirm level and in individual facilities (Jacobsen, 2008). In this study, we targeted the regional and interfirm levels, where opportunities for energy cascade can be divided into two: the business-to-business mode (B2B), where excess heat or cold is utilized by firms other than the energy-producing firm, and district heating and cooling (DHC), where excess heat is transported into urban areas.

1.2 Key actors and agency: Place-based leadership and change agency

The development of industrial symbiosis demands changes at different organizational, intra-organizational, geographical, and institutional levels, which can be promoted through deliberate actions by actors. Deliberate actions promoting change are referred to as 'change agency'. Grillitsch and Sotarauta (2020) have identified three types of change agency that, together and separately, contribute to regional development and transition: Schumpetarian innovative entrepreneurship, institutional entrepreneurship, and place-based leadership. All three are essential for the development of industrial symbiosis.

According to Grillitsch and Sotarauta, place-based leadership entails "(a) launching and guiding interactive development work that crosses the many organizational boundaries and professional cultures, and (b) guaranteeing the versatile engagement of various stakeholder groups and helping them to contribute to and take advantage of development processes and their fruits" (p. 213; see also Collinge & Gibney, 2015; Gibney et al., 2009). Place-based leadership should look beyond both the interests of individual actors and the short term. Hence, place-based leaders are interested in mobilizing actors and coordinating their actions beyond their own self-interest in order to stimulate the development of a specific area or industrial sector. In the context of industrial symbiosis, place-based leadership can promote and facilitate cooperation and the exchange of excess heat/cold among local actors.

As the market side in industrial symbiosis processes is often unknown, innovative entrepreneurship by private firms, public bodies and network organizations is important to recognize and act on hidden business opportunities. Such entrepreneurship can be either enabled or constrained by institutional influences, making institutional entrepreneurship important. Institutions can be divided into formal institutions including rules, laws, and regulations on the one hand, and informal institutions such as norms, values, and culture on the other. Institutional entrepreneurs can be

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individuals, groups of individuals, or organizations that initiate processes of change that contribute to the creation of new institutions and/or the transformation of existing ones (Battilana et al., 2009).

In short, innovative entrepreneurs find and take opportunities for industrial symbiosis, while place-based leaders coordinate the actions of innovative entrepreneurs and institutional entrepreneurs create stimulating framework conditions for industrial symbiosis.

1.3 Stimulating and hampering conditions for industrial symbiosis

Given the many levels at which change needs to happen for its development, there are various preconditions that can stimulate (or hamper) industrial symbiosis. In a vast literature review, Fraccascia et al. (2020) recognized four forms of drivers, barriers, and enablers (DBAs) for increased use of excess energy: (i) financial, (ii) technological, (iii) regulatory, and (iv) institutional. Financial DBAs are connected to monetary investments and benefits related to industrial symbiosis synergies, while technological DBAs involve technical conditions influencing the implementation of such synergies. Regulatory DBAs are concerned with binding or stimulating legislation for the development of industrial symbiosis, which may or may not already be in place. Finally, institutional DBAs revolve around the (informal) institutional framework in which the industry is embedded, that is, the organizational structures of the firms involved, their business models, and their strategic behaviour concerning the implementation of industrial symbiosis.

In our framework, illustrated in Figure 1, the first two DBAs relate to vital resources needed to accomplish a successful symbiosis, such as finance, knowledge, and competence. To forge connections between the energy-producing side and the market side, place-based leadership needs to be present because this type of leadership has the role of pooling and coordinating the necessary resources that enable symbiosis. Regulatory and institutional DBAs are institutions; formal institutions constitute the regulatory framework which the development of symbiosis needs to navigate, while informal institutions are important as they set “the rules of the game” regarding, amongst others, a culture of collaboration, which is inevitable in industrial symbiosis.

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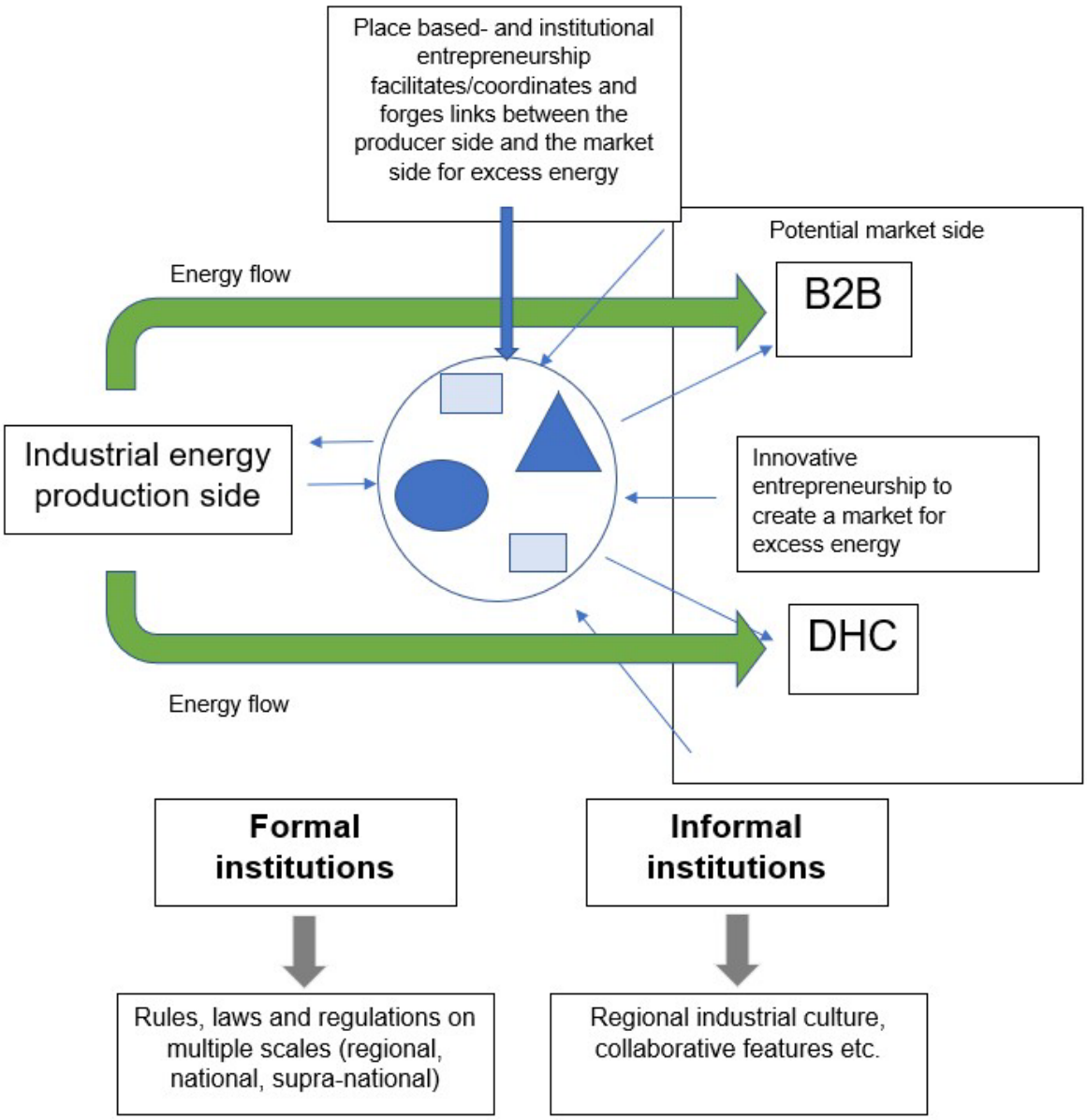
Figure 1: Illustration of processes and agency that support the development of industrial symbiosis.



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Chapter 2 Industrial symbiosis in European regions

The authors conducted document analysis of reports and articles. Another main source of information was interviews. Between November 2022 and February 2023, we conducted online interviews with respondents from of Dunkirk, Brunsbüttel, and Barcelona and face-to-face interviews in Agder. The reports included the INCUBIS D1.1 report "Gaps and needs analysis of regional ecosystems" and other documents (e.g., other INCUBIS reports, public records). The report was completed March 15, 2023. Any ongoing processes or forthcoming reports and policies in the regions after this date are not included in the data employed. The following sections provide descriptions of the five case regions.

2.1 Agder region, Norway

General description

The Agder region is located in the south of Norway. It has a population of approximately 300,000 spreads over 16,000 km^2. One third of the population lives in or near the city of Kristiansand. The area has a strong presence of resource-intensive process industry due to its proximity to the rest of Europe and the historical availability of electric power, especially hydropower. These industries are not clustered together through industry parks but distributed across the region, typically somewhat isolated without direct symbiosis opportunities surrounding them. In addition, the region has fostered strong sectors in wood-based industries, suppliers to the oil and gas sector, and tourism.

Drivers and barriers in industrial symbiosis

Industrial symbiosis projects exploiting excess heat in this region would be useful for production that requires relatively low temperatures year-round, like fish farming and food production in greenhouses. Further, several areas are in the process of being regulated for industrial development, especially around the planned giga battery factory (Morrow). Here, it will be possible to plan and build fully functioning industrial symbiosis parks. Several actors in Agder have acted to establish industrial symbiosis in the region. For example, a large process manufacturer (Glencore) and a waste incineration plant (Returkraft) deliver DHC to Kristiansand municipality in cooperation with the regional energy distributor (Å Energi). Interest in energy symbiosis is present, as are established forums for cooperation on regional energy symbiosis.

Industrial symbioses have until recently not been widespread in the region. Parts of Agder have established district heating infrastructure, particularly in Kristiansand, but there is still an unexploited overcapacity of heat (approx. 2 Twh). Agder has separate industrial sites for large process manufacturers, and the development of industrial symbioses will require new businesses able to utilize excess heat. One major barrier concerning industrial symbiosis around already existing industries is the lack of space and regulated areas for building new facilities. Another barrier is the lack of users and links between them within proximity of suppliers.

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Actors and agency

An industrial cluster (Eyde) consisting of a core of process industries mainly from the Non-ferrous metals sector, has been a driving force for industrial symbiosis in Agder since 2016. One of their projects involved collecting information on firms' side streams and making a heat roadmap. Through a collaboration with Agder County, they have included information on excess heat into the county's map over available industrial sites in the region, published on the county's official website.

As part of their circular economy strategy, Agder County has taken a pro-active role alongside the Eyde cluster and established a public–private cooperation network called 'Agder Symbiose' (Agder Symbiosis) to facilitate the establishment of new industrial symbiosis projects in the region. Agder Symbiose consists of representatives from Agder County, the two biggest municipalities in the region, the region's university, the Eyde clusterand other regional industrial partners. However, the network is in its early development and is particularly concerned with the dissemination of information about industrial symbiosis, mobilizing activities and the financing of collaborative firm-level projects through a small -yet- dedicated regional fund.

Formal and informal institutions

Policies at regional (Regionplan Agder 2030[4]), national (National Strategy for Developing a Green Circular Economy[5]), and European (The European Green Deal[6]) levels promote the development of sustainable solutions, including energy efficiency. However, there have until recently been no policies specifically stimulating the development of industrial symbiosis. On 1 February 2023, a government-appointed energy commission published a report assessing present and future energy needs that urged increased exploitation of excess heat in Norway.

The trust level in Agder is described as generally high, and many companies are actively involved in networks and collaborations to share knowledge and reduce risk, which indicates a strong culture for cooperation. The process industries have collaborated since 2007 through the Eyde cluster.

2.2 Barcelona region, Spain

General description

The Barcelona region is located in the territory of Catalonia in the north-eastern corner of Spain. Barcelona is the capital of Catalonia (32,108 km^2) and the heart of a metropolitan region covering an area close to 2,500 km^2 holding nearly 5,000,000 inhabitants. Its location on the Mediterranean and the transport infrastructure have given the region a top-ranking strategic position and made it a meeting point for trade and international business.

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[4] https://agderfk.no/vare-tjenester/regionplan-agder-2030/regionplan-agder-2030-les-planen/

[5] https://www.regjeringen.no/contentassets/a116f209e493471bb26c81cf645152a3/kld_strategi_sirkularokonomi_sammendrag_eng_0507.pdf

[6] https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en

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Drivers and barriers in industrial symbiosis

Several energy symbioses exist in the Barcelona region, both B2B and DHC. The biggest driver for industrial symbiosis seems to be improving indicators for sustainability alongside energy efficiency. In light of dramatically increased energy prices from 2021 onwards, the latter has received increased interest among firms. There are several consulting firms working proactively with the industry to find solutions accomplishing industrial symbiosis (though they are not working in identical fields).

Lack of financial investment and data on the quality and quantity of excess heat constitute challenges for B2B symbiosis. There is a need for stronger incentives in the form of monetary means for regional industry to be willing to try new solutions and projects. Still, the main barrier is described as a lack of trust between companies. This is described as a cultural barrier where users don't trust the efficiency of the governance system or are worried there will be too many issues (lack of knowledge).

Actors and agency

A mix of stakeholders, including national and regional authorities, a research institute, an industrial association, and an energy cluster, have been emphasized as important supporters for new industrial symbiosis projects in the region. Still, new solutions for industrial symbiosis seem to be dependent on 'third linked parties' such as consulting firms to navigate middle ground and stimulate increased cooperation in the region.

Formal and informal institutions

2018 is described as marking a shift in sustainable regulations, and numerous regulations have since been developed to promote efficient use of energy resources. However, few regulations have targeted the reuse and recovery of thermal energy and distribution networks.

The collaboration culture in Barcelona is described by interviewees and the D.1. report as weak and/or absent with low levels of trust. Cultural issues are described as the main obstacles for industrial symbiosis, appearing especially in a lack of political will.

2.3 Humber region, UK

General description

The Humber region is located in the north of England. It has one of the largest harbour complexes in the UK. The region hosts a diverse set of energy-intensive industries, from the processing of metals, chemicals, and food to oil and gas and energy production, which are spread across an estuary and three ports. Humber is the UK's highest CO_2 emitting industrial area, with regional emissions per capita twice the national average.

Drivers and barriers in industrial symbiosis

Several symbiosis and synergy projects are planned in Humber. Cost savings and environmental commitments are considered the main drivers for industrial symbiosis, as is the great potential of unexploited excess heat.

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One barrier to industrial symbiosis is uncertainty regarding national policy, which limits long-term planning and investment and raises risk. Lack of metering at industrial sites prevents potential energy efficiencies from being discovered and utilized. However, the biggest issues seem to be a lack of facilitators, risk, and legal aspects related to the operation of a plant converting excess heat into electricity.

Actors and agency

Companies in the region have made large investments in manufacturing infrastructure, research centres, and the renewable energy sector. Regional companies have also increased investments in energy efficiency and industrial symbiosis networks; an Energy Savings Opportunity Scheme audit identified a number of opportunities for energy savings and symbiosis. Companies in the region, however, express the need for a third party to run these investments and operations.

Formal and informal institutions

Industrial symbiosis has no regulations or guidelines at either the regional or the national level but is impacted by the legal framework on energy efficiency and decarbonization. There are several programmes and support mechanisms working to build strategies on industrial symbioses, one being the Local Enterprise Partnership, which has a mandate to coordinate with the region's local authorities to find a standardized approach to local planning related to industrial symbiosis.

2.4 Dunkirk region, France

General description

The industrial port region of Dunkirk is located in northern France, close to the border of Belgium and to Great Britain. The region is made up of 21 municipalities over an area of 250 km^2 and has a population of about 200,000 inhabitants. Dunkirk Port is France's third-largest port and home to several heavy manufacturing industries, including steel and aluminium production, and, more recently, pharmaceuticals and cans for beverages.

Drivers and barriers in industrial symbiosis

Several industrial symbioses exist in Dunkirk and include both DHC networks and B2B opportunities. While the sustainability aspect is not considered the main driver behind industrial symbiosis, air quality is a priority (and concern). Thus, the reduction of greenhouse gases is essential in the region, making market pressure and image-building contributing drivers. Still, the economic factor appears to be the main driver of industrial symbioses, to benefit from fiscal advantages and to reduce energy costs.

Companies lack in-house expertise concerning industrial symbioses, and they do not have the time to investigate such projects. Smaller companies are struggling with the implementation of B2B, as they do not see business opportunities connected to it. They need support to understand the benefits and opportunities of industrial symbiosis. For several B2B opportunities, location is considered a barrier. Further, financing and contractual aspects of business models seem to be a barrier, as even when symbiosis projects are feasible technically, the optimal contractual model is

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challenging to determine (i.e., who pays for the infrastructure, what happens if the producing company runs out of business, etc.).

Actors and agency

An innovation park, 'Euraenergie', has been set up to support the transformation of the Dunkirk region in the fields of energy transition and circular economy, and the mayor in Dunkirk is described as "proactive" in industrial symbiosis. Still, there is a lack of stakeholder management, and communication between firms, authorities, and the innovation park is inefficient because of a lack of staff.

Formal and informal institutions

Industrial symbiosis is not yet regulated but is impacted by the legal framework for waste, water, and energy. This framework is considered a driver for industrial symbiosis, but there still exist conflicts between policy at the regional level and rules and regulations at the national level. Thus, there is a need for coherence between regional policies and national laws and regulations.

The collaboration culture among industry in Dunkirk is described as strong and characterized by high levels of trust.

2.5 Brunsbüttel region, Germany

General description

The Covestro Industrial Park Brunsbüttel is located in the state of Schleswig-Holstein in Germany, directly on the world's busiest artificial waterway, the Kiel Canal. The region holds over 12,500 jobs and constitutes the largest and most important industrial area in the state. With close access to a deep-sea port on the Elbe and only a few nautical miles from the second-largest seaport in Europe, the region has direct access to the world market. Chemical industry, oil and gas, and renewable energy are important industries in Brunsbüttel.

Drivers and barriers in industrial symbiosis

Industrial symbiosis in the Covestro Industrial Park involves both district heating and B2B. One important driver for industrial symbioses is the internal focus in and amongst companies and their need to optimize processes and reduce cost and waste. Another important and external driver for industrial symbiosis is a new law on energy efficiency that obliges companies to share information on excess heat. Infrastructural integration of (industrial) waste disposal in the electrical network can significantly improve energy efficiency. Companies also express a wish to utilize more of their excess heat.

The infrastructure between the companies is mainly one-directional, meaning that greater utilization requires upgrading and expanding infrastructure, which comes with great costs and is considered a barrier. The greatest barrier, however, is considered the long case-processing time for authorizations.

Actors and agency

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Being owner of the industrial park, Covestro has led in facilitating and planning common initiatives by organizing regular meetings with all industrial stakeholders and with representatives of regional authorities to discuss industrial symbiosis-relevant issues. ChemCoast, an industrial network, connects stakeholders and partners in both private and public sectors at the regional and national levels to streamline industrial interaction and to optimize the use of resources.

Formal and informal institutions

The innovation system and innovation policies for sustainable growth in Germany are characterized by multi-level governance and, until recently, did not specifically target industrial symbiosis. The framework is considered a barrier to industrial symbiosis, as the processing time to obtain approvals is lengthy, and regulations on competition prevent 'too much' cooperation between companies. A law on energy efficiency now obliges companies to share information on excess heat.

The collaboration culture among the industry in Covestro Industrial Park is described as mediocre with declining levels of trust. Companies share some knowledge and cooperate, but information on internal processes tends not to be shared.

Chapter 3 Analysis

Based on our model and case review, we conducted an analysis of commonalities and differences to better understand general tendencies in opportunities and barriers in industrial symbiosis in parts of Europe. From this, we highlight key lessons with implications for policy targeting the development of industrial symbiosis.

3.1 Actors and agency

Most regions have at least one actor attempting place-based leadership by facilitating policies and financing or coordinating cooperation for industrial symbiosis. There are actors attempting to perform institutional entrepreneurship by actively promoting industrial symbiosis to local authorities in order to implement goals and strategies for increased energy efficiency from industry in public plans and policies. In some regions, one and the same actor performs both these types of agencies at once, while in other places different types of actors perform place-based leadership and institutional entrepreneurship. Across the different regions, actors performing the two types of leadership are rarely of the same type. They vary from network organizations, government agencies, industrial parks, and innovation parks to private companies and individuals. In other words, their organizations vary in their authority and ability to evoke formal institutional changes and to engage in institutional entrepreneurship. Furthermore, the importance of a third party to perform place-based leadership is emphasized in all regions as crucial for collaboration. A third-party position, especially from an actor or actors performing place-based leadership, might act as a moderating voice among firms by navigating "middle ground" and creating sufficient trust and opportunities for common projects.

This aligns with Grillitch and Sotarauta's argument that place-based leaders can guide interactive development beyond the interest of individual actors to stimulate long-term development. There is a

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need in all regions for an actor to take on such a coordinating and facilitating role, and it is important that this actor create both formal and informal cooperation practices between other actors in each region.

Furthermore, it also seems important that those performing place-based leadership have the capacity (in terms of resources) to follow up initiatives in a timely manner. Despite initiatives and engagement in the regions, the capacity to follow through continuously, build relationships, and access knowledge among local firms seems to be a bottleneck several places, e.g. in Barcelona.

3.2 Production and market

The characteristics of the production and market sides vary between the five regions. Few actors in the regions have a sufficiently clear picture about opportunities related to excess heat and cold in their surroundings, e.g., as there is little non-aggregated data available on excess heat from production processes. This is furthermore hampered by a reluctance to share industrial data. As it is the characteristics of the production side, regarding types of firms and industries and location patterns, that set the standards for what types of symbiosis are possible and what types of actors will constitute the potential market, this is a significant yet manageable bottleneck

The Humber region has a diverse industrial system containing actors from different sectors. It has enormous potential for waste heat recovery (Hayes et al., 2020). However, the cluster firms are spread out, making the reuse of energy between existing industrial sources (B2B) more difficult. This is also the case in the Barcelona region, which stretches over an area of 32,108 km^2 around the city. Yet, the potential for energy synergies in Barcelona is high, especially if linked to environmental infrastructures (i.e., waste energy recovery plants, sludge drying plants etc.) or the distribution of heat from biomass waste. These two cases demonstrate that the potential for the development of functioning B2B symbiosis is high in regions where the industrial structure is diverse, where heat-generating actors within process industry are spread out, and there is available space for new companies in the immediate surroundings.

Furthermore, in most regions, there are issues relating the infrastructure, sometimes due to distance and at other times due to limitations for the direction of the energy flow within existing industrial parks. This is demonstrated in Agder, which is characterized by separate production sites with resource-intensive process industries, narrowing possibilities for symbiosis down to the establishment of new businesses that can make use of excess heat (such as greenhouses/ food production). These separate production sites may allow for “tailor-made” synergies, by planning the development of industrial symbiosis more or less from scratch. The port of Dunkirk also has a high concentration of heavy industries providing a large quantity of untapped waste heat which, if developed into a utility network, could attract new industries (particularly SMEs). The possibilities for symbiosis between existing companies is hampered by locations on different sides of the canal, which is also the case across the Humber region. In the case of Brunsbüttel, the industrial park is dominated by SMEs bound together by well-developed infrastructure and distribution networks, both within and outside the park. This enables the potential for symbiosis between existing actors in the region, but the park also has some free space for new companies, especially within new recycling technologies such as pyrolysis plants (for the advantage of symbiosis).

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3.3 Institutional factors

3.3.1 Formal institutions

Even though TheEuropean Green Deal[7] and The Circular Economy Action Plan[8] influence overall national strategies for a more circular economy in each of the case regions, the reuse and recovery of thermal energy for distribution has not specifically been targeted, despite its significant potential. Still, the number of regulations and policies promoting energy efficiency is increasing, e.g. the REPowerEU Plan[9] and The Green Deal Industrial Plan for the Net-Zero Age[10]. This provides some guidelines for relevant actors as well as a certain coherency of mutually reinforcing mechanisms that did not exist before 2020 and have created a new fertile ground.

The main barrier concerning the existing legislative framework is a lack of cohesion and alignment between rules and laws at the national level and policies at the regional level. There is also a need to assess and interpret possible solutions for industrial symbiosis according to the EU taxonomy, especially the 'no significant harm (DNSH)' principle.[11] This may constitute a major issue in regions where industry is scattered over a large area (such as the Agder case) and industrial symbiosis is dependent on the development of new facilities in the immediate surroundings of the 'energy-providing' firm. Further, the task of navigating and interpreting the policy landscape constitutes a large barrier, especially for small and medium-sized firms with a limited amount of time and resources available for this type of work. This fact is underpinned by several of our interviewees in Agder firms, who stated that they did not have the resources to focus on anything but their firm's core activities.

In some cases, such as Brunsbüttel in Germany, making changes within existing production was described by our local informants as overregulated, making processes for industrial symbiosis complex and extremely time-consuming. This example may point to a need for a simplified regulatory environment. Further, industrial symbiosis is completely reliant on firms' willingness to share information concerning energy and excess heat. While this might not be a problem in regions characterized by high levels of trust, it remains a major issue in regions where there has historically been little collaboration between industrial players. To enable the exploitation of possibilities for industrial symbiosis, there is a need to regulate the sharing of industrial data in a confidential way[12] without violating EU's rules on competition[13]. This is partially addressed by 'The Data Act', a proposal of which the commissioner for Internal Market, Thierry Breton, has commented; "*Today is an*

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[7] https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en

[8] EC, Closing the loop - An EU action plan for the Circular Economy, 2015

[9] https://ec.europa.eu/commission/presscorner/detail/en/ip_22_3131

[10] https://ec.europa.eu/commission/presscorner/detail/en/ip_23_510

[11] https://eu-taxonomy.info/info/eu-taxonomy-overview

[12] https://ec.europa.eu/commission/presscorner/detail/en/ip_22_1113

[13] https://european-union.europa.eu/priorities-and-actions/actions-topic/competition_en

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important step in unlocking a wealth of industrial data in Europe, benefiting businesses, consumers, public services and society as a whole. So far, only a small part of industrial data is used and the potential for growth and innovation is enormous. The Data Act will ensure that industrial data is shared, stored and processed in full respect of European rules. It will form the cornerstone of a strong, innovative and sovereign European digital economy"[14].

3.3.2 Informal institutions

In each case, some form of national or regional strategy towards net-zero emission or use of completely renewable energy sources is stimulating initiatives in industrial symbiosis, to an extent. However, contextual (region-specific) factors influence the implementation of, and possibilities for, industrial symbiosis strategies in various ways.

In Humber, the industrial culture is described as collaborative, and regional companies are driven to invest in industrial symbiosis networks and energy efficiency. The lack of facilitators in the region remains an issue, and there are no voluntary guidelines established from an industrial symbiosis perspective. Still, the "green way of doing things" is also recognized as the "right way", and this narrative is driven by both cost savings potential and environmental commitments. This position may partly be explained by the emergence of the UK National Industrial Symbiosis Program (NISP) that was subsequently discontinued after having created awareness and opportunities initially[15][16].

In Barcelona, the collaborative tradition is described as weak, and lack of trust is described as hampering the implementation of industrial symbiosis strategies. Even though the number of initiatives towards symbiosis has increased during the last couple of years, firms' willingness to share industrial data is low, making the recognition of possibilities for symbiosis dependent on third-party (consulting) firms. In addition, there has been a lack of political interest, which has until recently also been the case in the Agder region in Norway. Here, symbiosis projects have until recently relied on firm activity (B2B) alone. This is considered a slow process, and there is a need for coordination and involvement from local authorities. However, several important initiatives have taken place in Agder in the previous year, one being that the county administration has developed a digital map visualizing areas regulated for industrial development and possibilities for energy. Together with the industrial cluster, Eyde, the county aims to complement this map with continual updates on available excess heat and cold, an initiative which simplifies the search for industrial symbiosis possibilities. Further, the tradition for collaboration in Agder (and Norway in general) is strong, and the industrial culture is described as having high levels of trust, which makes fertile ground for the development of symbioses. This is also the case in Dunkirk, where synergies between actors have been developed over the past 40 years due to several industrial ecology approaches. Due to this long collaborative tradition, structures facilitating the development of industrial symbioses are developed. Still, the engagement of relevant stakeholders is observed to have declined over time, constituting a problem as industrial symbiosis projects can be time-consuming (especially due to regulatory

[14] https://ec.europa.eu/commission/presscorner/detail/en/ip_22_1113

[15] http://www.futuresdiamond.com/casi2020/casipedia/cases/national-industrial-symbiosis-program-uk/

[16] https://www.international-synergies.com/about-us/our-history/

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barriers). In Brunsbüttel, several clusters and networks connect actors in the region, and industrial stakeholders and regional authorities meet regularly to discuss issues relevant to symbiosis and to plan common initiatives. Despite having many formal arenas for knowledge sharing, declining levels of trust between firms is an issue, hampering the development of symbiosis in the region.

3.4 Lessons from the case studies and their implications for policy

3.4.1 Assign agency to actors for production–market matchmaking

To fulfil the potential for industrial symbiosis, there is a need for place-based leadership in each region. The objectives for this leadership are 1) to ensure the collection and sharing of relevant industrial data, 2) to facilitate the identification of symbiotic opportunities and create a matchmaking arena for producers and potential users, and 3) coordinate support for industrial symbiosis among firms, authorities, industrial networks and clusters, and others.

This actor should be assigned its role by, or take this role in understanding with, regional authorities. The actor or actors should have (or be able to create) hands-on experience, credibility, and trust among companies, a role which a private organization might best fulfil. It can also be beneficial for the actor(s) to be in a third-party position and not have self-interest in any symbiotic relationships, to best navigate common ground among companies and moderate collaborations and negotiations.

Insights from cluster programmes. Several types of actors can fulfil this facilitating role, such as cluster organizations. An inspiration could be the Norwegian Innovation Cluster Programme, which is funded by the Norwegian government through the three national organizations Innovation Norway, the Research Council of Norway, and the Industrial Development Corporation of Norway (SIVA). The programme stimulates innovation and industrial development through creating synergistic effects among companies and other actors, both within and across industries and regions. A similar arrangement targeting industrial symbiosis rather than industrial development could ensure the presence of a coordinating actor in regions, while also constituting a channel in which companies and other stakeholders in industrial symbiosis could communicate necessary changes to the institutional framework. Furthermore, a programme could help in building trust, sharing good practice and advice among regions in and beyond a country, reduce risks by building competence on legal and technical issues related to infrastructure across regions, and provide funding for the development of necessary infrastructure.

Regarding matchmaking between producers of excess heat/cold and potential receivers, there is also a need for market formation. The detection of opportunities for symbioses requires mapping of excess heat/cold from existing industries. To connect the production and market sides, this data needs to be made available, either publicly or distributed by demand through a facilitating actor, so that potential stakeholders might discover and take advantage of symbiosis partnerships. Here, the process from a confined industrial area, such as Brunsbüttel, will inevitably vary to a more regional context, like in southern Norway, by depending on involvement from a wider partnership. A common meeting ground, such as network forums and incubators, can stimulate the sharing of data and identification of collaborative symbiosis projects. In addition, there is a need to regulate industrial areas in a way that makes them available for industrial symbiosis when new companies are establishing themselves, especially in regions where industrial areas are spread out and the development of industrial symbiosis will largely rely on new establishments. Industrial areas are often

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regulated by local authorities, which means that there is a need to create awareness of the benefits of, and regional opportunities for, industrial symbiosis among decision makers. A variety of stakeholders can promote industrial symbiosis; however, coordinating actors in regions, with the necessary technical insight, can also take on this role.

3.4.2 Create favourable framework conditions through integration and experimentation

To support the development of industrial symbiosis, several considerations regarding the legal framework need to be addressed.

First, it is important to integrate and root industrial symbiosis in local and regional plans and strategies. The explicit mentioning of industrial symbiosis in guiding documents signals that it is a priority area and may reduce uncertainty and risk for companies. It can build awareness and alignment across departments in the governance system and promote and prioritize industrial areas suited for industrial symbiosis to stakeholders.

Second, as policy interest in stimulating industrial symbiosis is relatively new, there is a need for policy experimentation through financial stimulus and experimentation clauses that go across levels of governance, e.g., through the creation of regulatory sandboxes. This will provide regional actors flexibility to test forms of collaboration without breaching conditions of competition and/or other terms and conditions that might be a barrier. Here, inspiration can be drawn from the IPCEI programme,[17] which provides state aid for projects considered to be of common European interest. However, this programme targets projects along existing (horizontal) value chains; hence, there is a need to "open up" for projects that go across value chains (vertical integration), such as in industrial symbiosis.

Furthermore, regions have different needs and conditions for industrial symbiosis. Thus, regions need different mixes of measures to create functioning symbiosis. The development of industrial symbiosis is, as such, a continuing process that will change according to the presence of different types of companies and their development of relevant technologies.

Policy recommendations

Policy recommendations are based on our analysis of the five European cases of Dunkirk, Humber, Brunsbüttel, Barcelona, and Agder. We have also used theoretical insights from previous studies where three types of agency, namely innovative entrepreneurship, institutional entrepreneurship, and place-based leadership, as well as institutions (e.g., regulations and norms) have shown to be important. Our recommendations are based on challenges and solutions related to the development of industrial symbiosis (i.e., the use of excess energy) that we identified in these regions and, as such, address systematic interdependencies and are broader than regulatory issues. For more on these recommendations, see section 3.4.

[17] https://competition-policy.ec.europa.eu/state-aid/legislation/modernisation/ipcei_en

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Because policy on industrial symbiosis is underdeveloped, our recommendations are not to be seen as a blueprint but rather as a guide for policy development. We recommend the following:

- Regional authorities should ensure that an actor in a region take on a facilitating and coordinating role (specifically for the development of industrial symbiosis).
    - The actor taking on the facilitating role should have the following qualifications:
        1) have, or be able to create, hands-on industry experience, credibility, and trust among companies.
        2) not have self-interest in the symbiotic relationships to be achieved, i.e. a third-party role.
    - The objectives for the facilitating actor should be:
        1) to be a centre for information and coordination requests and support for stakeholders.
        2) to ensure the collection and sharing of relevant industrial data to facilitate the identification of symbiotic opportunities and to create a matchmaking arena for producers and potential users.
        3) to identify and engage potential stakeholders.
        4) to contribute to the support of industrial symbiosis among firms, authorities, industrial networks and clusters, and others.
- Ensure market formation through:
    1) making relevant industry data available for potential stakeholders, e.g., by creating a data record.
    2) creating a common meeting ground for stakeholders to interact, share data, identify opportunities, and create awareness around industrial symbiosis, e.g., network forums or incubators.
    3) regulating industrial areas appropriately for future symbiosis projects.
- Industrial symbiosis should be integrated in local and regional authority plans, strategies, and budgets.
- Framework conditions should be shaped through policy experimentation, e.g., by:
    - the development of regulatory sandboxes through:
        - experimentation clauses that go across levels of governance.
        - financial stimulus.

On a finishing note, we again mention that our study was completed 15 March 2023, meaning that any developments regarding industrial symbiosis after this date may require modifications to these recommendations. Further, the success of industrial symbiosis should not be understood only as a result but rather as a continuous process.

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