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Advancing Industrial Symbiosis: The Dynamic Role of Public Organisations

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ABSTRACT

Industrial symbiosis is a key circular economy strategy that relies on collaboration among diverse actors to turn residual streams into new value. Although prior research acknowledges supportive public-sector involvement, there is a lack of understanding of how public organisations' roles evolve over time as industrial symbiosis initiatives develop. This study addresses this gap through a qualitative case study of a regional industrial ecosystem in northern Sweden. Drawing on 25 interviews with public organisations, support actors and producers, five distinct public-sector roles are identified (policymaker, facilitator, knowledge broker/data provider, participant and financier). The study shows that roles shift across industrial symbiosis development phases, and a framework is developed that links role configurations to phase-specific barriers. The study contributes by conceptualising public organisations as dynamic ecosystem actors and by offering a practical framework that helps public organisations to align roles with evolving ecosystem needs to support long-term circular economy transformation.

1 | Introduction

The circular economy logic has gained increased attention in recent years as a potential alternative to the current linear economic growth model (Geissdoerfer et al. 2020). The world is currently facing multiple challenges related to the linear model of take, make and waste (Frishammar and Parida 2021), including problems with climate change, biodiversity, land loss, pollution and waste (Andersen 2024). As a result, researchers and companies are exploring potential solutions to reduce the environmental impact and improve resource efficiency through circularity efforts (Domenech et al. 2019). The circular economy is commonly defined as a regenerative system in which resource input and waste, emission and energy leakage are minimised by slowing, closing and narrowing material and energy loops (Geissdoerfer et al. 2017). Industrial symbiosis can be seen as an advanced form of the circular economy that focuses on the collaboration between multiple different actors who exchange residuals to create new value (Chertow 2000). Industrial symbiosis can be defined as a practical approach that requires a minimum of three organisations or companies to be involved in resource exchange, with at least two resource exchanges such as materials, energy or water (Chertow 2007; Sun et al. 2017). The benefits of industrial symbiosis are related to its characteristics. These include environmental benefits such as reduced waste and increased resource efficiency, which result in reduced greenhouse gas emissions (Sun et al. 2017; Neves et al. 2020), as well as economic benefits such as reduced costs achieved through collaborative synergies and shared infrastructure (Daddi et al. 2017).

One key element in industrial symbiosis is the creation of collaboration between different types of actors. Collaboration with other actors in the network provides companies with important inputs and partnerships that are needed for the transition towards industrial symbiosis (Frishammar and Parida 2019). Examples of actors that can be part of such a network are public organisations, non-profit organisations, private companies and customers (Thakur and Wilson 2024). Public organisations include actors such as regional governments, municipalities, universities, county administrative boards, local business

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development companies and research institutions. Actors within a network can either play an active role as main actors in the resource exchange or a supporting role as support actors. For a successful transition to and adoption of industrial symbiosis, it is important that all network actors embrace its concepts and understand its implications (Bolger and Doyon 2019). Active roles are often adopted by private companies (Chertow 2000), whereas public organisations more frequently take on supporting roles (Fric et al. 2025). By supporting and guiding businesses towards industrial symbiosis, public organisations can play a crucial role in facilitating its adoption. Their policies, incentives and regulations can influence companies' willingness to engage in these practices, particularly as environmental legislation and stakeholder pressure drive the demand for sustainable solutions (Muzamwese et al. 2024). Beyond supporting environmental and economic objectives, public organisations also play an important role in fostering the social dimension of industrial symbiosis by promoting regional development, employment, stakeholder engagement and community acceptance of industrial transition initiatives (Neves et al. 2020; Fric et al. 2025).

However, despite the many benefits of industrial symbiosis, numerous projects are faced with challenges during the transition to commercial models (Domenech et al. 2019). Examples of challenges include finding the right residual exchange partner (Yazan and Fraccascia 2020; Neves et al. 2020), trust issues between companies—where companies may be unwilling to share sensitive information for fear of industrial espionage (Muzamwese et al. 2024)—and lack of funding (Domenech et al. 2019). Industrial symbiosis can be understood as an ecosystem in which value creation depends on coordination among heterogeneous actors rather than the actions of individual firms. Such ecosystems require governance mechanisms that facilitate collaboration, align incentives, reduce uncertainty and coordinate resource exchanges (Adner 2017; Jacobides et al. 2018). Public organisations represent one important governance actor because they possess mandates, legitimacy and resources that enable them to shape the institutional conditions supporting industrial symbiosis. Given the potential of industrial symbiosis and the challenges it faces, it is of great interest to study how it can become the industry norm and, specifically, what role public organisations should play in this transition. Public organisations could benefit from a better understanding of how to foster industrial symbiosis in the region, to attract companies and to improve the environment.

The industrial symbiosis concept has recently been the focus of numerous studies, examining different aspects such as barriers (Corsini et al. 2024), critical factors and maturity stages (Golev et al. 2015), eco-industrial parks (Farel et al. 2016), regional networks (Domenech et al. 2019) and emergence phases (Mortensen and Kørnøv 2019). These studies contribute interesting and valuable insights into how industrial symbiosis development can become successful. However, Mortensen and Kørnøv (2019) identified a need for further research to focus on groups of actors engaged in the evolution of industrial symbiosis. This highlights a research gap concerning the role of public organisations at different phases of industrial symbiosis development. To address this research gap, this study seeks to answer the following research question: How can public organisations foster industrial symbiosis by adopting different roles throughout the evolution of industrial symbiosis development? This study contributes theoretical knowledge by identifying the activities and functions that different roles can provide to mitigate barriers and foster industrial symbiosis development. It serves as the foundation for developing a contingency framework and mapping the evolution phases, highlighting the importance of the various roles played by public organisations. The study seeks to provide practical insights for managers in public organisations on how to foster industrial symbiosis by adopting different roles and engaging in specific activities and functions.

2 | Theoretical Background

2.1 | Characteristics of Industrial Symbiosis and Public Organisations

Industrial symbiosis, as a concept, has evolved to describe an industrial ecosystem that mimics the natural ecosystem in order to minimise industries' impact on nature (Chertow 2000). It requires collaboration between different companies; a minimum of three companies are required based on the definition of industrial symbiosis (Chertow 2007; Dai et al. 2022). Another important characteristic is the exchange of resources and residuals (Ahmed et al. 2023). Industrial symbiosis can take different forms, although most scholarly research has focused on its association with eco-industrial parks (Corsini et al. 2024). For example, one of the early studies of industrial symbiosis was conducted by Chertow (2000) who found that the potential for industrial symbiosis development depends on the specific conditions of the region or local area. Mortensen and Kørnøv (2019) argue that the importance of geographical proximity depends on the context and the actors involved.

Industrial symbiosis involves collaboration among multiple actors with different responsibilities and capabilities, including private companies, public organisations, research institutions and intermediary organisations (Thakur and Wilson 2024). Public organisations, such as municipalities, regional authorities, universities, county administrative boards and public-owned development companies, differ from private firms in that they operate under public mandates and are accountable for promoting broader societal objectives rather than solely commercial interests (Bryson et al. 2014). These characteristics enable them to support long-term regional development through policymaking, public procurement, infrastructure investments and coordination of multiple stakeholders. This makes public organisations particularly important in the context of industrial symbiosis, where collaboration extends beyond individual firms and depends on supportive institutional conditions. By reducing barriers, coordinating actors and creating incentives for collaboration, public organisations can facilitate the transition towards industrial symbiosis and the broader circular economy while contributing to environmental, economic and social development (Domenech et al. 2019; Fric et al. 2025; Palagonia et al. 2025).

Industrial symbiosis can emerge through a *top-down* approach, *bottom-up* approach or a combination of the two (Farel et al. 2016). The *top-down* approach shares similarities with the managerial approach to *planned networks* described by

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Domenech et al. (2019), which emerge as a result of a central plan or vision, with the goal of developing shared infrastructure and services as well as promoting residual exchanges. The *top-down* approach is most common when the primary driver for implementing industrial symbiosis is related to environmental benefits (Farel et al. 2016). In such cases, *public organisations* play an important role and become *main actors*, similar to *planned networks* in which a central plan or vision underpins the creation of the network. These networks are often conceptualised as eco-industrial parks with colocated actors, designed to maximise the sharing of infrastructure and services as well as residual exchanges (Domenech et al. 2019).

The *bottom-up* approach is most common when the primary driver is related to economic benefits (Farel et al. 2016). In this kind of network, private companies play a more prominent role in creating the network. This is linked to the fact that economic benefits are seen as the main motivation for companies to implement industrial symbiosis (Patricio et al. 2018). As a result, *public organisations* play a limited role in the formation of industrial symbiosis networks yet retain the potential to support and foster their development through complementary roles as *support actors*. It shares similarities with the managing approach of *self-organised activity* described by Domenech et al. (2019). This approach occurs when industrial actors establish direct interaction with each other concerning resource exchanges.

In cases where a combination of *top-down* and *bottom-up* approaches is used, both economic and environmental factors act as drivers for the implementation of industrial symbiosis (Farel et al. 2016). In these cases, *public organisations* play an important role in the creation of a network together with private companies. This approach shares similarities with the *facilitated networks* described by Domenech et al. (2019), in which a third party plays an important role as an intermediary and coordinates activities. This creates the opportunity for *public organisations* to act as *support actors*, taking on the role of an intermediary who coordinates activities. They act as a link between the actors active in residuals exchange, providing information about the network's different actors and identifying and presenting solutions for them (Fric et al. 2025). Private actors, such as nonprofit organisations, platform providers and various types of companies, can also be part of an industrial symbiosis network (Thakur and Wilson 2024) and provide supporting activities. Platform providers can, for example, provide online platforms that inform network actors about potential partners, waste and residuals produced within the network (Mollica et al. 2024).

The diversity of actors involved in industrial symbiosis creates opportunities for public organisations to contribute in different ways throughout the development of industrial symbiosis initiatives. Rather than acting solely as regulators or facilitators, public organisations can assume multiple roles depending on the needs of the ecosystem and its stage of development. These roles enable public organisations to support collaboration, reduce barriers and create conditions that foster industrial symbiosis. In doing so, they can contribute to enhanced competitiveness of local companies, reduced costs through collaboration synergies and shared infrastructure (Daddi et al. 2017), job creation and increased regional employment (Neves et al. 2020), reduced waste and environmental impacts (Daddi et al. 2017; Sun et al. 2017; Neves et al. 2020) and improved access to green financing (Muzamwese et al. 2024). Understanding how these roles evolve throughout industrial symbiosis development is therefore central to explaining how public organisations contribute to the governance of industrial symbiosis ecosystems.

2.2 | Critical Factors in Industrial Symbiosis Development

The development of industrial symbiosis and its different approaches involve a range of interrelated critical factors, encompassing both barriers and enablers (Golev et al. 2015). It is important that actors involved in developing industrial symbiosis understand how to address these critical factors in order to mitigate barriers and enhance the impact of enablers on its development. Many researchers have studied and categorised them. Mirata (2004) identified five categories: *economic and financial, informational, organisational and motivational*, *technical* and *political*. Golev et al. (2015) adapted these categories, adding two more: *community* and *commitment to social development*.

Firstly, the *economic* category includes numerous critical factors that influence the development of industrial symbiosis (Mirata 2004; Golev et al. 2015; Muzamwese et al. 2024), such as the need for significant investment in new technology, infrastructure and real estate (Mirata et al. 2024; Muzamwese et al. 2024). *High investment costs* together with a *lack of economic strength* to proceed with industrial symbiosis projects (Domenech et al. 2019), and *difficulties in attracting external funding* (Corsini et al. 2024), constitute significant barriers. According to Corsini et al. (2024), these barriers become major obstacles, particularly for smaller companies adopting industrial symbiosis. Therefore, the need for financial support is crucial, whether through public or private funding (Behera et al. 2012). Initiatives financed through public funds face a specific barrier, as the funding stream is often closely tied to the project and typically ends when the project concludes (Domenech et al. 2019). Therefore, it is essential that such initiatives find a way to secure *long-term funding*. Difficulties in identifying *cost–benefit relationships* and determining *return on investment* represent two additional economic barriers (Domenech et al. 2019). Despite these barriers, the *economic* category can also function as an enabler for industrial symbiosis development. Different types of support related to funding can raise awareness, awaken interest and drive actors' motivation to develop new synergies and collaborations (Mortensen and Kørnøv 2019). This is because economic benefit is the main driver for companies to implement and develop industrial symbiosis (Behzad et al. 2024).

Secondly, the *information* category includes critical factors such as the need for detailed data (both qualitative and quantitative) regarding residuals and local industries' utility requirements (Golev et al. 2015). It is important that the data are both *timely and reliable* so that the network is provided with the information required to make well-informed decisions (Mirata 2004). The flow of information through the network is important to reduce the risk of misunderstandings and asymmetric information among actors (Panyathanakun et al. 2013). *Lack of detailed information* (Golev et al. 2015), *risk of communication failures* (Mirata et al. 2024) and *leakage of intellectual properties*

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(Ji et al. 2020) can be considered barriers to industrial symbiosis development. To address these barriers, networks can use databases that provide information on resource flow to create an overview of the resources exchanged within the network (Mortensen and Kørnøv 2019).

Thirdly, the *cooperation* category is vital for the development of industrial symbiosis (Chertow 2007; Golev et al. 2015; Vanhamäki et al. 2020; Mirata et al. 2024), given that one of the main characteristics of the concept relates to the collaboration and exchange of residuals between numerous actors (Chertow 2000). The number of actors involved in residual exchanges within a network presents an issue due to the *high level of collaboration required* (Chertow 2007; Yazan and Fraccascia 2020). The rationale for creating collaborations lies in the potential to generate added value through partnerships (Yazan and Fraccascia 2020). However, the decision to engage in industrial symbiosis is also a strategic one, requiring companies to evaluate the costs, risks, investments and expected benefits associated with collaboration. Market characteristics and investment requirements can therefore influence firms' willingness to cooperate and implement industrial symbiosis initiatives (Mollica et al. 2024). Although collaborations can create added value for companies, *identifying suitable collaboration partners* can also be challenging (Domenech et al. 2019; Neves et al. 2020). This is particularly important because the diversity of actors within networks has been identified as an important feature to enhance synergies (Behzad et al. 2024), and companies from different sectors need to find each other. In contrast to the findings of Domenech et al. (2019) and Neves et al. (2020), Corsini et al. (2024) reported that the identification of network partners did not appear to be a barrier on a regional level. Their motivation was that there was greater knowledge of other companies within a region, which made it easier to initiate symbiotic collaborations, compared to companies located in a wider geographical area. Another motive noted by Corsini et al. (2024) was that the studied companies participated in specific programmes and platforms, which may have helped in finding appropriate partners. Other barriers related to the *cooperation* category include *confidentiality issues* (Mauthoor 2017), *sharing of information* (Mirata 2004; Golev et al. 2015) and *codependency* (Bansal and McKnight 2009; Herczeg et al. 2018).

Fourthly, the *technical* category includes critical factors such as the *physical, chemical and locational attributes* of input and output streams of waste, residuals and resources (Mirata 2004); *technical knowledge* (Golev et al. 2015); *logistics* (Domenech et al. 2019; Fric et al. 2025); *utilities*, *managerial resources and processing* (Mirata 2004); *the availability of key technologies* (Mirata 2004; Dong et al. 2016); and *infrastructure* (Mortensen and Kørnøv 2019). *Technical feasibility* when applying new technologies in the development phase is also an important consideration (Golev et al. 2015). To overcome technical barriers, Golev et al. (2015) suggest that the involvement of consultants, research institutions and universities can play an important role in providing the network with the required expert knowledge.

Fifthly, the *regulatory* category encompasses critical factors for the development of industrial symbiosis, as regulations can both discourage and constrain companies in their adoption of industrial symbiosis practices (Corsini et al. 2024). *Environmental legislation* (Golev et al. 2015), *policies* (Mirata 2004; Wu et al. 2016; Mortensen and Kørnøv 2019), *regulations* (Mirata 2004; Wu et al. 2016; Park et al. 2016), *laws, taxes*, *fees*, *fines*, *levies*, *subsidies* and *credits* (Mirata 2004) are all legal instruments that can influence the development of industrial symbiosis and become either barriers or enablers (Wu et al. 2016). *Policies* play an especially important role in creating awareness of industrial symbiosis opportunities and interest in gaining its benefits (Mortensen and Kørnøv 2019). Lack of *policy support* constitutes a barrier to the development of industrial symbiosis (Ji et al. 2020). Regulations can become a barrier when they, in some cases, make it more cost-effective to send materials to landfill rather than engage in residual resource exchanges (Mauthoor 2017). To mitigate this risk, support in the form of fiscal incentives for companies that use residuals or waste in their production can be important (Corsini et al. 2024).

Sixthly, the *commitment to social development* category is critical because of the importance of creating *motives* for managers and companies to participate in industrial symbiosis projects (Golev et al. 2015). One motive for companies may be the potential to improve the competitiveness and sustainability of network actors (Neves et al. 2020). The attitude, willingness and workload of managers together with the *capability* and *culture* of a company (Park et al. 2016) are other critical factors.

Lastly, the *community* category is important because it involves creating awareness of the environmental and economic impacts that different industries generate (Golev et al. 2015). According to Golev et al. (2015), it requires not only a *well-established communication system* between the network and the community but also *environmental education programmes* to prevent *public opposition* to the development of industrial symbiosis initiatives in the local area. From a community perspective, focusing on industrial symbiosis development can attract new companies to the local area (Aid et al. 2017), increase the competitiveness of local companies and create incentives for them to remain in the area (Martin and Harris 2018), community development (Afshari et al. 2020) and environmental benefits (Chertow and Ehrenfeld 2012).

The seven categories include a variety of critical factors that present both barriers and enablers for industrial symbiosis development (Golev et al. 2015). The different categories of critical factors highlight the need to involve diverse actors who can transform potential obstacles into drivers for implementing and advancing industrial symbiosis. For example, public authorities have greater impact on the *regulatory* category through their ability to adapt regulations and legal instruments (Mortensen and Kørnøv 2019), whereas their impact on the *cooperation category* is more limited, as it requires other forms of expertise.

2.3 | Industrial Symbiosis Evolution Phases

The development of industrial symbiosis can be divided into different phases. Recent research has demonstrated that different sustainability assessment methods are required across the industrial symbiosis life cycle, from the identification of opportunities to implementation and monitoring, highlighting that governance and support mechanisms must evolve alongside the

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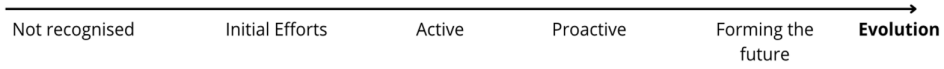

FIGURE 1 | The five evolution phases.

maturity of industrial symbiosis initiatives (Ramírez-Rodríguez et al. 2024). Behzad et al. (2024) explain that the creation of industrial symbiosis networks consists of two steps: (1) involving potential actors by sharing the symbiosis idea and (2) identifying potential actors for both internal and external symbiosis. Mortensen and Kørnøv (2019) stated that the emergence of industrial symbiosis consists of three phases: (1) *the pre-emergence phase*, create awareness of and interest in its benefits to attract actors and formulate a symbiotic idea; (2) *the emergence phase*, identify potential symbiotic partners; and (3) *the postemergence phase*, prepare and organise its establishment. The first two steps described by Mortensen and Kørnøv (2019) can be applied to any regional industrial symbiosis development, according to Behzad et al. (2024), and show clear similarities with the two steps they outlined. In the pre-emergence phase, *policies* are an extremely important factor, with other important factors including *funding*, *timing* and *history* (Mortensen and Kørnøv 2019). Key actors in this first phase are the research and education institutions (Behera et al. 2012), whereas governmental agencies, regional governments, municipalities, local authorities and public agencies also play important roles (Valentine 2016). Mortensen and Kørnøv (2019) stated that public-sector participation is crucial for further development in the emergence phase. They also noted that *bridging actors* play an important role in introducing ideas and pushing them forward to create awareness and stimulate interest among other actors (Mortensen and Kørnøv 2019). Furthermore, they argued that, in the postemergence phase, *policies* become very important along with the availability of *funding* and *infrastructure*, and *consultants* and *interest associations* are expected to play a larger role (Mortensen and Kørnøv 2019).

On the other hand, Golev et al. (2015) divided industrial symbiosis development into five different stages based on its maturity: (1) *not recognised*, the concept has no recognition in the local area, and there is a lack of collaboration and use of residuals; (2) *initial efforts*, better understanding of the importance of environmental efforts, some synergy projects have been implemented, and the potential of residuals has been recognised by some companies; (3) *active*, companies show growing interest in collaboration, previous work has been successful, and some kind of joint communication is in existence; (4) *proactive*, detailed investigations into new synergy opportunities occur frequently, the joint communication provides actors with detailed information, and a regional strategy provides guidelines and a long-term perspective; (5) *forming the future*, all actors continuously work together to create their desired future, and a long-term perspective now drives further developments.

Although Mortensen and Kørnøv (2019) focused on what actors needed to do to make industrial symbiosis networks emerge, Golev et al. (2015) placed their emphasis on the regional perspective and the maturity level of the industrial symbiosis concept in a region or geographical area. Similarly, Harfeldt-Berg et al. (2025) highlight the importance of assessing stakeholder readiness throughout different stages of industrial symbiosis development, emphasising that the support needs of industrial symbiosis initiatives evolve over time. All perspectives are important in determining the importance of *public organisations* at different phases in the evolution of industrial symbiosis. Mortensen and Kørnøv (2019) provide important insights into how industrial symbiosis networks can be created, whereas Golev et al. (2015) present a timeline of different stages of industrial symbiosis maturity. There are linkages between the emergence phases identified by Mortensen and Kørnøv (2019), and the maturity stages described by Golev et al. (2015). In the *pre-emergence* phase, the focus is on creating awareness and interest. This is of particular importance in the *not recognised* stage because the concept is not yet recognised by local companies. Although the identification of symbiosis partners is the main objective in the *emergence* phase, local companies in the *initial effort* stage show a better understanding of the benefits of industrial symbiosis and are therefore more willing to seek potential collaborations. Lastly, in the *initial efforts* stage, some synergy projects have been implemented, highlighting the need to prepare and organise their establishment. However, attention is also given to preparing and organising new industrial symbiosis projects in later stages: *active*, *proactive* and *forming the future*. With this in mind, the stages proposed by Golev et al. (2015), supported by insights from Mortensen and Kørnøv (2019), form the basis for the evolutionary phases. The stage names from Golev et al. (2015) are retained as the names of the evolution phases. Figure 1 illustrates these evolution phases.

3 | Methodology

3.1 | Research Approach and Case Selection

This study examined the complex phenomenon of industrial symbiosis, which made a qualitative, exploratory approach appropriate (David and Sutton 2011). This approach helped to create a deeper understanding of industrial symbiosis and the different roles public organisations can play in its development. A case study design was considered particularly suitable because it enables an in-depth examination of a contemporary phenomenon within its real-world context, allowing for a richer understanding of the interactions, processes and perspectives of the actors involved (Yin 2018; Eisenhardt 1989). One important advantage of this approach was the possibility to continuously compare the collected data with previous data through the evaluation and refinement of the research questions, theoretical foundation and interview guide throughout the study. The research therefore adopts a case study design focusing on the Norrbotten region in Sweden.

The Swedish context provides a particularly relevant setting for examining the role of public organisations in industrial symbiosis. Sweden's decentralised governance system assigns municipalities and regional authorities significant responsibilities for regional development, environmental planning, public procurement and sustainability transitions, enabling public organisations to actively support industrial symbiosis initiatives

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(Södergren 2026). Norrbotten was selected as the empirical setting due to its ongoing green industrial transition and the growing interest among regional actors in industrial symbiosis and circular economy solutions. The region provides a particularly relevant context for studying the role of public organisations because it combines several characteristics associated with industrial symbiosis development. First, Norrbotten hosts a diverse industrial base with significant residual streams and multiple ongoing initiatives exploring resource exchanges and circular business opportunities. Second, public organisations at municipal and regional levels have actively engaged in supporting industrial symbiosis through regional development strategies, publicly funded projects and collaborative initiatives involving municipalities, the regional government, the county administrative board, universities and business development organisations. At the time of the study, the region included several ongoing industrial symbiosis and circular economy initiatives at different stages of development, providing opportunities to study both emerging and more mature collaborations. Furthermore, several companies had already begun utilising residual resources to create new value, allowing the study to capture industrial symbiosis initiatives with varying levels of maturity.

The diversity of industrial symbiosis initiatives in Norrbotten has resulted in the involvement of a wide range of actors, including municipalities, the county administrative board, the regional government, the university, non-profit organisations, private companies and public-owned business development companies. This diversity made the region particularly suitable for exploring how different public organisations contribute to industrial symbiosis development and how their roles are perceived by other ecosystem actors. Interviewing representatives from these actor groups enabled the collection of rich insights into the barriers, opportunities and support mechanisms associated with industrial symbiosis.

In addition, Norrbotten presents a unique geographical context. As a sparsely populated region with long distances between cities and industrial facilities, it faces specific challenges related to logistics, infrastructure, collaboration and resource exchanges. These contextual characteristics make the region an especially relevant setting for examining how public organisations can support and foster industrial symbiosis development under challenging conditions. Consequently, the case offers valuable insights into the role of public organisations in facilitating industrial symbiosis within regional industrial ecosystems undergoing sustainability transitions.

3.2 | Data Collection

Data collection was primarily conducted through interviews and consisted of two stages: exploratory interviews followed by semistructured interviews. The exploratory interviews were undertaken to gain an initial understanding of the industrial symbiosis landscape in Norrbotten and to identify key issues, actors and contextual factors relevant to the study. This preliminary phase helped refine the focus of the research and ensured that the subsequent data collection was grounded in the regional context. The exploratory interviews were conducted with representatives from a publicly owned business development company and a consultancy firm that had been actively involved in industrial symbiosis projects in Norrbotten.

Insights from the exploratory interviews, together with the theoretical background, were used to develop the interview guide for the semistructured interviews. The interview guide focused on five overarching themes: background, to establish the respondent's experience and role in industrial symbiosis; challenges and barriers, to identify factors influencing industrial symbiosis development; opportunities, to explore potential enablers and future development; relationships, to understand interactions between different actors; and collaborations, to examine existing and potential forms of cooperation within industrial symbiosis ecosystems. These themes were selected because they directly reflected the study's research objective of understanding the barriers to industrial symbiosis and the evolving roles of public organisations in fostering its development. The semistructured format provided a balance between consistency across interviews and flexibility to explore emerging topics in greater depth. Although the themes remained consistent throughout the study, individual questions were adapted to the type of respondent (e.g., public organisations, support actors and producers) and the specific context of each interview. The interview guide was continuously refined throughout the data collection process to incorporate new insights and improve the understanding of industrial symbiosis development and the role of public organisations.

According to Saunders et al. (2016), semistructured interviews are the most advantageous approach when data collection involves complex or open-ended questions and when the order of questioning may need to vary due to differing conditions across interviewed organisations. The respondents were initially selected using a purposeful sampling strategy based on known industrial symbiosis initiatives in the Norrbotten region and an initial list of organisations identified through regional projects, public documents and recommendations from the exploratory interviews. The aim was to ensure representation from the main actor groups involved in industrial symbiosis development, including public organisations, support actors and companies actively engaged in or exploring industrial symbiosis initiatives. Selection criteria required that respondents had direct experience of industrial symbiosis, circular economy initiatives, regional collaboration or decision-making related to industrial symbiosis development. Snowball sampling was subsequently used to identify additional respondents with complementary expertise and perspectives. At the end of each interview, participants were asked to recommend other individuals with substantial knowledge or practical experience of industrial symbiosis in the region. This process enabled the inclusion of respondents occupying different roles within the industrial symbiosis ecosystem while ensuring that all participants possessed relevant expertise related to the study's research objectives.

To capture multiple perspectives on the role of public organisations, respondents were categorised into three groups. Public organisations (A) included municipalities, the regional government, the county administrative board, universities and publicly owned development organisations that influence industrial symbiosis through policy, coordination, research and regional development. Support actors (B) comprised organisations such

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TABLE 1 | Presentation of the 25 semistructured interviews.

ID	Actor type	Organisation description	Interview type
A1	Public organisation	Region	Face-to-face
A2	Public organisation	Region	Video meeting
A3	Public organisation	County administrative board	Phone call
A4	Public organisation	Municipality	Video meeting
A5	Public organisation	Public-owned business development company	Video meeting
A6	Public organisation	Public-owned business development company	Video meeting
A7	Public organisation	Public-owned business development company	Video meeting
A8	Public organisation	University	Face-to-face
A9	Public organisation	Project organisation	Video meeting
A10	Public organisation	Project organisation	Video meeting
A11	Public organisation	Project organisation	Video meeting
B1	Support actors	Advocacy group	Face-to-face
B2	Support actors	Expert	Video meeting
B3	Support actors	Consultant firm	Video meeting
B4	Support actors	Consultancy firm	Video meeting
B5	Support actors	Investor and wholesaler	Video meeting
C1	Producers	Greenhouse company	Video meeting
C2	Producers	Energy company	Video meeting
C3	Producers	Steel company	Face-to-face
C4	Producers	Food company	Video meeting
C5	Producers	Dairy company	Video meeting
C6	Producers	Bread company	Video meeting
C7	Producers	Food producer	Video meeting
C8	Producers	Food producer	Video meeting
C9	Producers	Food producer	Face-to-face

as consultants, advocacy groups and investors that facilitate industrial symbiosis without directly participating in resource exchanges. Producers (C) represented private companies actively involved in industrial symbiosis as suppliers and/or users of residual resources. Including these heterogeneous actor groups enabled the study to examine public-sector roles from both the perspective of the public organisations themselves and from the organisations they support and collaborate with.

The semistructured interviews were conducted using various interview approaches—19 by video, five face-to-face and one by phone. The semistructured interviews lasted for approximately 30–45 min. Data collection continued until no substantially new themes relating to the roles of public organisations, barriers and industrial symbiosis development emerged across interviews. This point was considered to represent sufficient thematic saturation for the purposes of the study. Table 1 presents the 25 semistructured interviews and related information, such as type of company, interview approach, duration, date and number of transcribed words. The ID is divided into A, B and C, where the interviews with ID A are *public organisations*, ID B are *support actors*, and ID C are producers and *main actors* playing active roles in the exchange of residuals.

In addition to the semistructured interviews, this study was triangulated with secondary data, including documents received from the companies, information from their web pages and public news. Collecting data from different sources provided the opportunity to fill gaps, capture a comprehensive view of the situation and achieve data triangulation.

3.3 | Data Analysis

The thematic analysis was conducted by using a qualitative data analysis software to help to identify relevant information in the interview data. The analysis was structured in four steps: (1) *identify quotations*, (2) *identify first-order concepts*, (3) *identify second-order themes* and (4) *identify aggregate dimensions*. Although the software facilitated the organisation and coding of the data, the interpretation of relationships between concepts, themes and dimensions remained the responsibility of the researchers. In the first phase, the purpose was to *identify quotations* with insights related to barriers. A total of 141 quotations related to barriers were identified from the 25 interviews. These quotations then formed the basis for the *first-order concepts*. A total of 23 *first-order concepts* were created by grouping quotations that contained similar information and insights. In the third step, the researchers compared and interpreted the

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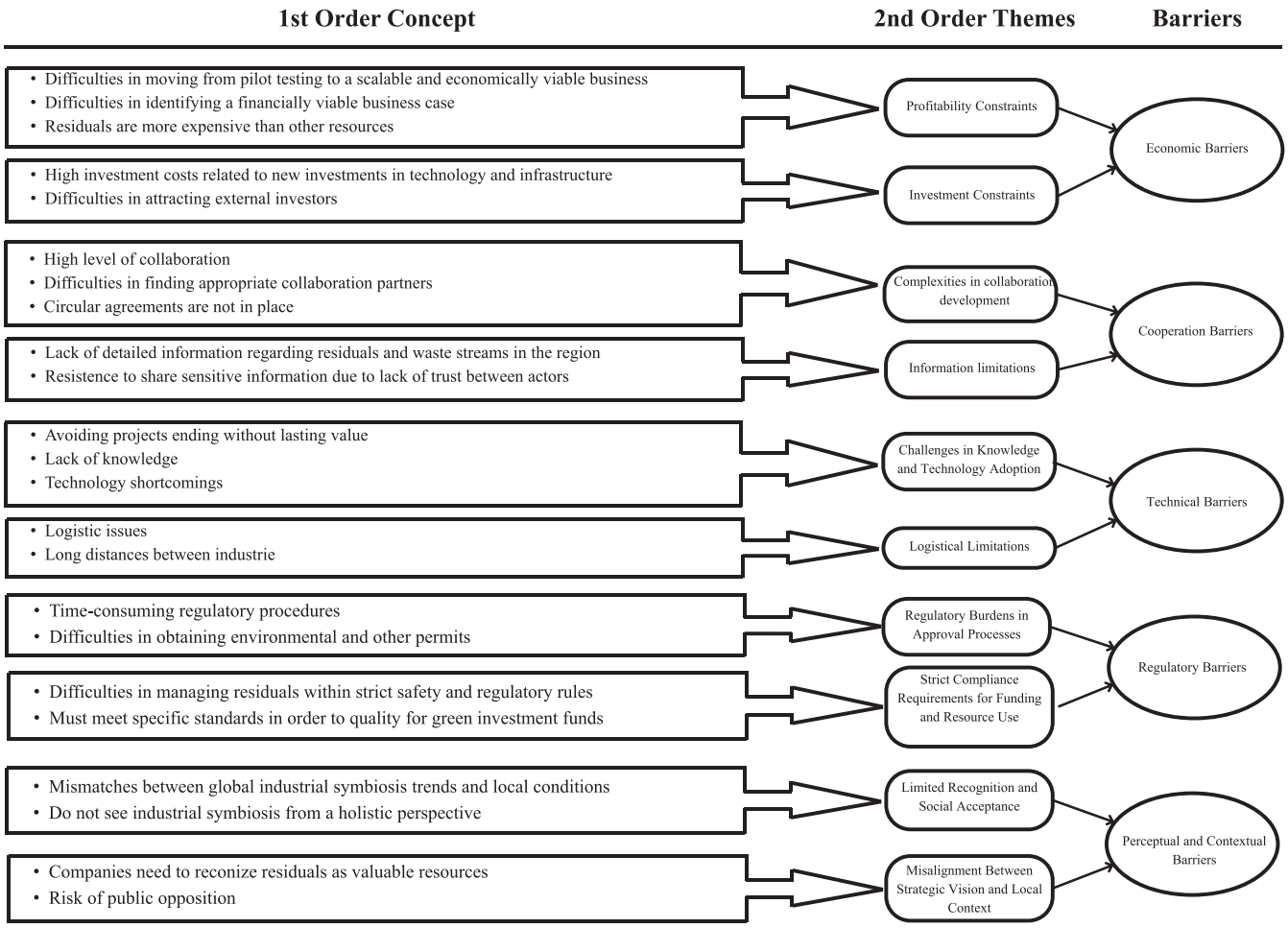

FIGURE 2 | Identified industrial symbiosis barriers from the interviews.

relationships between the *first-order concepts* to develop broader themes; a total of 10 *second-order themes* were created. The fourth and last step was to combine the *second-order themes* into five *aggregate dimensions*. This process was inductive in nature, meaning that the concepts and themes emerged directly from the data. This process followed the guidelines of Gioia et al. (2013). The thematic analysis process was conducted a second time, following the same steps. However, the difference lay in the identified quotations identified from the interviews, which in the second round focused on how to foster industrial symbiosis development. A total of 202 quotations were identified in the first step. These quotations then provided the basis for the creation of 23 *first-order concepts*. The *first-order concepts* were then grouped into 10 *second-order themes* focusing on *activities*. In the final step, these themes were combined into a total of five *aggregate dimensions* focusing on *roles*. The separation of the process into two phases was intended to create a better understanding of the existing barriers to industrial symbiosis in the studied region. This approach then enabled the identification of *activities* and *roles* that *public organisations* could play in mitigating these barriers and fostering the development of industrial symbiosis. Figures 2 and 3 present the two coding trees resulting from the thematic analysis, illustrating the progression from first-order concepts to second-order themes and aggregate dimensions.

4 | Findings

4.1 | Barriers to Industrial Symbiosis

The interviews resulted in the identification of five categories of barriers related to industrial symbiosis development. Figure 2 presents the coding tree involving the five categories of barriers identified in this study.

The first category, *economic barriers*, relates to *profitability* and *funding constraints*. Companies participating in industrial symbiosis initiatives face challenges associated with *high investment costs*, as new technologies and infrastructure are often required to create value from residual streams. Another barrier identified from the interview data was the difficulty in *attracting external investors*, particularly for large-scale initiatives. This stemmed from the additional risk associated with industrial symbiosis initiatives, which require collaboration among multiple actors. Respondent C1 stated: 'When building an industry where two or more parties depend on each other, the risk increases. And that, in turn, makes financing difficult. Investors always make a risk analysis'. The profitability constraint relates to the difficulties in *identifying a financially viable business model*. It is derived from the *difficulties in scaling these types of initiatives* and the fact that, in many cases,

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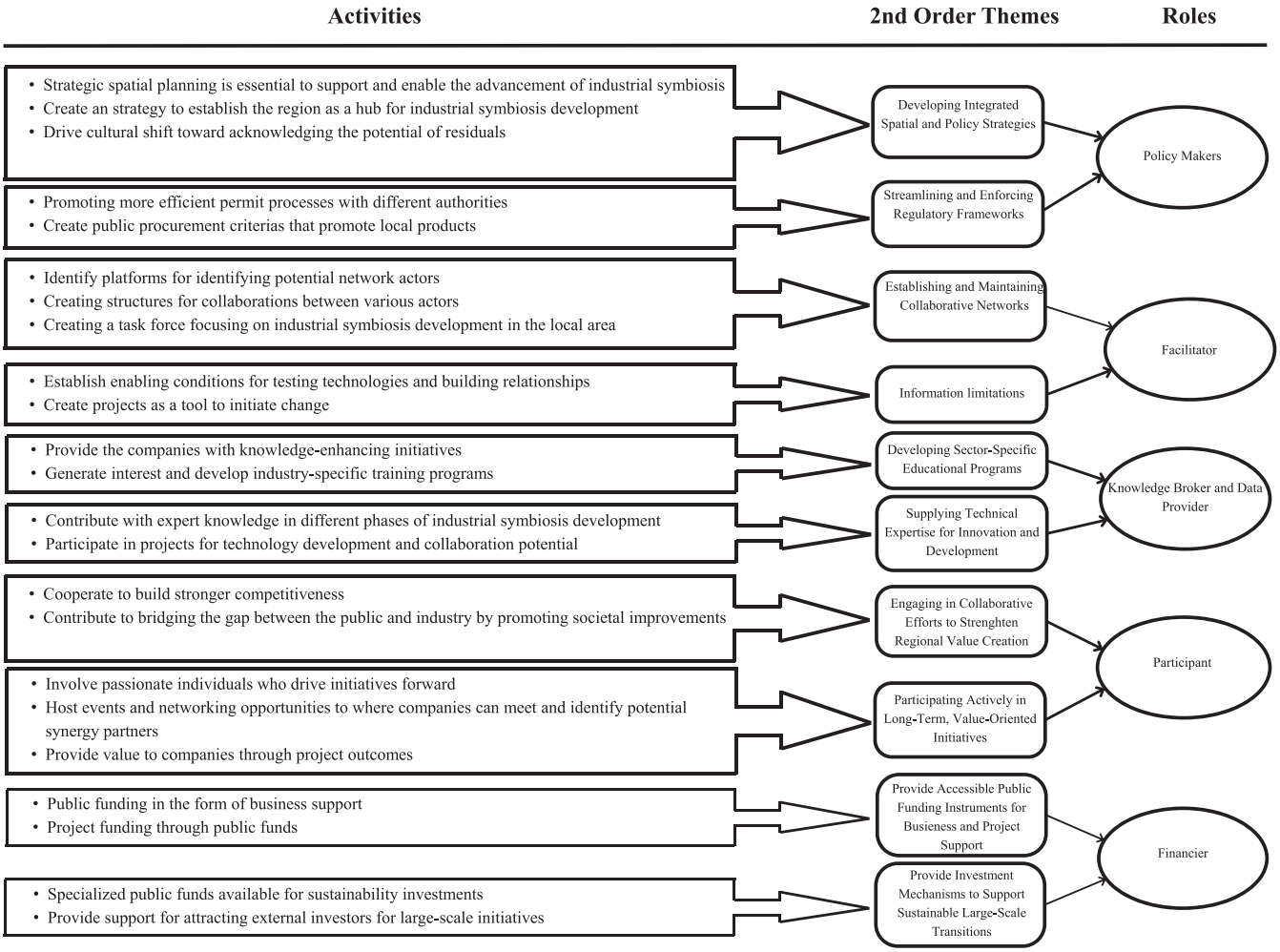

FIGURE 3 | Coding tree of the roles public organisations can play and their related activities.

residuals are more expensive than other resources. Respondent A7 explained: 'We have our projects where we have connected data centers and greenhouses and such. But we have not scaled it up into a larger operation'. Respondents A4, A9, C3, C5, C6 and C9 mentioned *high investment costs* as a barrier to implementing new technologies and infrastructure needed to utilise residuals effectively.

The second category, *cooperation barriers*, relates to *limitations in collaborative development* and *information sharing*. Both themes reflect barriers similar to those identified by previous researchers, such as the need for a *high level of collaboration* (Chertow 2007; Yazan and Fraccascia 2020), *difficulties in finding appropriate partners* (Domenech et al. 2019; Neves et al. 2020) and *resistance to sharing information* (Mirata 2004; Golev et al. 2015). Another related risk is linked to the *codependency* inherent in industrial symbiosis and its definition. The codependency risk has been identified by Bansal and McKnight (2009) and Herczeg et al. (2018). Respondent C6 stated: 'We ended the project to focus on residual streams. Initially, a factory was planned, but during construction and production, our partner decided to continue without using residual streams, which ultimately ended the collaboration'. This shows the importance of minimising the impact of the *cooperation barriers* category, as it comprises barriers related to collaboration, which is a fundamental aspect of industrial symbiosis. Collaborations are associated with the previously mentioned barriers of *difficulty in finding appropriate collaboration partners* and *high levels of collaboration*. The challenge of finding the right partner is illustrated by respondent C6 who reported having to end a collaboration because the partner moved on without using residuals. Respondent C6 stated: 'More and more people are starting to learn what others are doing, breaking down the mindset of, I work over here on this and had no idea that person existed or was doing that'. The *high level of collaboration* relates to the number of different actors involved in industrial symbiosis development. Respondent B2 recounted: 'In my experience, collaboration often involves very different companies, big and small, or from different industries, and they are not used to working together'. Resistance to *sharing information* and *lack of detailed information regarding residuals* are other barriers linked to the *cooperation barrier*. Respondent C6 stated: 'There is a need to gain an understanding of what types of residual streams could be shared here and what a symbiosis could look like'. Respondent B3 contended: 'We would need to create that confidence and trust that those companies need in order to share that confidential information, as often they are afraid that maybe competitors might use it as an advantage'.

The third category, *technical barriers*, involves two different themes: *challenges in knowledge and technology adoption*, and

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logistical limitations. The first relates to the *lack of required knowledge*, as mentioned by Golev et al. (2015), the *importance of projects that create long-term benefits*, the *need for technology development* and *limited access to testing new technology*. Respondent A2 maintained: 'There is also a built-in mechanism in a project to have a plan for what happens after it ends. But at the same time, it can be a challenge to reach that point'. Respondent B2 claimed: 'Getting people to discuss new approaches is hard without a shared language around the table'. *Lack of required knowledge* and *technology shortcomings* are other factors impacting the development of industrial symbiosis. Respondent B4 stated: 'Smaller companies often lack the resources to experiment or find a shared space to collaborate on new ideas'. Respondent C8 argued: 'There is a lack of knowledge, and support is needed'. Logistical and transportation limitations were identified as barriers due to long distances between industries, similar to the findings of Domenech et al. (2019). Fric et al. (2025) also identified logistics as a barrier. Respondent C3 referred to: 'Limitations in the railway system', and respondent B5 drew attention to the: 'Long distances, and the need for effective and affordable logistic solutions'.

The fourth category, *regulatory barriers*, encompasses the two themes of *regulatory burdens in approval processes* and *strict compliance requirements for funding and resource use*. The first focuses on the difficulties in obtaining permits, as respondent C1 explained: 'Industry needs land close to the anchor company as building far away is costly. One project was cancelled because the municipality would not sell us enough land'. Another respondent highlighted the difficulty in obtaining permits: 'Applying for environmental permits is an extremely demanding process, and a major obstacle'. This is in line with Golev et al. (2015) who argued that environmental legislation, specifically obtaining permits, is often a barrier for companies implementing industrial symbiosis. The second theme focuses on the regulatory requirements of *meeting specific criteria to qualify for public funds* and *difficulties in managing residuals within strict safety and regulatory requirements*. Respondent C1 mentioned that: 'Applying for green investments requires that we live up to certain standards' and respondent C9 explained: 'There are a lot of regulations around it. But for the climate investments we have made, we have been able to use them'.

The fifth category, *perceptual and contextual barriers*, focuses on the importance of *identifying residuals as resources*, the importance of *having a holistic perspective*, *mismatches between global trends and regional conditions* and the *risk of public opposition*. The *risk of public opposition* was also identified by Golev et al. (2015). These factors are important considerations for p*ublic organisations*—in particular, actors such as regional governments and municipalities. This is due to the necessity of adapting the industrial symbiosis concept to the region's unique characteristics to really foster its development. It is therefore important to *see industrial symbiosis from a holistic perspective* and *adapt it to the local conditions*. Respondent A2 contended: 'I see obstacles in the lack of a holistic view of circularity. I believe a support system should be developed to integrate with the existing ecosystem'. Equally, respondent B4 argued: 'Municipalities are quite protectionist. They want projects in their own area to show results. We need to think beyond location and enable symbioses between industries, small businesses, utilities, and energy companies, regardless of place'.

The identified barrier categories broadly correspond to those proposed by Golev et al. (2015) and this study contributes by identifying how these barriers manifest within a regional industrial symbiosis ecosystem and in linking them to the governance roles that public organisations can adopt to mitigate them. Furthermore, the study identifies a perceptual and contextual barrier category that extends previous classifications by highlighting the importance of adapting industrial symbiosis to regional conditions and changing perceptions of residual resources.

4.2 | Roles for Public Organisations

The thematic analysis of the interviews resulted in the identification of five different roles that *public organisations* can play to foster the development of industrial symbiosis. These roles are *policymaker*, *facilitator*, *knowledge broker and data provider*, *participant* and *financier*. The variety of roles that *public organisations* can play in the development of industrial symbiosis reflects the numerous and diverse barriers associated with it. In playing these roles, *public organisations* can help to mitigate these barriers and foster implementation and development of industrial symbiosis. Each role encompasses activities aimed at mitigating the associated barriers. Although some similar activities may appear across multiple roles, the distinction between roles is based on their primary governance purpose rather than the activity itself. Similar activities may therefore be undertaken under different roles depending on the objective they serve within the industrial symbiosis ecosystem. Figure 3 shows the coding tree that presents the different activities and roles.

The first role *public organisations* can play is that of *policymaker*, where strategy development serves as an important tool to create incentives and motives that influence the course of development. This can be on both the regional and the municipality level. The strategy creates incentives and motives for companies to invest in certain areas due to the strong link between the strategy and the project funding. Respondent B4 explained: 'Many projects are based on the regional development strategy. The regional strategy decides the areas that we can apply for funding in'. Therefore, it is highly important to create a strategy—either regional or municipal—that is based on regional and local conditions. In sparsely populated regions like Norrbotten with long distances between industries, the adaptation of the strategy is important. This is to create incentives for different types of initiatives to take shape, both in cities and the countryside, which face distinct barriers. With the help of a strategy focused on circularity and industrial symbiosis, a region or municipality can be *established as a hub for industrial symbiosis development*. The region's low self-sufficiency level can act as an accelerator, as mentioned by respondents A3, A8, A9, B4 and C7. Norrbotten, for instance, has a low self-sufficiency level of food production (Landquist and Behaderovic 2021). The strategy can work as a tool to increase incentives for companies to invest in new technologies and collaborations, thereby helping companies to scale

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operations and enhance overall regional food production. This is beneficial for the region and its municipalities, as it provides more jobs and, at the same time, helps them achieve higher levels of self-sufficiency. The importance of strategies and policies has been identified in previous research. Mortensen and Kørnøv (2019) recognised their essential role in the early phases of industrial symbiosis development, providing incentives for companies to adapt and implement the concept into their business models. Respondent A1 explained: 'We are responsible for the regional development strategy. As we renew it, we have gathered over 1500 inputs, which is why we are shifting focus, now placing much more emphasis on circularity and regional strengths'.

Strategic spatial planning and *driving the cultural shift towards acknowledging residuals as valuable resources* are other activities provided by the *policymaker* that can help foster industrial symbiosis. Respondent C6 highlighted the need for *strategic spatial planning:* 'It is important to create the right conditions by considering location, infrastructure needs, and who to engage with. Municipalities do not need to become experts but show curiosity, linking it to planning and vision'. Respondent B2 agreed and recounted a previous experience from the development of an industrial symbiosis network: 'They proactively created conditions by ensuring detailed plans and available land to be able to attract more actors in the future'. Respondent A1 highlighted the need for a cultural shift towards acknowledging residuals as valuable resources: 'To identify residuals as a resource, it requires volumes'. A1 also emphasised the need to engage the public in driving this shift: 'So it has to be at the consumer level somehow, that people can contribute that little extra'.

Other important activities the *policymaker* can provide are *promoting more efficient permit processes* and *creating public procurement criteria that promote local products*. The first creates additional motives for companies to implement industrial symbiosis. Effective permit processes reduce the barriers associated with obtaining permits and other regulatory burdens. Respondent A8 identified one benefit that Norrbotten possessed as a region: 'Those who establish themselves here do not have to go through a lot of intermediaries before reaching the person responsible. Instead, the decision-making paths are often short and efficient'. He continued: 'That does not mean the process moves quickly. But you do get through to the right person'. Respondent C3 cited the close relationship between the company and the municipality on spatial planning: 'We have been working with the municipality since we started. In the beginning, for example, because of all the infrastructure'. The *creation of public procurement criteria that promote local products* is important because it positions various *public organisations* as key long-term customers, helping to share the risks associated with the high costs of industrial symbiosis investments—a factor identified as critical for its development. Respondent A4 noted: 'Public organisations can provide the security needed to dare to invest, knowing there is a market for what you produce. I hope we will see more such collaborations across the region, given the great potential and need to increase production'. Public organisations primarily emphasised strategic planning and policy development, whereas producers highlighted the importance of procurement and efficient permitting processes.

The second role is the *facilitator*. This role is key within an industrial symbiosis network and can be played by both *public organisations* and private actors. Respondents noted the benefits of each approach, expressing a preference for companies finding each other independently, while conceding that some initial help may be required. Respondent B2 noted: 'The power of a company finding a business opportunity in taking on a facilitating role is the more companies they bring into the symbiosis, the more money they make'. B2 continued: 'The municipality initially acted as facilitator, stepped back once operations stabilised, but re-engaged during challenges. Today, around ten municipal employees work actively with symbiosis efforts'. This illustrates how the importance of a municipality as a facilitator can fluctuate during the evolution of industrial symbiosis development.

Two important activities for a *facilitator* are providing *opportunities to test both new technologies and relationships* and *creating projects to initiate change*. The importance of providing facilities for testing refers to the complexity of industrial symbiosis, where large investments in new technology and infrastructure are often required. Respondent B2 noted that a municipality had taken a facilitator role in an industrial symbiosis network and highlighted the importance of providing testing opportunities: 'Often, instead of going straight from idea to large-scale implementation, there is a need to test relationships, technology, or new applications, and they have created conditions for testing at different stages'. Many respondents explained that they participated in or facilitated projects with the purpose of identifying new ways to use residuals. Projects can be used to *initiate change* as they are time-based, with a clear beginning and ending. The *facilitator* can create projects to guide the development of industrial symbiosis in specific directions, which can be linked to the formulation of strategies and policies promoting industrial symbiosis. With such strategies, it is easier for the *facilitator* to initiate and secure funding for projects related to industrial symbiosis, thereby driving the transition towards a circular economy.

Another important responsibility of a *facilitator* is *establishing structures for collaboration between various actors*. This includes supporting the creation of *circular agreements*, providing guidelines on setting up *long-term contracts* between providers and users of residuals within the network, and securing *information sharing*. *Public organisations* acting as *facilitators* can ensure that confidential information shared within the network is securely protected, fostering trust among members and mitigating trust-related barriers, such as *resistance to sharing information, as* noted by both respondents and researchers (Golev et al. 2015; Mirata 2004). This approach ensures that the network both enhances overall performance and benefits each individual company or organisation involved. *Public organisations* can provide secure solutions for the network, such as *online platforms* that provide information on residuals, members and potential partners. Other structures to mitigate barriers related to *circular agreements* and *resistance to information sharing* include regular communication and meetings. Respondent A2, who worked in the region, noted: 'My colleagues working with business support aim to visit each local business function once or twice a year, physically or digitally, to meet companies with development ideas and explore possible support, often in collaboration with other actors'.

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It is also important to prevent situations such as the one described by C6 under the *cooperation barrier*, where the collaboration had to be terminated because the partner proceeded without using residuals. The *facilitator* should strive to avoid such situations by providing the network with *structures for collaboration*. These structures should tackle trust issues arising from the risk of partners shifting to other resources by removing barriers to the use of residuals and facilitating the identification of suitable partners. Respondent B2 noted: 'The municipality has maintained a helicopter perspective, identifying current needs and barriers, helping remove obstacles, and facilitating matchmaking to find collaboration partners'. Respondent A2 asserted: 'We work to build structures that support the entire food chain, from farming and processing to distribution and consumption, collaborating with key actors like LRF, the county administrative board, the university, businesses, and business promoters'.

Platform identification is important as it can mitigate the barrier of *difficulty in identifying the right collaboration partner*. B4 noted: 'For larger companies, establishing collaboration forums with smaller firms can help transform residuals into business opportunities, creating mutual growth and unlocking synergies between them'. Events and workshops hosted by *public organisations* or other actors, such as private companies, non-profit organisations and interest organisations, where companies can meet and collaborate provide additional platforms for identifying new partners. Respondent B4 remarked: 'We connect smaller companies, often food producers, to explore new business opportunities, build networks, and find symbiotic collaborations where one's waste becomes another's valuable resource'.

The third role that *public organisations* can play is *knowledge broker and data provider*. Here, the key element is to enhance knowledge about industrial symbiosis by providing activities such as *contributing expert knowledge*, *participating in projects*, *developing industry-specific training programmes* and *providing industrial symbiosis networks with knowledge-enhancing initiatives*. Respondent B4 stated: 'We need experts from consulting, public sectors, or research to address the whole system. It is crucial to consider the entire chain of inputs, outputs, waste flows, and knowledge, not just isolated parts'. Respondent A8 explained that a university or research institute could contribute expert knowledge by participating in a project: 'If there are calls for pilot projects, involving top researchers can speed up solutions. This was part of the intelligent food production system, using sensors and cameras to monitor growth and measure various parameters'. This illustrates how *public organisations, acting* as knowledge brokers, can play an important role in enhancing understanding of the industrial symbiosis concept and support its continuing development.

Concerning the need to provide activities related to *developing industry-specific training programmes*, respondent C9 noted: 'We need support from municipalities and authorities, especially to review education programmes. There is high demand in automation due to industrialisation, but we also need opportunities from a young age to train in food production'. Respondent C6 emphasised the importance of reviewing how schools and universities can better support the food industry through education, stating: 'I would say naturally Luleå University, schools, and public kitchens. It is also interesting what students learn about food, food systems, and production, not just small-scale units'. These two quotations provide important insights into the need for *public organisations* to attract new people who recognise the opportunities of using industrial symbiosis approaches to enhance food production efficiency and develop new innovative products.

Respondent C8 exemplified how *public organisations* can provide *knowledge-enhancing* activities such as study trips: 'They went on study trips and built a strong network, which I think is essential. It is worth investing in long-term collaboration to support development and strengthen the region'. Respondent A8 made reference to a historically established network of companies from the food industry in the region: 'They went on study visits together and had a strong network, from what I understand. I believe that kind of collaboration is important long term, working together on development to strengthen this region'. However, this network was no longer active, which has resulted in less collaboration between local companies today. This highlights the need to provide different types of knowledge-enhancing programmes, delivered through projects, education programmes or field trips, all aimed at improving understanding of the industrial symbiosis concept, identifying new products, developing more efficient production solutions and attracting new workers. Universities and support actors primarily emphasised education and knowledge exchange, whereas producers stressed the need for practical technical expertise.

The fourth role that *public organisations* can play is that of *participant*. In this role, *public organisations* are more actively involved in the operations of the industrial symbiosis network. One of the key activities in this role includes *cooperating to build stronger competitiveness*. This may take different forms, including acting as a customer. If *public organisations* require products produced by an industrial symbiosis network, they can become long-term customers to reduce the risks associated with industrial symbiosis investments. Respondents A4, A9, C3, C5, C6 and C9 commented that risks with high investment costs could have a negative impact on companies' willingness to invest in industrial symbiosis initiatives. In the case of the food sector in Norrbotten, *public organisations*—the *region*, the *municipalities* and the *universities*—can all choose local products to foster the local food industry and become the stable long-term customer needed to reduce the risks associated with high investment costs. These actors have a large demand for food in their operations, such as in schools, elderly care facilities and events. A4 noted: 'As a municipality, we have a constant need for purchases. Acting as an enabler is key, but since companies bear all risks, it is difficult for them to invest'. Meanwhile, B5 highlighted the potential for *public organisations* to become key customers: 'I see several opportunities, municipalities and regions can act as key customers by directing procurement towards local suppliers, creating markets and boosting local business much more than they currently do'.

Another important activity provided by the *participant* is *helping to bridge the gap between the industry and the public*. Respondent C3 referenced close collaboration with the local municipality: 'We have worked closely with the municipality to create new ski trails and a snowmobile path, allocating resources to support this. Their cooperation has been essential'. This is intended

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to reduce the risk and impact of *public opposition* to industrial developments.

The other three activities—*hosting events and networking opportunities*, *involving passionate individuals who drive initiatives forward* and *providing value to companies through project outcomes*—focus on the potential of *public organisations* as project owners (owners or coowners), with people from *public organisations* acting as project leaders. Having a passionate individual in the role of project leader can drive the development of industrial symbiosis and deliver concrete value through project outcomes. Respondent B2 noted: 'It takes someone willing to go beyond routine, see the potential, believe in it, and inspire others to think and act differently'. Respondent A6 also highlighted the need for passionate and knowledgeable individuals. Respondent C6 stated: 'I believe the best approach is time consuming, you need to visit food producers to ask about their residual streams, what happens to them, and exploring opportunities, while connecting people and gathering detailed insights'.

Ensuring that projects result in long-term benefits is another key aspect of the participant role. B4 remarked: 'I believe it is important to build on the results that have emerged from various initiatives and projects and incorporate them into a broader, more holistic perspective', whereas C8 highlighted the benefits of one of the projects in which they participated: 'The difference lies in having the lab and the resources to actually develop a final product, that is what sets this apart from previous projects'. This underscores the need to create projects that provide value for the industry and ensure that its outcomes have long-term benefits.

Lastly, *public organisations* can play the role of *financier*. In this capacity, key activities focus on providing different kinds of support through *public funding*. *Public organisations* can provide public funding through business support, as respondent A2 noted: 'We have, among other things, designed targeted support for food processing companies within our business support programmes'. Through this type of funding, *public organisations* can direct their funding to certain industries or categories of companies. This can be used to foster industrial symbiosis and circularity among local companies. In addition to business support funding, *public organisations* can provide specific funding streams related to projects. Three of the respondents—A9, A10 and A11—were project leaders focusing on industrial symbiosis and managing residuals to identify new business opportunities. Respondent A11 noted: 'We have applied for funding from Vinnova and the European Social Fund, and in both projects, we received co-financing from Region Norrbotten'. The regional funding in the form of project funds is also highlighted by respondent A2: 'These project funds are key to driving change. Our contribution is usually part of the total, with EU funding as the main source and us as co-financiers'. Public funds can be a part of the total funding, as respondent C6 mentioned 'We applied for funding with partners to build the physical lab and received support from the EU, the region, and others. Now we have 16 million SEK over three years to run the lab'. This type of public funding is often provided at the regional or municipal level or from the EU, with the EU supplying the main funding and regions and municipalities acting as cofinanciers.

A third type of public funding comes from specialised national funds focusing on large-scale sustainable projects. Some of the interviewed companies received finance from these national funds for investment in larger circularity projects. One such national fund mentioned by C4 and C9 was *Klimatklivet*, which focuses on larger sustainability investments. Because this type of public funding does not fully cover the investment, companies must seek additional finance from other sources. Respondent C9 explained: We funded our sustainability investments partly with our own capital, support from the bank, and co-financing from Klimatklivet. For example, some investments at the farm were partially funded through Klimatklivet alongside bank loans and equity. *Public organisations* performing the financier role can also guide companies on how to combine their funds with other types of funding streams. This is due to the variety of funding types, both public and private. Respondent A5 explained how they had combined funds from different organisations: 'So we launched the project, with us as the project owner. It is funded by the Tillväxtverket and the region', similar to C9's comment regarding their sustainability investments.

5 | Discussion and Framework Development

From an ecosystem governance perspective, industrial symbiosis depends on governance mechanisms that coordinate diverse actors, facilitate collaboration and address barriers that hinder the development of resource exchange networks (Adner 2017; Jacobides et al. 2018). The findings on industrial symbiosis barriers, together with the identified roles, formed the basis for Figure 4, which illustrates how the importance of different public-sector roles and barriers fluctuates during the development of industrial symbiosis. The framework was developed by integrating the empirical findings with the evolution phases proposed by Golev et al. (2015) and Mortensen and Kørnøv (2019). The evolution phases were therefore derived deductively from the existing literature, whereas the roles emerged inductively from the thematic analysis. The placement and relative importance of each role and barrier within the different phases were determined through an iterative interpretation of the interview data, considering respondents' descriptions of when specific activities, roles and barriers were most critical. Consequently, the curves and barrier boxes in Figure 4 represent a qualitative assessment rather than a quantitative measurement. The vertical position indicates the relative importance of both roles and barriers, whereas the horizontal position and length of each barrier box indicate the phases during which the barrier is particularly important.

Similarly, the contingency framework (Table 2) was developed by comparing the identified barriers with the activities associated with each role. Relationships were assessed based on the extent to which respondents described a particular role as contributing to the mitigation of a specific barrier category. The relationship scale presented below Table 2 (strong, moderate, weak or no relationship) therefore represents an interpretive synthesis of the qualitative findings rather than a numerical scoring system. An important finding is that different divisions within a public organisation may simultaneously adopt different governance roles depending on the needs of the ecosystem and the stage of industrial symbiosis development.

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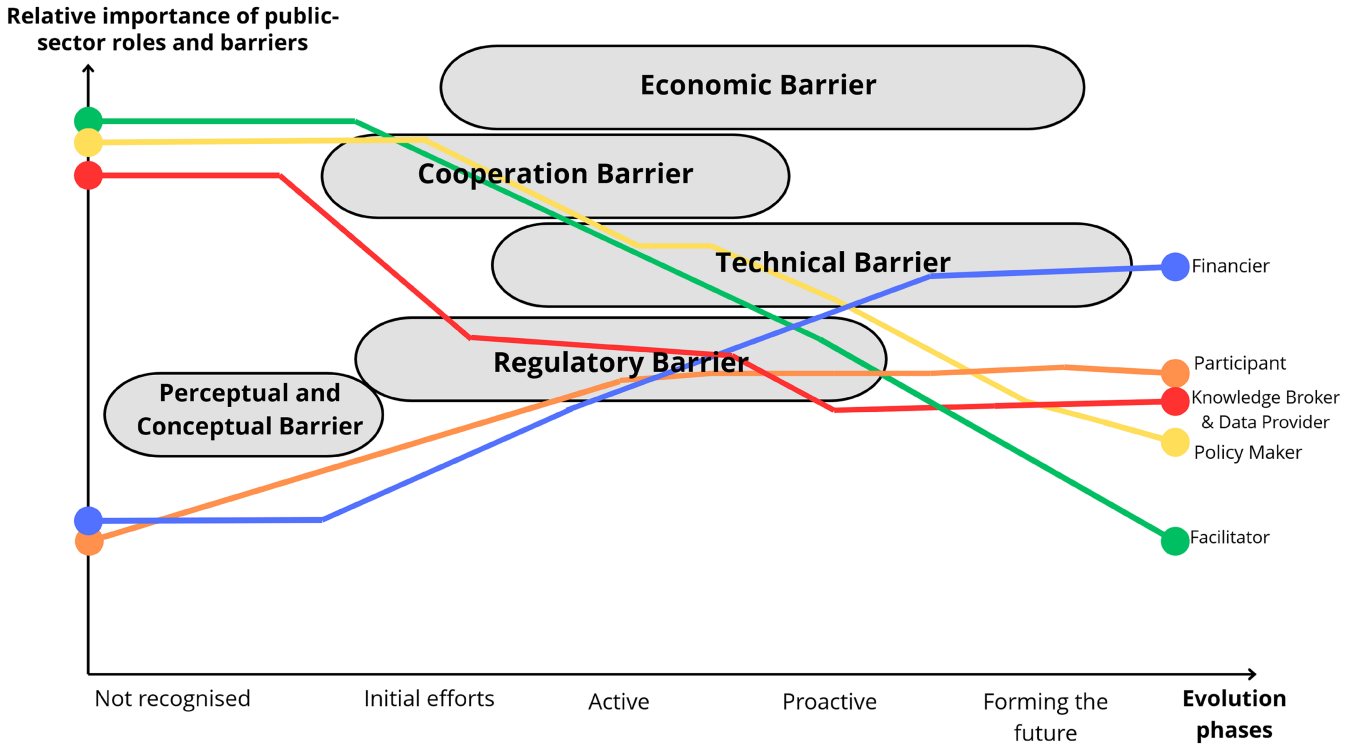

FIGURE 4 | Evolution of public-sector roles and barriers during industrial symbiosis development.

TABLE 2 | Contingency framework with roles and barriers.

	Policymaker	Facilitator	Knowledge broker and data provider	Participant	Financier
Economic barriers	+	+	+	+	+++
Cooperation barriers	+	+++	+	++	–
Technical barriers	+	++	++	++	+
Regulatory barriers	+++	+	+	+	–
Perceptual and conceptual barriers	++	++	++	+	–

Note: Relation: +++ strong relation. ++ moderate relation. + weak relation. – no relation.

In the first phase, the *perceptual and conceptual barriers* exert an impact on the development of industrial symbiosis. This is based on the concepts identified within this barrier category, such as the need to recognise *residuals as valuable resources* and to *adopt a holistic perspective*. This is in line with Golev et al. (2015) who noted that companies show limited interest and understanding of benefits associated with industrial symbiosis in the early phases. In the later phases, understanding and interest increase, which reduces the impact of this barrier. To mitigate this barrier, the roles of *policymaker*, *facilitator*, *knowledge broker and data provider* are particularly important, whereas the *participant* role is more limited. This underscores the critical importance of the three roles in the early phases. The *policymaker* can create interest and incentives for companies to explore opportunities for collaboration and the implementation of industrial symbiosis. This can be achieved through *strategies* and *policies*, such as *a regional strategy focusing on circularity and industrial symbiosis*, or *public procurement criteria that promote local products*. The strategy has to be adapted to regional and local conditions to promote various types of industrial symbiosis networks, particularly in sparsely populated regions such as Norrbotten, where Type 4 and Type 5 networks, as described by Chertow (2000), are more suitable due to the long distances between cities and industries. Although the creation of a colocated eco-industrial park may be preferred in cities, strategic *spatial planning* remains essential. *Public organisations* play an important role as *facilitators* in the early phases by demonstrating the benefits of industrial symbiosis particularly in facilitating the formation of early networks, as private companies often do not perceive the economic advantages of facilitating such networks at this stage. The *knowledge broker and data provider* possess expert knowledge in the field and have an important role to play in educating other actors. Universities and other *public organisations* can offer *education programmes*, *implement knowledge enhancing initiatives* and *participate in projects* to increase general understanding of the concept.

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Regulatory barriers have their strongest impact during the three middle phases. This is because the number of initiatives and projects increases (Golev et al. 2015), which gives rise to more regulatory issues, such as permits, environmental legislation and policies. This is because it takes time to establish effective processes for submitting and reviewing permit applications and to adapt the current laws and regulations to fit the new circular economy model and the adoption of industrial symbiosis. The *policymaker* has a strong relation to this barrier category as it plays an important role in mitigating it, due to its responsibility for regulations and policies. This can be achieved by *promoting more efficient permit processes*, *spatial planning*, *implementing strategies and policies* and *creating public procurement criteria*. Mortensen and Kørnøv (2019) referred to the importance of implementing policies to create awareness of industrial symbiosis, especially in the early phases. The *facilitator* can *create structures for collaboration*. The *knowledge broker and data provider* can assist with *expert knowledge* on how to adopt the regulations, whereas the *participant* can contribute to *projects* by providing the network with valuable insights regarding companies' and other actors' views on regulations and permit processes. These three roles are only weakly related to the *regulatory barriers*.

The *technical barriers* have their strongest impact in the later phases, due to the increased frequency of implementation and adoption of new initiatives and projects related to industrial symbiosis. As companies and organisations explore new ways to use residuals as resources to create new products, there is a strong demand for technology and expert knowledge. Another barrier associated with the increasing number of initiatives is logistic issues, as highlighted both in interviews and in the existing literature (Fric et al. 2025). The *facilitator*, *knowledge broker and data provider*, and *participant*, are moderately related to these barriers and play important roles in mitigating them. The *facilitator* provides the network with the testing facilities to simplify the transition from an idea to a pilot test and, ultimately, to full-scale production. The *knowledge broker and data provider* contribute with expert knowledge and data, which aligns with the findings of Golev et al. (2015) regarding the need to engage research institutions, universities and consultants to access such expertise. The *participant* contributes by creating value from project outcomes that can be used to mitigate technology and logistic issues. The roles of *policymaker* and *financier* are weakly related to the technical barriers. They can support mitigation by d*riving a cultural shift* or *providing guidance on how to fund* initiatives and projects.

The *cooperation barriers* have their strongest impact during the middle phases. With the growing number of networks, the importance of certain factors becomes more pronounced. This was identified in both the interview data and in the existing literature, including the *selection of appropriate collaboration partners* (Neves et al. 2020), *maintaining a high level of collaboration* (Yazan and Fraccascia 2020) and facilitating *information sharing* (Golev et al. 2015). The *facilitator* is strongly related to the cooperation barriers, playing an important role in their mitigation by facilitating *information sharing* and identifying and supporting the *selection of appropriate collaboration partners*. The *participant* is actively involved in collaboration with other actors within a network, either as a *project leader* or as the *host of events and workshops*. These activities are important because they create a first contact between potential collaboration partners. The roles of *knowledge broker and data provider*, and *policymaker*, are weakly related to cooperation barriers. They support their mitigation by providing knowledge-enhancing initiatives such as field trips and education programmes. This can broaden the perspectives of potential collaboration partners and deepen their understanding of the key factors to consider when selecting a partner. The *policymaker* can support the identification of partners and information sharing processes by creating *policies* and *strategies* that encourage companies and other actors to join networks.

Economic barriers have their greatest impact in the middle and later phases. In the first phase, the interest in industrial symbiosis is confined to private companies. This is due to limited understanding of its benefits, both environmental and economic (Golev et al. 2015). The result is a low number of initiatives and projects related to industrial symbiosis. In the second phase, networks begin to emerge, with the consequent need for financing. Actors then need to mitigate these economic barriers to further develop and implement industrial symbiosis. The *financier* has a strong relationship with economic barriers and plays an important role in mitigating them. It does this by reducing the impact of factors that were identified in both the interviews and the existing literature—*high investment costs* (Domenech et al. 2019) and *difficulties in attracting external investors* (Corsini et al. 2024) through the provision of *public funding*, *project funding* and *support for attracting external investors*. Other roles with a more limited relationship are *policymaker*, *facilitator*, *knowledge broker and data provider* and *participant*. The *policymaker* can contribute by creating policies and strategies promoting industrial symbiosis initiatives. The *facilitator* can provide the network with testing opportunities to reduce the risk inherent in large-scale projects, particularly those associated with *moving from pilot tests to scalable and economically viable businesses*. The *knowledge broker and data provider* can provide *expert knowledge* and reduce the challenges related to *identifying a financially viable business model*. The *participant* can act as a key *long-term customer*, helping to reduce the risk of *high investment costs* for companies.

The roles of *policymaker, facilitator* and *knowledge broker and data provider* played by *public organisations* are most important in the early phases. The *policymaker* can increase interest in the concept by creating *strategies* and *policies* that provide incentives for companies to adapt industrial symbiosis. The *facilitator* plays a role because projects need support, and private companies often do not recognise the economic benefits in these early phases, showing limited interest in facilitating them. The *knowledge broker and data provider* contribute their *expert knowledge*. The importance of these three roles declines in the later phases, as interest and understanding from other actors increase. This results in a reduced need for completely new strategies and policies to be established, as private companies show a greater interest in facilitating due to the economic benefits identified, and other actors demonstrate enhanced understanding of the concept. The roles of *participant* and *financier* are less important in the early phases due to limited activity related to industrial symbiosis. The importance

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of both roles increases in the later phases as the number of projects and initiatives grows, creating a greater need for participation and financing. From an ecosystem governance perspective, these findings demonstrate that public organisations do not perform a single governance function throughout industrial symbiosis development. Rather, they adopt different governance roles as the needs of the ecosystem evolve, shifting from enabling and coordinating collaboration in the early phases to supporting implementation and long-term development in the later phases. This dynamic perspective extends previous research by highlighting that effective ecosystem governance depends not only on the presence of public organisations but also on their ability to adapt their roles to the changing requirements of industrial symbiosis development.

The proposed framework also highlights that the involvement of public organisations is not without potential tensions and trade-offs. Although public organisations can facilitate collaboration, coordinate actors and reduce barriers, they must simultaneously balance multiple and sometimes conflicting objectives, including economic development, environmental sustainability, regulatory compliance and public accountability. This reflects recent discussions in the industrial symbiosis literature, which argue that public actors must navigate complex governance arrangements while balancing the interests of multiple stakeholders (Fric et al. 2025; Palagonia et al. 2025). Similarly, recent research has shown that the decision to engage in industrial symbiosis is influenced by strategic considerations and uncertainty regarding collaboration, highlighting the importance—but also the limitations—of public organisations in reducing these uncertainties (Mollica et al. 2024). Consequently, public organisations should not be viewed as permanent coordinators of industrial symbiosis ecosystems. Rather, from an ecosystem governance perspective, their governance roles should evolve alongside the maturity of industrial symbiosis initiatives, with greater responsibility gradually transferred to private and hybrid actors as collaboration becomes institutionalised (Jacobides et al. 2018; Adner 2017). This dynamic view complements previous studies that have primarily conceptualised public organisations as facilitators by demonstrating that effective ecosystem governance depends on the ability of public organisations to adapt their governance roles as industrial symbiosis ecosystems evolve (Paquin and Howard-Grenville 2012; Fric et al. 2025).

6 | Conclusion

This study examined how public organisations foster industrial symbiosis by adopting different roles throughout the evolution of industrial symbiosis development. Drawing on a qualitative case study in northern Sweden, the findings identify five governance roles that public organisations can adopt and demonstrate that their relative importance changes as industrial symbiosis initiatives mature. By integrating these roles with identified barriers and evolution phases, the study develops a phase-based framework that advances understanding of ecosystem governance in industrial symbiosis while providing practical guidance for public organisations supporting circular economy transitions.

6.1 | Theoretical Contribution

This study contributes to the industrial symbiosis literature by advancing understanding of the dynamic roles that public organisations play in fostering symbiotic networks. The study demonstrates how public organisations contribute to governing industrial symbiosis ecosystems by coordinating actors, reducing barriers and creating conditions that enable collaboration throughout different phases of development. Prior research had identified that private companies typically assume the primary, 'active' roles in resource exchanges, whereas public organisations serve supportive functions. However, the specific nature and timing of these public-sector contributions have remained underexamined. Responding to Mortensen and Kørnøv's (2019) call for research on groups of actors across the industrial symbiosis development phases, our findings map out five distinct roles for public organisations—policymaker, facilitator, knowledge broker and data provider, participant and financier—and illustrate how their importance fluctuates over the evolutionary phases of industrial symbiosis. In doing so, we extend the general insights of Mortensen and Kørnøv (2019) by focusing specifically on public organisations as critical actors, detailing how they strategically shift roles from initiating collaborations to supporting mature synergies. Notably, the research demonstrates that public organisations are not monolithic in their involvement: Different agencies or even divisions within a single public organisation can simultaneously adopt different roles to meet various needs. Rather than performing a single governance function, public organisations adapt their governance roles as industrial symbiosis ecosystems evolve, highlighting the dynamic nature of ecosystem governance. This nuanced perspective builds on earlier observations that public actors are crucial facilitators, offering a more granular view of how and when these facilitating and supportive activities are employed throughout the symbiosis development process.

Furthermore, this work enriches theoretical understanding by linking public-sector roles to the specific barriers and success factors identified in industrial symbiosis initiatives. We developed a contingency framework connecting the five roles with common barrier categories (economic, cooperation, technical, regulatory and perceptual) faced during symbiosis development. This approach bridges the gap in prior frameworks such as Golev et al. (2015), which delineated critical factors and maturity stages, by explicitly showing how public organisations can mitigate each type of barrier. The findings corroborate the barrier classifications of earlier studies—for instance, the economic, cooperation, technical and regulatory challenges observed in our case align with the categories reported by Mirata (2004) and Golev et al. (2015). At the same time, we extend the literature by identifying a perceptual and conceptual barrier category that had received less attention in previous work. This category captures issues such as the mismatch between global circular economy narratives and local industrial realities and the need for firms to adopt a holistic view of residual resource value. By highlighting this perceptual barrier—alongside newly documented challenges such as time-consuming regulatory procedures and the risk of projects ending without lasting value—our study adds conceptual depth to the understanding of what impedes industrial symbiosis adoption. Overall, by integrating

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a roles-based perspective with barrier mitigation across the development stages, this research extends both the industrial symbiosis and ecosystem governance literature. It demonstrates that effective ecosystem governance is not characterised by a single governance mechanism but by the ability of public organisations to adapt their governance roles to the changing needs of the ecosystem over time. In doing so, the study complements earlier phase-based models (e.g., Mortensen and Kørnøv 2019) with a richer explanation of how public organisations contribute to governing industrial symbiosis ecosystems throughout their evolution.

6.2 | Managerial Implications

From a practical standpoint, the findings offer valuable guidance for public-sector managers and other ecosystem stakeholders seeking to stimulate industrial symbiosis. Firstly, the contingency framework can be used as a diagnostic and planning tool for public organisations. By identifying the dominant barriers in a given context—be it economic constraints, coordination difficulties, technical gaps, regulatory hurdles or perception problems—public managers can determine which role(s) their organisation is best positioned to play in overcoming those challenges. For example, if businesses are hesitant to engage due to unclear benefits (a perceptual barrier), public agencies might emphasise the policymaker role to create incentives or the knowledge broker role to educate and demonstrate the value of circular practices. If regulatory complexity slows down symbiosis projects, public actors in the policymaker role can streamline permitting processes or adapt policies to facilitate exchanges. In essence, managers should strategically match their interventions to each barrier, using the framework's mapping of roles to barriers as a practical guide.

Secondly, our phase-based evolution map provides insights into how public organisations can time their involvement for maximum impact. In the early phases of industrial symbiosis development, when private firms may not yet recognise the economic potential of exchanging residual resources, public organisations have a crucial catalyst function to perform. They should proactively adopt the facilitator role to convene actors, broker initial connections and even provide shared infrastructure or pilot testing environments. Our case showed that a public body acting as facilitator in the nascent stages helped jump-start collaboration that otherwise would not occur due to the lack of immediate profit incentives. As initiatives progress and the network of firms begin to see tangible benefits, the need for direct public facilitation should lessen. Public managers can then adopt more supportive or oversight positions—for instance, stepping back to let private companies lead the day-to-day coordination, while continuing to provide guidance and policy support in the background. This dynamic handoff is exemplified by the finding that public organisations may begin as facilitators but later transition to a supporting facilitator role or advisory stance once the industrial ecosystem becomes self-sustaining.

Thirdly, public organisations can directly bolster the business viability of symbiosis initiatives by embracing roles such as participant and financier in targeted ways. In our study, when high upfront investment costs threatened the implementation of novel resource exchanges (an economic barrier), a public organisation helped mitigate this by acting as a key customer and reliable end user of the new synergies' outputs. Such a participant role—for example, a municipality committed to purchasing biogas generated from local industrial waste—reduces demand uncertainty and investment risk for private firms, thereby encouraging them to proceed with symbiotic projects. Similarly, as financiers, public actors can offer seed funding, grants or assistance in securing external investment for industrial symbiosis ventures, addressing the financial barriers that companies may not be able to overcome alone. Managers in public agencies should note that these more direct forms of involvement may be pivotal in the middle to later stages of symbiosis development, when scaling up pilot projects or infrastructure requires both capital and confidence. By thoughtfully adopting and later ceding these roles at appropriate times, public organisations not only facilitate the launch of industrial symbiosis networks but also help embed them into the regional business ecosystem. In sum, the practical implication is that public managers must be flexible and responsive, ready to act as policy enablers, network builders, knowledge providers, partners and financiers as circumstances require, thereby nurturing industrial symbiosis from concept to sustained practice.

6.3 | Limitations and Future Research

This study has both contextual and conceptual limitations that open pathways for future research. Empirically, it is grounded in a single regional case in northern Sweden (Norrbotten), a sparsely populated area characterised by long distances between industries and a strong public-sector presence. These contextual factors are likely to influence the prominence of certain roles—particularly the importance of facilitation and financing by public organisations. The purposive and snowball sampling focused on actors already engaged in industrial symbiosis, with many respondents representing the food sector. Consequently, some identified barriers and activities may reflect sector-specific or regional characteristics rather than universally applicable patterns. In the short term, future research should focus on comparative studies across different sectors, regions and governance contexts to assess the transferability of the framework. A comparative multiple-case study approach would be particularly suitable, as it would enable researchers to examine how industrial structure, geographical conditions and institutional environments influence the roles adopted by public organisations. Such studies would help identify which findings are context-specific and which are applicable across different industrial symbiosis settings.

A further limitation relates to the study's focus on public organisations. Although this focus was necessary to address the research purpose, it means that the interactions between public organisations and other actor groups, such as private firms, intermediaries and non-profit organisations, were examined only to a limited extent. Future research should therefore adopt comparative approaches to investigate how the roles of public organisations complement, overlap with or differ from those of other actors involved in industrial symbiosis development. Comparative multicase studies across different sectors and governance contexts could provide a more comprehensive

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understanding of ecosystem governance and collaboration dynamics.

Another limitation concerns the broad categorisation of public organisations. The study includes municipalities, regional authorities, universities and development agencies despite their differing mandates, resources and institutional responsibilities. As a result, potential variations in role adoption and coordination between different types of public organisations were not examined in detail. Future research should therefore investigate how these differences influence the roles adopted by public actors and their contribution to industrial symbiosis development. In addition, longitudinal studies are needed to examine how these roles evolve over time as industrial symbiosis initiatives mature. Such research could provide insights into whether public organisations adapt their roles, withdraw as market actors assume greater responsibility or institutionalise long-term support through policies, infrastructure and governance mechanisms.

Author Contributions

Henrik Drugge: conceptualization, methodology, software, data curation, formal analysis, validation, investigation, visualization, writing – original draft, writing – review and editing. **Wiebke Reim:** conceptualization, methodology, investigation, validation, supervision, funding acquisition, project administration, resources, writing – original draft, writing – review and editing.

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Conflicts of Interest

The authors declare no conflicts of interest.

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