

INDUSTRIAL SYMBIOSIS FOR SMALL BUSINESSES: A SOCIAL-ECONOMIC PERSPECTIVE

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Abstract: Industrial symbiosis, which is an integral to the circular economy, involves collaborative resource exchanges for economic and environmental benefits. In industrial symbiosis networks, large enterprises dominate resources and benefits. Yet, Small and Medium sized Enterprises (SMEs) which are often the driver of sustainable development struggle to implement industrial symbiosis because of their more informal management structure. When collaborating without the involvement of large companies, SMEs often face operational challenges. This study investigates the socio-economic factors influencing the adoption of industrial symbiosis among small and medium-sized enterprises (SMEs) and explores its potential contribution to their sustainable competitive advantage. A systematic literature review of 90 articles was conducted, revealing publication trends, high-frequency keywords and industry distribution through descriptive analysis. The thematic analysis identified five key socio-economic themes, with two themes analysed in depth in this paper, revealing crucial research gaps and offering promising areas for future research. Limitations include the potential exclusion of relevant articles, incomplete analysis of the remaining three socio-economic themes and a lack of empirical research to support the findings. Future research directions are to investigate the remaining themes and conduct empirical studies involving SME stakeholders, policymakers and academics to further enhance the understanding and implementation of industrial symbiosis for sustainable competitive advantages for SMEs.

Keywords: Industrial symbiosis; SMEs; Circular economy; Socio-economic impact; Sustainable development

1. INTRODUCTION

Industrial symbiosis is a key concept within industrial ecology, which encourages collaborative exchange of resources (materials, energy, water, by-products) for mutual economic and environmental benefits (Cavalcanti et al., 2020; Lütje & Wohlgemuth, 2020). Symbiosis is a critical component of the circular economy, since it maximises the use of resources and energy while reducing emissions (Yazan & Fraccascia, 2020; Zhu et al., 2021). Arguably, SMEs are crucial to implementing sustainable development goals, but often they lack an awareness of eco-friendly production practices (Tan et al., 2022). Due to their less formal management structures than large organisations (Dwikat et al., 2023), SMEs find it difficult to overcome the lack of awareness on sustainable manufacturing techniques. This weakness creates challenges for SME owners and managers in their pursuit of competitive performance and sustainable advantage (Suryantini et al., 2024).

SMEs view industrial symbiosis as a viable business model for cost-sharing and cost-reduction solutions, supported by research from Carissimi et al. (2023), Cicchiello et al. (2023), Tan et al. (2022), Yazan & Fraccascia (2020), Giannoccaro et al. (2023), Daquin et al. (2023), and Mallawaarachchi et al. (2023). Studies by Ahmad Fadzil et al. (2022) and Corsini et al. (2022) even suggest a potential 25% profit boost in the initial stages of adopting industrial symbiosis. However, long-term profitability, particularly under uncertain product demand, requires further investigation as highlighted by Daş et al. (2022).

Social and coordination skills are recognised as facilitators of symbiosis (Haller et al., 2022). However, individual factors which play a crucial role for successful implementation, such as skills development (Rentería Núñez & Perez-Castillo, 2023), human capital (Dwikat

et al., 2023; Suryantini et al., 2024) and skilled labor availability (Oughton et al., 2022), remain under-researched. While the economic and environmental benefits of industrial symbiosis are well-studied, its social dimension, including socio-economic impacts like job creation and community well-being (Chen et al., 2022) and the role of socio-political factors in forming symbiosis relationships (Neri et al., 2023), remain under-researched. Hence, this study aims to explore the socio-economic factors of industrial symbiosis for offering SMEs a sustainable competitive advantage. Consequently, two research questions are formulated to guide the investigation.

- Research question – 1 (RQ-1): To what extent does industrial symbiosis contribute to the socio-economic development of small businesses?
- Research question - 2: (RQ-2) What are the key socio-economic factors that influence small businesses' adoption of industrial symbiosis?

This paper follows a structured format. Section 2 establishes the conceptual foundation. Section 3 details the chosen methodology for the literature review, including data collection from publication databases, the filtering process, and data analysis techniques. Section 4 presents the descriptive and thematic analyses, respectively, culminating in the interpretation of findings to address the research questions. The discussion in Section 5 identifies research gaps and further elaborates on the findings, leading to the development of a conceptual framework and research propositions. Finally, the paper concludes by summarising its contributions to knowledge, implications for socio-economic factors in industrial symbiosis, limitations and opportunities for future research.

2. CONTEXTUAL BACKGROUND

2.1 *Industrial Symbiosis Drives Business and Environmental Performance*

Chertow et al. (2008) established industrial symbiosis as a powerful tool for achieving economic and environmental benefits in regional development. Building on this foundation, Deutz & Lyons (2008) further emphasised the potential of industrial symbiosis to enhance the environmental performance of firms that adopt it. These studies have laid the groundwork for understanding industrial symbiosis as a driver of both business and environmental sustainability.

In recent years, research on industrial symbiosis has shifted its focus towards the challenges faced in implementing it. Two key factors influencing the decision of a company to adopt symbiosis are geographical proximity and a strategic alignment with other businesses (Lucia Mortensen et al., 2023; Oughton et al., 2022). Interestingly, studies suggest that companies producing a single product type may be more receptive to symbiosis compared to those with diversified product lines (Cavalcanti Sá de Abreu et al., 2020; Zhu et al., 2020).

2.2 *SMEs as Sustainability Leaders*

Industrial symbiosis offers a promising business model for SMEs, presenting both economic and environmental benefits (Akhtar et al., 2022; Mura et al., 2020). However, to ensure profitable ventures, understanding successful models from the SME perspective is crucial (Kokoulina et al., 2019). While large enterprises can add complexity to these networks due to their significant influence (Xue et al., 2023), the key challenges for SMEs lie in identifying suitable partners, navigating internal cultural shifts and developing the necessary skills for adoption (Noegroho & Wijaksono, 2023; Herbst, 2023; Rentería Núñez & Perez-Castillo, 2023). Furthermore, a current preference for recycling over reduction and reuse methods

highlights a potential knowledge gap, limiting the exploration of various circular economy strategies (Carissimi et al., 2023). By addressing these challenges and cultivating awareness, SMEs can unlock their full potential as sustainability leaders through industrial symbiosis.

2.3 *Challenges in SME Participation of Industrial Symbiosis*

Studies demonstrate that cost-sharing strategies can reduce the financial burden for businesses participating in industrial symbiosis (Daquin et al., 2023; Giannoccaro et al., 2023; Yazan & Fraccascia, 2020). However, a common misconception persists among SMEs that sustainable practices like symbiosis are expensive (Mura et al., 2020). A knowledge gap exists regarding the reasons why SMEs perceive industrial symbiosis as expensive. Addressing this gap can strengthen the economic case for symbiosis adoption.

SMEs face two barriers to participating in industrial symbiosis. High upfront costs associated with technology, training and implementation challenges are significant hurdles (Ali et al., 2021). Additionally, limitations in product pricing, infrastructure investment considerations and the lack of financial risk assessment models further complicate matters for SMEs (Castellet-Viciano et al., 2022; Liu et al., 2023). Understanding these economic challenges is crucial for overcoming hesitancy among SMEs and promoting wider adoption of industrial symbiosis.

While studies have shown economic benefits for SMEs, including a 25% profit increase through symbiosis adoption (Ahmad Fadzil et al., 2022), there is a knowledge gap regarding cost variability and uneven benefit distribution within symbiosis networks (Corsini et al., 2022; Harfeldt-Berg & Harfeldt-Berg, 2023; Noori et al., 2023). This gap is due to large companies

capturing a larger share of the benefits within symbiosis (Xue et al., 2023). Despite these challenges, understanding these cost variations and ensuring a more equitable distribution of benefits will be crucial for maximising the potential of symbiosis for all participants, especially SMEs.

2.4 The Social Imperative for Sustainable Symbiosis

Sustainable competitive advantage of a firm depends on prioritising intellectual, relational and human capital alongside financial aspects (Dwikat et al., 2023; Tan et al., 2022). This signifies not only the financial aspects but also social aspects are essential for a successful symbiosis. Equally significant, this gives the rationale for using the term socio-economic perspective in the study. Current research neglects the social dimension, focusing only on environmental and economic factors (Chen et al., 2022), especially skilled workforce (Oughton et al., 2022) and local government/industry collaboration (Taqi et al., 2022) are critical areas of under-explored socio-economic factors.

Equitable distribution of benefits can be harnessed through effective leadership skills (Kokoulina et al., 2019; Mortensen et al., 2023) such as communication within networks (Cavalcanti Sá de Abreu et al., 2020) and nurturing trust and cooperation (Lütje & Wohlgemuth, 2020).

In the socio-economic lens, larger networks tend to have weaker connections (Liu et al., 2022). This can be overcome through strong social ties within the symbiosis networks (Howard et al., 2022; Noori et al., 2023). Therefore, investigating the reason for why larger networks tend to have weaker connections through socio-economic factors such as partner selection skills as mentioned by (Agudo et al., 2023a; Schlüter et al., 2022) will uncover the essential aspects of stronger symbiotic relationships in larger

networks.

3. RESEARCH METHOD

3.1 Systematic Literature Review (SLR)

Given the research focus, a well-suited literature review approach is essential. In this case, the study is dealing with a situation where SMEs are a familiar concept, while industrial symbiosis is a relatively new field, pioneered by Chertow et al. (2008). This necessitates a comprehensive review to establish a strong foundation in both domains. A Systematic Literature Review (SLR) offers the ideal approach for this purpose. SLRs are known for their rigorous methodology, ensuring reproducibility, thoroughness and the inclusion of high-quality articles (Surucu-Balci et al., 2024; Truant et al., 2024; Grimaldi et al., 2022; Sudan et al., 2023). This focus on credibility and reliability aligns perfectly with the objective of the study: to provide evidence-based suggestions for implementing industrial symbiosis among SMEs.

3.2 PICO Framework for framing research questions

Next, the literature review focused on crafting clear research questions using the PICO framework (Population, Intervention, Comparison, Outcome) (Xie et al., 2022; Frimpong et al., 2023). This well-established approach helps formulate targeted research questions. The PICO framework is suitable as a similar study successfully employed it to investigate the link between collaboration and long-term competitive advantage among educators (Koskenranta et al., 2022). Inspired by this success, this study utilised the PICO framework to explore the relationship between industrial symbiosis and competitive advantage in SMEs.

PICO FRAMEWORK	
P (Population)	Small and medium-sized enterprises (SMEs)
I (Intervention)	Adoption of Industrial Symbiosis
C (Comparison)	Participation and non-participation in industrial symbiosis
O (Outcome)	Socio-economic factors influencing adoption.

TABLE 1 PICO FRAMEWORK FOR FORMULATING RESEARCH QUESTIONS (CREATED IN MICROSOFT WORD)

In table 1, the Population (P) is Small and Medium-sized Enterprises (SMEs). The Intervention (I) is industrial symbiosis. The Comparison (C) element involves contrasting industrial symbiosis with other drivers of socio-economic resources. The Outcome (O) of interest is to evaluate the factors influencing the sustainable competitive advantage of SMEs. By applying this framework, the study identified key areas for further exploration and formulated specific research questions to guide future investigation.

3.3 Data Collection

To ensure the inclusion of relevant research from diverse disciplines, a systematic literature review was conducted using several databases, including Scopus, EBSCO, ProQuest and Web of Science (Beloskar et al., 2024; Davaei & Gunkel, 2023; Jacobs et al., 2000; Mahajan et al., 2023; Rani, 2023; Saini et al., 2023).

DATABASE	KEYWORDS	FILTERS APPLIED	NUMBER OF ARTICLES
SCOPUS	("industrial symbiosis" OR "industrial ecology" AND "small businesses" OR "small-scale industries" AND "sustainable competitive advantage" OR "business sustainability")	"Articles and review papers" and "English language"	172
EBSCO	("industrial symbiosis" or "industrial ecology" "small businesses" or "small-scale industries" and "sustainable competitive advantage" or "business sustainability")	"Articles with linked full-text, peer-reviewed status and published in English language"	157
PROQUEST	("industrial symbiosis" OR "industrial ecology" AND "small businesses" AND "sustainable competitive advantage")	"Articles published within the last 12 months (December 2022 to December 2023)"	366
WEB OF SCIENCE	("industrial symbiosis" or "industrial ecology" "small businesses" or "small-scale industries" and "sustainable competitive advantage" or "business sustainability")	"Articles published between 2022 and 2024, limiting document type to "article" and language to "English"	540
Total			1235

TABLE 2 META-SEARCH ACROSS FOUR DATABASES: KEYWORDS USED, FILTERS APPLIED AND NUMBER OF ARTICLES RECEIVED (CREATED IN MICROSOFT WORD)

A meta-search conducted across Scopus, EBSCO, ProQuest and Web of Science identified 1235 articles on industrial symbiosis, small businesses and sustainable advantage (Table 2). To ensure an efficient analysis, relevant search filters were applied. These filters included language restrictions (English only) and publication date limitations (2022-2024 for ProQuest and Web of Science).

The search strategy employed straightforward keywords for "industrial symbiosis" and "sustainable competitive advantage." However, to capture the broader field of small and medium-sized enterprises (SMEs) across

various terms, we opted for "small businesses" and "small-scale industries" instead of solely using "SME" or its variants like "SMBs" or "MSMEs." This approach ensured a more comprehensive dataset encompassing SMEs and other relevant small business types. This broader search strategy resulted in a manageable set of 1235 articles for the next stage: article selection.

3.4 Data Analysis

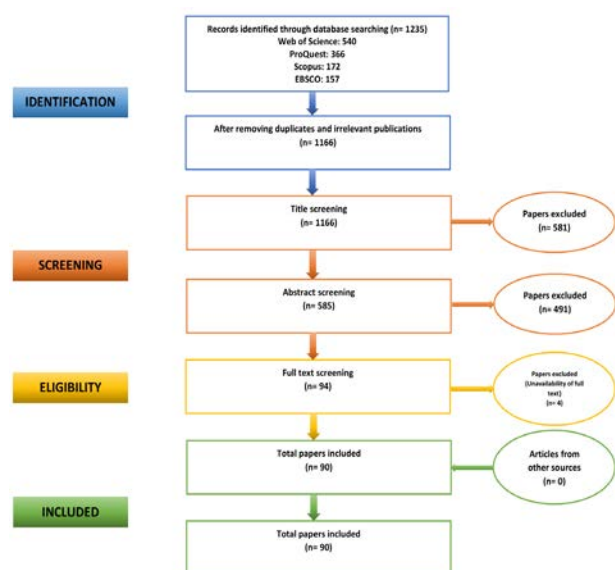


FIGURE 1 PRISMA FLOW DIAGRAM OF THE STUDY (CREATED IN MICROSOFT WORD)

Figure 1 depicts the PRISMA flow diagram outlining the rigorous selection process that narrowed down 1235 articles to 90 for in-depth analysis (descriptive and thematic). Following the initial retrieval of 1235 articles through the SLR, duplicates and irrelevant publications were removed. Irrelevant publications included company documents, magazines, conference proceedings with work in progress and articles designated as "called off." This resulted in 1166 articles.

Next, title and abstract screening were conducted using keywords related to the research questions (industrial symbiosis, SMEs and sustainable competitive advantage). This process excluded articles not directly discussing

these topics. Title screening excluded 491 articles, leaving 585 for abstract screening. During abstract screening, an additional 491 articles were excluded. Four articles were unavailable for full-text download in December 2023. Consequently, 90 articles were included for the full-text review stage.

Microsoft Excel and Rayyan (Baskoro et al., 2023), a dedicated platform for systematic reviews, were utilised throughout the screening process for both titles and abstracts.

4. FINDINGS

4.1 Descriptive Analysis

The objective of the descriptive analysis is to utilise the 90 selected articles to identify trends and relationships without deep analysis. This analysis leverages various techniques, including bibliometrics, word clouds, network visualisation and article distribution by industry focus.

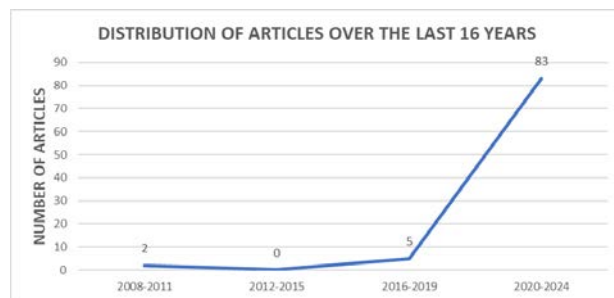


FIGURE 2 BIBLIOMETRIC ANALYSIS OF THE SELECTED 90 ARTICLES (CREATED IN MICROSOFT EXCEL)

Figure 2 illustrates the distribution of articles on industrial symbiosis over the past 16 years, divided into four periods: 2008-2011, 2012-2015, 2016-2019 and 2020-2024.

- **2008-2011:** Researchers published only 2 articles, indicating minimal activity.
- **2012-2015:** No articles appeared, suggesting a lack of interest in the topic.
- **2016-2019:** The number of articles increased slightly to 5, reflecting emerging interest.

- *Green Cluster*: Keywords like "industry," "waste," "product," "company," "collaboration" and "water" are clustered together. This green cluster possibly emphasises the operational aspects of industrial symbiosis, focusing on how different industrial activities can be linked.
- *Red Cluster*: Terms like "sustainability," "enterprise," "SMEs," "business," and "impact" form a distinct red cluster. This cluster suggests a focus on the broader implications and roles of businesses, particularly SMEs, in promoting sustainable practices.
- *Blue Cluster*: The blue cluster, containing keywords like "challenge" and "case study," indicates the presence of research studies that address challenges and practical applications within the context of industrial symbiosis.

In summary, figure 4 the network diagram underscores the central role of industrial symbiosis, while also revealing its connections to business impacts and broader sustainability themes.

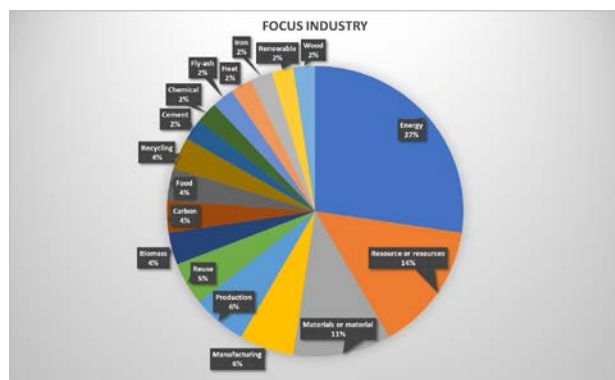


FIGURE 5 PIE CHART: DISTRIBUTION OF ARTICLES BASED ON THE INDUSTRY (CREATED IN MICROSOFT EXCEL)

Figure 5 presents a pie chart illustrating the distribution of articles by focus industry. The largest category, with 27%, focuses on energy exchange. This is followed by resources (14%) and materials (11%), which deal with raw material exchange. Manufacturing and

production each account for 6% of the articles, while reuse constitutes 5%, suggesting an interest in the study area of circular economy.

Next comes the category encompassing biomass, carbon, food and recycling (4%). This cluster can be broadly termed as "bio economy." Finally, 2% of the articles discuss various sectors relevant to this research area, including cement, chemical, fly-ash, heat, iron, renewable and wood.

The descriptive analysis revealed a significant surge in research activity in the field of industrial symbiosis in recent years (2020-2024) through an analysis of publication trends. This highlights the growing recognition of industrial symbiosis as a key strategy for achieving sustainability.

Next, the examination of high-frequency keywords identified three A priori themes to facilitate the next stage of thematic analysis based on these keywords. Concurrently, the network visualisation demonstrated the centrality of "industrial symbiosis" and its connections to broader sustainability goals and the role of businesses, particularly SMEs.

Finally, the distribution of articles by industry focus provided insights into areas of application. Energy exchange, raw material exchange, circular economy, bio economy and a category encompassing diverse sectors indicate the broad applicability of industrial symbiosis across various industries.

4.2 Thematic Analysis

The descriptive analysis served its purpose by providing a solid foundation for the research through the identification of various patterns and trends. This foundation then informed the thematic analysis.

Thematic analysis commenced with template analysis. The rationale for using template analysis stemmed from the need to organise themes efficiently when undertaking complex data analysis, especially considering the large dataset of 90 SLR articles (Yasin et al., 2023).

Additionally, template analysis offered advantages in capturing the interdisciplinary nature of responsible management challenges (Laasch et al., 2023) and examining the interplay between different elements (Wuersch et al., 2023). This aligned perfectly with the objective of the study, which involved exploring various disciplines (industrial symbiosis, SMEs and sustainable competitive advantage) and understanding the interplay between them.

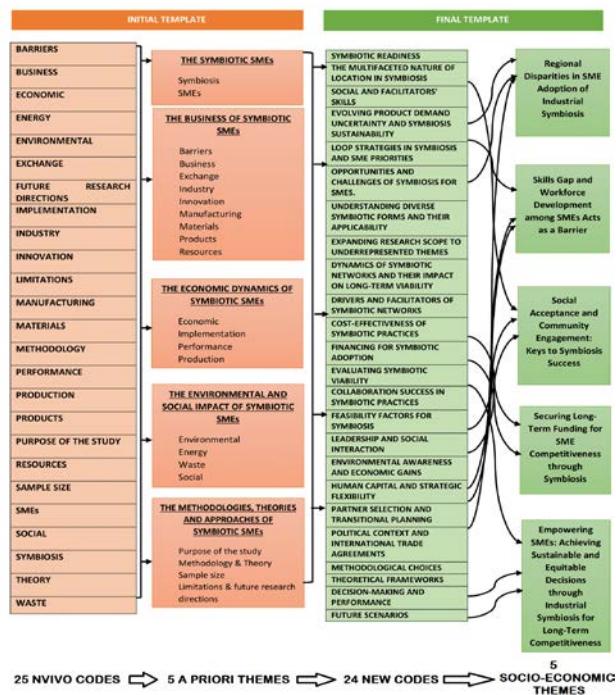


FIGURE 6 TEMPLATE ANALYSIS (CREATED IN MICROSOFT WORD)

Figure 6 depicts the initial stage of the template analysis. Using NVivo 12 software, 25 codes were derived from the 90 SLR articles. These initial codes were then organised into 5 distinct A priori themes based on existing knowledge gathered from the descriptive analysis. Following a full-text reading of all 90 articles under the lens of these 5 A priori themes, revealed 24 new codes.

The final stage of template analysis refined these 24 codes. By analysing the 24 new codes, the researchers identified 5 socio-economic themes as the main themes for further analysis.

Theme- 1: Regional Disparities in SME Adoption of Industrial Symbiosis

This theme "Regional Disparities in SME Adoption of Industrial Symbiosis" examines case studies across diverse regions by understanding the factors influencing the success of industrial symbiosis adoption (Costa et al., 2010; Yu et al., 2015).

The effectiveness of government policies designed to promote industrial symbiosis varies considerably. While tax breaks for utilising waste products may be a deciding factor in some cases (Yu et al., 2015), others highlight the importance of "green jobs" created within symbiosis networks (Li et al., 2015). However, slow bureaucracy and unclear regulations can hinder the development of symbiosis, as evidenced by the Porto Marghera case study (Mannino et al., 2015).

There exist research gaps in this area. Firstly, a broader assessment is needed to determine the efficacy of various government interventions, such as tax incentives, in promoting symbiosis globally. Secondly, a comparative analysis of policy approaches across diverse contexts could shed light on best practices for overcoming challenges like slow bureaucracy and unclear regulations. Further research is needed to understand the extent to which symbiosis leads to equitable job creation through "green jobs."

Studies from the Humber region (UK) and Dalian Economic Development Area (China) suggest that prioritising renewable energy incentives can encourage symbiosis among companies (Velenturf, 2016; Zhe et al., 2016). While this adds to the existing knowledge base, there is a limitation in examining cases from different regions to address the effectiveness of providing incentives for symbiosis, as raised by Yu et al. (2015).

The renowned Kalundborg case study emphasises the importance of bilateral agreements for successful symbiosis (Branson, 2016), which may facilitate initial collaboration (Ghali et al., 2017). However, the long-term

success of symbiosis also on factors like institutional capacity building, social capital and stakeholder awareness (Guo et al., 2016; Spekkink, 2015; Walls and Paquin, 2015). While initial bilateral agreements hold value (Branson, 2016), determining the relative importance of each factor (institutional capacity, social capital and stakeholder awareness) presents a future research opportunity.

Similarly, future research should investigate the risk of power imbalances within symbiosis networks, as highlighted by Hein et al. (2017). Dominant stakeholders may exert undue control over decision-making and resource allocation, potentially creating long-term inequities.

Building on concerns about power imbalances, a Chinese coal mining case study highlights self-regulation as a potential strategy to prevent monopolies and promote healthy competition within symbiosis networks (Wang et al., 2018). However, a vital research gap remains: identifying mechanisms for monitoring the efficacy of self-regulation in creating a more equitable participation within symbiosis initiatives.

The findings of Song et al. (2018) highlight the importance of collaboration platforms for promoting symbiosis. However, a key question remains: how can collaboration platforms be designed to consider companies of varying sizes and technical capabilities?

Charles et al. (2018) shed light on the creation of periodic employment opportunities through symbiosis. However, their findings raise questions regarding the quality and longevity of these positions, which is a future research opportunity.

The case study by Mohammed et al. (2018) reveals that a fertilizer production plant created nine skilled daily jobs for plant operation, including operators and supervisors. This directly addresses concerns about job quality raised by Charles et al. (2018). However, further research is needed to determine if this pattern of

high-skilled job creation extends to other industries participating in symbiosis.

A noticeable research gap exists concerning industrial symbiosis involving more than two units, hampering the expansion of larger networks (Huang et al., 2019). This aligns with the proposition by Branson (2016) that bilateral agreements can form symbiosis networks, stressing the need for further exploration in this domain to facilitate the development of larger symbiosis networks.

By addressing these research gaps, it is possible to understand the factors influencing the successful adoption of industrial symbiosis, particularly among SMEs in different regions.

Theme- 2: Skills Gap and Workforce Development among SMEs Acts as a Barrier for Symbiosis Adoption

This theme, "Skills Gap and Workforce Development among SMEs as a Barrier for Symbiosis Adoption," explores the barriers and opportunities for SMEs to engage in industrial symbiosis.

Limited technical expertise and resources hinder SMEs from utilising sophisticated data analytics tools to optimise resource exchange (Cavalcanti Sá de Abreu et al., 2020). Even with adequate resources, educating the workforce on data analysis and symbiosis practices remains crucial for successful implementation (Krom et al., 2022; Liu et al., 2023). Additionally, SMEs need strong negotiation skills to establish agreements for resource exchange within symbiosis networks (Yazan & Fraccascia, 2020). These factors contribute to a skills development gap that must cater to the diverse needs, sizes and sectors of SMEs.

A lack of awareness of potential partners and their waste streams presents a barrier to symbiosis development (Giannoccaro et al., 2023; Wang et al., 2023). Furthermore, the lack of specialists to support partnership development creates hurdles for establishing symbiosis networks (Taqi et al., 2022). Training

programs can improve communication, collaboration and negotiation skills necessary for successful partnerships (Yazan & Fraccascia, 2020; Schlüter et al., 2022). Building trust within these networks requires programs that promote communication and collaboration (K. Liu et al., 2022; Schlüter et al., 2022). However, there is a critical need for a skilled and adaptable workforce proficient in analysing data on products, demand and by-products (Daş et al., 2024; Morales et al., 2022).

Collaboration between industry and academia is essential to develop a framework that facilitates industrial symbiosis (Patricio et al., 2022). Conversely, policymakers can bridge the information gap and facilitate symbiosis by developing data-sharing platforms (L. Wang et al., 2022). A crucial challenge lies in creating cost-effective data analysis tools designed for SMEs with limited technical knowledge. Information-sharing strategies like showcasing success stories and hands-on workshops can enhance SME knowledge (Krom et al., 2022; Liu et al., 2023).

Beyond information-sharing strategies, collaboration among stakeholders is critical for developing data-driven and long-term policies (Boom Cárcamo and Peñabaena-Niebles, 2022). Tailoring policies to address the skills gap across various regions, considering social, economic and cultural nuances, remains a key challenge (Akar et al., 2023; Agudo et al., 2023a; Akberdina et al., 2023).

By addressing these barriers and turning them into opportunities, industry, academia and policymakers can enable SMEs to participate successfully in industrial symbiosis networks.

5. CONCLUSION

This study investigated the socio-economic factors influencing the adoption of industrial symbiosis among SMEs, aiming to explore its potential contribution to their sustainable competitive advantage. A systematic literature review was conducted to analyse 90 articles. Descriptive analysis revealed publication

trends, high-frequency keywords, linking keywords using network visualisation and the distribution of articles based on industry types. The thematic analysis uncovered five key socio-economic themes for deeper investigation:

1. Regional disparities in SME adoption of industrial symbiosis
2. Skills gap and workforce development among SMEs as a barrier
3. Social acceptance and community engagement: keys to symbiosis success
4. Securing long-term funding for SME competitiveness through symbiosis
5. Empowering SMEs: achieving sustainable and equitable decisions through industrial symbiosis for long-term competitiveness

In this developmental paper, the first two themes were analysed in depth. Analysing the first theme, “Regional Disparities in SME Adoption of Industrial Symbiosis,” revealed a critical gap where government interventions play a crucial role, but their effectiveness varies depending on the context. While tax breaks and renewable energy incentives can be successful, slow bureaucracy and unclear regulations can hinder progress. Future research should explore best practices for policy intervention and design.

Analysing the second theme, “Skills Gap and Workforce Development among SMEs as a Barrier for Symbiosis Adoption,” revealed that limited technical expertise, data analysis skills and negotiation skills in SMEs create a barrier to symbiosis adoption. Additionally, a lack of awareness of potential partners and specialists further impedes symbiosis development. Training programs and industry-academia collaboration are crucial to bridging the skills gap, providing an intriguing future research opportunity.

6.1 Theoretical Contributions

This study contributes to the theoretical understanding of industrial symbiosis and advances sustainability research in two ways:

1. The study investigates the socio-economic factors of industrial symbiosis, a novel area of research since previous studies have primarily focused on the environmental and economic aspects, neglecting the social dimension.
2. By examining the social dimension, particularly job creation through skills development, the study challenges and expands the concept of sustainability in industrial symbiosis. This approach answers the critical question about how sustainability concepts like industrial symbiosis can truly be considered sustainable, thus contributing to the broader discourse in sustainability research.

6.2 Practical Contributions

This study offers two practical contributions:

1. SMEs, which often struggle to harness the benefits of industrial symbiosis compared to large companies, will benefit from the findings of the study as it offers solutions specifically tailored to SMEs.
2. The study provides guidance for policymakers to design effective regional policies that address the specific challenges and opportunities for SMEs to benefit from industrial symbiosis. SMEs can invest in workforce development programs to bridge the skills gap and create a culture of collaboration within symbiosis networks. Similarly, academia can collaborate with industry to develop cost-effective data analysis tools and educational programs tailored to the needs of SMEs.

6.3 Limitations and Future Work

This study has limitations. The findings of the study are based on systematic literature review focused on published articles. The systematic literature review may have excluded some relevant articles due to stringent filtering protocols, though high-impact peer-reviewed

papers were included. The framework used might generate diverse interpretations, but it aims to stimulate discussion on the socio-economic impacts of industrial symbiosis among SMEs.

Future research can address these limitations by:

- Investigating the remaining three themes to unlock the full research gaps and future research opportunities.
- Conducting an empirical research that includes SME stakeholders, policy makers and academics.

By addressing these limitations and pursuing further research, we can enhance the understanding and implementation of industrial symbiosis, empowering SMEs to contribute to a more sustainable and competitive future.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this developmental paper.

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