Technological Forecasting & Social Change 208 (2024) 123656

Contents lists available at ScienceDirect

Technological Forecasting & Social Change

journal homepage: www.elsevier.com/locate/techfore

Industrial ecosystems: A systematic review, framework and research agenda

Thommie Burström [a,*], Tom Lahti [a], Vinit Parida [b], Joakim Wincent [a]

[a] *Hanken School of Economics, Finland*
[b] *Luleå University of Technology, Sweden*

ARTICLE INFO

Keywords:
Industrial ecosystem
Synergies
Policy
Review
Transformation
Sustainability

ABSTRACT

There is confusion surrounding the concept of industrial ecosystems (IEs). This research therefore presents a systematic literature review on the subject of industrial ecosystems and outlines several paths for future research. The paper defines the key characteristics of IEs, identifies three perplexity drivers that contribute to the conceptual ambiguity of IEs, proposes a four-tier integrative IE framework that outlines the core components of IE research, and presents a conceptual model that clarifies how synergetic effects emerge, leading to IE transformation. Articles are categorized into four categories (industrial symbiosis, metabolism, architecture, and orchestration) from which ten propositions are delineated. The study encourages researchers to tap into several areas from the view that this is a broad, but still rather unexplored area of research with high relevance for policy.

1. Introduction

In the past decade, the concept of industrial ecosystems (IEs) has garnered increased interest among researchers (Miao et al., 2020; Sjödin et al., 2022) and policymakers (EC ASMR, 2022). For instance, IEs are pivotal in the European Commission's strategy for industrial policy and industry transformation towards sustainability and digital leadership (European Commission, 2022). IEs predominantly foster business-to-business relationships (Frosch & Gallopoulos,1989; Andreoni, 2018) and are crucial when policymakers aim to enhance market resilience by tackling strategic dependencies, investments, and international partnerships (European Commission, 2022). Despite the growing popularity of the IE concept, there has been no systematic literature review on the subject to date, and IE boundary conditions (BCs) appear to be vague and perplexing. As reflected by Cote (2009, 9) “I am not sure that the theory or practice can adequately describe what would constitute a functioning, mature industrial ecosystem”. Thus, there is a need to clarify IE boundary conditions.

Busse et al. (2017, 580) define BCs as “The boundary conditions function of a given theory depicts the accuracy of theoretical predictions for any context. As such, it describes the generalizability of a theory across contexts”. BCs serve to create conceptual clarity and precision. Some clarity on IE BCs has been provided by the IE definition from Frosch and Gallopoulos (1989, 144). They proposed that traditional linear manufacturing models should “be transformed into a more integrated model: an industrial ecosystem. In such a system the consumption of energy and materials is optimized, waste generation is minimized and the effluents of one process […] serve as the raw material for another process”. This initial definition provides some limited understanding of IE characteristics, but further studies clarifying the concept are needed.

Indeed, compared to other streams of ecosystem research, the characteristics of IEs are much less understood. For example, key characteristics of innovation ecosystems (Adner, 2006; Jackson, 2011; de Vasconcelos Gomes et al., 2018), platform ecosystems (Cenamor and Frishammar, 2021), and business ecosystems (Moore, 1993) are well understood. In fact, Jacobides et al. (2018) discuss, compare, and synthesize the fundamental elements of these three ecosystem types and lay the groundwork for a specific ecosystems theory. Such fundamental knowledge remains to be developed in relation to IEs. Thus, there is a need to identify the key characteristics of IEs so that they can be positioned in relation to other types of researched ecosystems and integrated into a general ecosystems theory. This research gap is somewhat surprising given that the concept was coined as early as 1989.

Furthermore, if IE literature is perceived as disparate, vague, and

* Corresponding author.
E-mail addresses: thommie.burstrom@hanken.fi (T. Burström), tom.lahti@hanken.fi (T. Lahti), vinit.parida@ltu.se (V. Parida), joakim.wincent@hanken.fi (J. Wincent).

https://doi.org/10.1016/j.techfore.2024.123656
Received 8 June 2023; Received in revised form 7 August 2024; Accepted 9 August 2024
Available online 15 August 2024

marked by perplexity (Cote, 2009), it is reasonable to ask why this is the case. According to Busse et al. (2017), conceptual perplexity arises from fragmented conversations in the extant literature. This seems to be the case in IE research where studies span a broad array of *topics,* such as the circular economy (Zaoual and Lecocq, 2018), digitalization (Sjödin et al., 2022), process engineering (Özyurt and Realff, 2001), *geographical scopes* (global, international, national, regional, and local) (Korhonen and Snäkin, 2005), *industrial contexts* such as manufacturing (Parida et al., 2019), and the green energy industry (Kim, 2019). It has been proposed that conceptual boundary conditions (BCs) should be explored (Busse et al., 2017, 600) as a way to mitigate conceptual perplexity. Thus, to clarify the BCs of the IE concept, a systematic literature review should be undertaken to identify factors that drive perplexity.

By understanding reasons behind perceived perplexity, it is possible to take the next step and develop a theoretical solution that can mitigate this perplexity (Busse et al., 2017). Extending the work of Korhonen and Snäkin (2005), who highlights the importance of categorizing IE studies, such a solution would discuss and position competing and complementary IE research contributions. Specifically, what seems to be lacking in IE research is a synthesized body of knowledge amalgamated into an integrative IE framework that illustrates the evolution of the IE research field and clarifies the relationship between disparate IE studies. We contend that such a framework can lay the ground for researching the dynamics within (antecedents), and their effect on the outcomes of IEs.

For example, while researchers and policymakers have acknowledged the pivotal role of IEs in driving industrial renewal/transformation, understanding of the collective collaborative mechanisms (antecedents) that drive such transformation (Shi and Li, 2019; EC ASMR, 2022; Sjödin et al., 2022) remains limited. In other words, synergies (excess value created through complementarity) among IE firms are necessary for transformation (fundamental shifts in how IE stakeholders conduct business) (Argenti et al., 2021) to occur. Such synergies materialize through an interplay between IE structures (properties of the IE surroundings such as infrastructure, roles, and interdependencies) and IE agency (purposeful actions performed by IE stakeholders such as leadership, implementation of production methods, the use of digital tools) (Chertow, 2000; Burström et al., 2021; Wurth et al., 2022). However, existing research has not systematically analyzed the relationship between IE structures, actions, synergetic effects, and industrial renewal/transformation as outcomes.

To address the research gaps described above, we outline the following research questions:

RQ1: What are the key characteristics of IEs?

RQ2: What factors drive fragmentation and perplexity in IE research?

RQ3: How can IE research be amalgamated into an integrative framework clarifying the relationship between disparate IE studies?

RQ4: What does the IE literature say about the synergetic effects in IEs, their antecedents, and their outcomes?

Through a systematic literature review and an in-depth content analysis (narrative approach) of 103 articles, our study has made the following contributions. *First*, while Jacobides et al. (2018) began to develop a theoretical foundation for ecosystem theory, IEs are outside the scope of their paper. Our study shows the special key characteristics of IEs and positions IE research in relation to previous ecosystem research. In doing so, this study expands the understanding and applicability of ecosystem theory. *Second*, this study contributes to previous literature addressing the fragmented nature of IE research (Korhonen et al., 2004b; Korhonen and Snäkin, 2005; Cote, 2009). Specifically, we reveal that BCs in IE research are unclear as a result of the effects of three perplexity drivers: definitional confusion, inter-conceptual confusion, and contextual fragmentation. *Third,* by presenting an integrative framework, we synthesize the existing body of knowledge and clarify the relationship between the dominant streams of IE research. *Fourth*, while previous research has provided an understanding of how isolated structural IE elements (e.g., infrastructure, roles, and interdependencies) or IE activities (e.g., leadership, implementation of production methods, the use of digital tools) can contribute to changes in IEs (Côté, 1997; Zaoual and Lecocq, 2018; Duan et al., 2022b), this study focuses on the creation of synergetic effects. We advance the research field by developing a theoretical model explaining how antecedents stemming from combinations of IE structures and IE agency can lead to synergetic effects among IE stakeholders, revealing that synergetic effects are crucial in generating industrial renewal/transformation.

The remainder of the paper is structured as follows. To provide an understanding of the research setting, a brief background of IE research is presented in Section 2. Thereafter, in Section 3 on Methods, we detail our systematic literature review (the selection of articles, the narrative approach in content analysis, and analytical procedures). Then, results of the first part of our content analysis are presented in Section 4. In this section, IE key characteristics are defined, and the IE research field is positioned against other main ecosystem fields in management research (Section 4.1). The perplexity of IE research is discussed in Sub-section 4.2 (definitional-, inter-conceptual confusion, and contextual fragmentation), and a synthesized integrative IE framework is outlined in Sub-section 4.3. Next, the results of the second part of our content analysis are discussed in Section 5, where we formulate ten propositions linked to a conceptual model of synergetic effects and IE renewal/transformation. Finally, our findings are discussed and our conclusions drawn in Section 6. This section offers policy (6.1) and future research (6.2) recommendations. Our paper serves as a step forward towards building an informed research community focused on IE studies that potentially could benefit from clarification of the BCs of IEs.

2. Origins of the industrial ecosystem concept

The aim of this section is to illuminate the origins of the IE concept. This fundamental understanding situates the research within a historical context and serves as a backdrop to our systematic literature review. The concept of IEs has a considerable history. As mentioned in the introduction section, Frosch and Gallopoulos first defined the IE concept in 1989. Their definition encapsulates the idea of an integrated system of interconnected and interdependent stakeholders driving innovative industrial transformation trajectories (Frosch and Gallopoulos, 1989).

Moreover, in their pioneering work, Frosch and Gallopoulos (1989, 144) adopted an ecological perspective on the manufacturing industry, proposing that an industrial ecosystem should function as an analogue of biological ecosystems. Their paper has garnered a vast number of citations. Notably, in 1993, Moore drew heavily on it and coined the concept of "business ecosystems" (see Moore, 1993). However, it took some time for Frosch and Gallopoulos (1989) to gain attention. As can be seen in Fig. 1, it has been regularly cited since publication. Nonetheless, it was not until 15 years later in 2004 that it started to gain more traction (source: Google Scholar).

Since Frosch and Gallopoulos (1989) adopted an ecology approach to industrial manufacturing they have been most commonly cited by researchers in that specific field of research. The topics covered by these citing works have included ecological sustainability (Shrivastava, 1995), green supply-chain management (Srivastava, 2007), and the circular economy (Korhonen et al., 2018). However, such research is not necessarily directly related to IEs.

Meanwhile, despite the extensive citation of the Frosch and Gallopoulos (1989) paper, it took considerable time for the IE concept to gain traction and emerge as a central research concept. For example, when searching publications using the term "industrial ecosystem" in the title (Google Scholar, all types of publications), we observed a trend shift in 2011 with more than 10 publications focusing specifically on IEs (Fig. 2). Compared to the general interest in the Frosch and Gallopoulos (1989) paper, there has been a slower increase in interest in the IE concept, although it is clearly on the rise.

In spite of the growing number of IE studies, there is a dearth of literature review articles explicitly studying the development of the IE

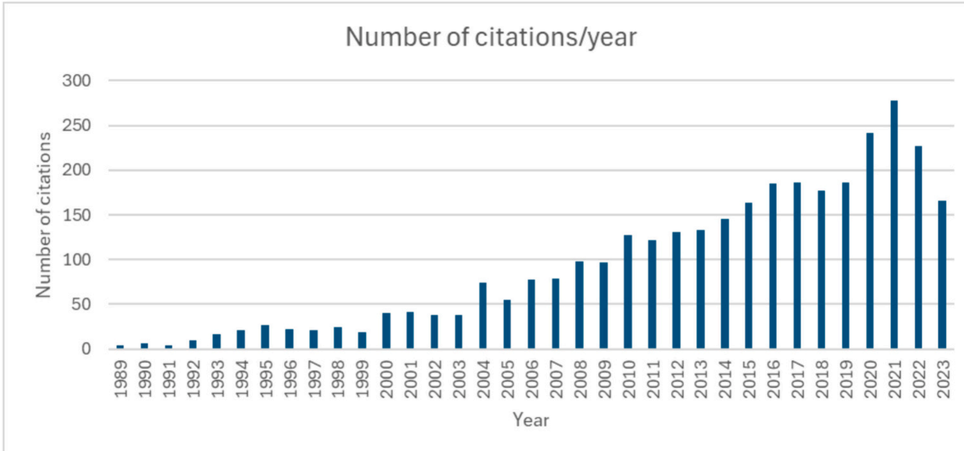

Fig. 1. Citations of Frosch and Gallopoulos (1989) article.

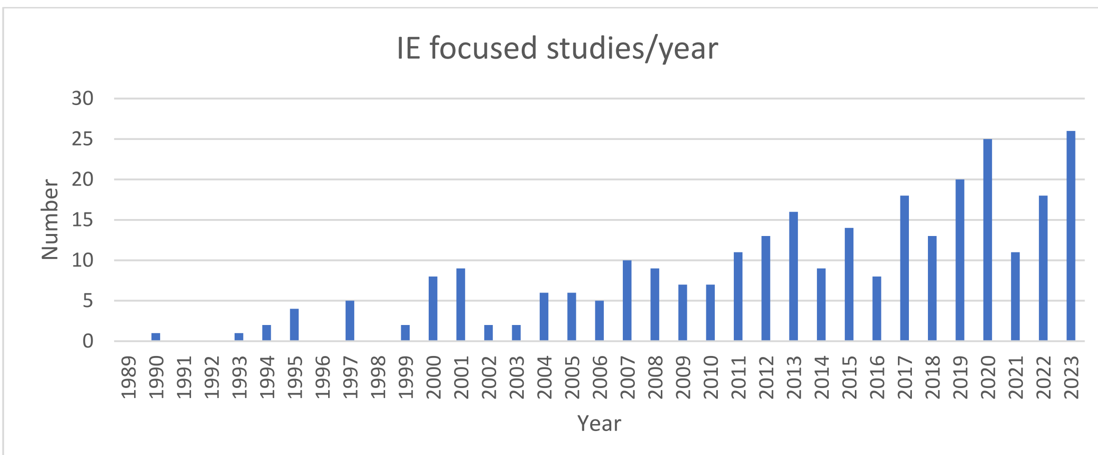

Fig. 2. Studies of the IE concept.

research tradition. A notable exception, however, is the paper by Tsujimoto et al. (2018), which reviewed four different ecosystem concepts, one of which was the IE concept. Tsujimoto et al. adopted a comprehensive approach and included 26 papers related to the IE concept in their study. They found that IEs are related to sub-concepts such as optimization, sustainability, and symbiosis. Therefore, to some extent, they clarified IE boundary conditions. However, as noted by Tsujimoto et al. (2018), understanding of the IE concept needed to be further refined. Such refinement offers scholars the opportunity to synthesize various theoretical constructs and disciplines (Stam, 2015). This paper therefore extends the work of Tsujimoto et al. (2018) and follows in the footsteps of other researchers who have recently clarified the boundary conditions of software ecosystems (Burström et al., 2022) and AI entrepreneurial ecosystems (Hannigan et al., 2022), for instance.

3. Method

Following the recommendations of Tranfield et al. (2003), we conducted a systematic literature review (which can be executed in various ways). Consistent with prior research (e.g., Burström et al., 2022; Wurth et al., 2022; Madanaguli et al., 2023), we employed a narrative approach in content analysis. The process is discussed in detail below.

Guided by the recommendations of Tranfield et al. (2003), we first established the need for a literature review. This necessity was evident given the challenges in comprehending the breadth and quality of IE research, coupled with a dearth of reviews on the subject. Drawing on Tranfield et al. (2003) again, we outlined criteria for article inclusion/exclusion, enabling us to compile a sample of pertinent articles. We applied two criteria: (1) publication in quality outlets, and (2) a clear focus on and contribution to IE research.

3.1. Publication in quality outlets

The initial selection criterion was that articles in the sample should be written in English and published in reputable peer-reviewed research journals (Podsakoff et al., 2005). We adhered to the established practice employed by other researchers (e.g., Gernsheimer et al., 2021; Burström et al., 2022; Wurth et al., 2022; Madanguli et al., 2023) and decided not to include sources such as reports, books, and conference papers. The widely recognized Academic Journal Guide (AJG) was utilized to identify esteemed research outlets. Additionally, drawing on Burström et al. (2022), we included only articles that were listed in the AJG list or had an Impact Factor (IF) exceeding 1.0. However, we made an immediate exception to the rule. We knew from previous readings that the Frosch and Gallopoulos (1989) article was seen as the origin of the IE concept. Thus, although not published in a quality outlet, it was included in the sample.

Then, in the first round of sampling, we conducted a search in Scopus to earmark papers that used the term “industrial ecosystem(−s)” in the title, abstract, and keywords. We did not use any filters to exclude journals or articles from any specific domain in this first search. We identified 309 potential articles (Fig. 3, 1st screening) distributed across

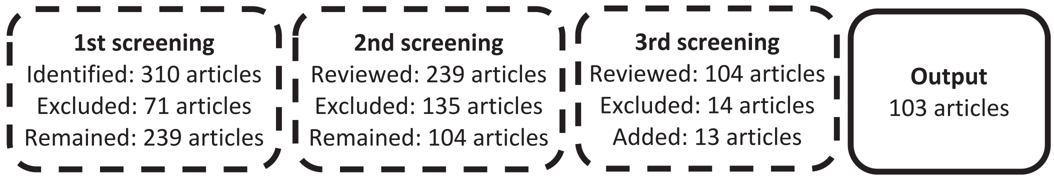

Fig. 3. Sampling process.

160 journals. A detailed description is found in Appendix 1 where journal inclusion/exclusion is motivated, and categorization of articles is performed. We then conducted a similar complementary search in Google Scholar, but we found no additional articles on this occasion. In this sample, 49 journals (with related 71 articles) did not meet the pre-specified quality requirements and, therefore, articles in these journals were excluded. After including the Frosch and Gallopoulos (1989) article, we were left with 239 articles distributed across 112 journals.

3.2. Focus on and contribution to IE research.

We continued to study the sample of 239 articles in greater detail. We studied each article in a thorough search for the terms "industrial ecosystem" and/or "IE (−s)". We expected to observe a consistent discussion pattern where the IE concept would be expounded in most sections of the articles. However, instead, we observed that the majority of these papers used the term industrial ecosystem(−s) as a buzzword or a catchphrase, and they did not make a contribution to the field. These papers typically mentioned IEs in the abstract or in the keywords but did not connect to IE literature or use the IE concept as a central theme. Thus, these papers clearly did not meet the criteria related to focus and contribution. Therefore, these 135 articles were excluded. Our sample thus consisted of 104 articles. Nonetheless, we retained doubts about the validity of some articles, and we were not sure that we had created a saturated sample of articles. Therefore, we continued to study the remaining 104 articles in depth.

This in-depth reading can be seen as a third screening where we tried to categorize articles in order to understand how they fitted together. The screening spanned the period during which we analyzed the material and developed sections 1 to 4. Through this procedure, we identified another set of 14 articles that discussed the IE concept only briefly; they were therefore removed. However, the in-depth reading helped us learn more about the IE concept, and it made us aware of the need to identify and add more articles (13). For example, we identified researchers who remained critical of the development of the IE concept (e.g., Cote, 2009), we were made aware of a central definition of critical use in our study (e.g., Wernik, 2001), and we identified key literature that tied the IE and orchestration concepts closer together (e.g., Best, 2015). In this case, we used Google Scholar to identify the literature (the Scopus search was insufficient). Finally, we examined the reference lists in each article in our remaining sample of 103 articles to find additional papers that were relevant. This activity yielded no further articles. We therefore settled on a total of 103 articles.

3.3. Data analysis

As we briefly explained in the earlier passage, the screening process and the data analytical process were linked together. Here, we continue to discuss the analytical process in detail. When writing a literature review, there is a need to gain a comprehensive understanding of the relationship between disparate streams of literature. Therefore, each article was scrutinized in detail, and through this process, we discerned how researchers had defined and discussed IEs.

To answer RQ1, "What are the key characteristics of IEs?", we decided to first study how key characteristics of other ecosystem types are described. Jacobides et al. (2018) describe the key characteristics of business, innovation, and platform ecosystems. Therefore, we drew on Jacobides et al. (2018) to establish a benchmark. Here, we identified four central themes that describe the essentials of business, innovation, and platform ecosystems: shared key targets, focal point, ecosystem views, and units of interest. Guided by these themes, we studied the IE literature and identified four key IE characteristics that demonstrate the uniqueness of the IE concept: synergy creation, industrial processes, production systems, and interconnectedness between industrial partners. Consequently, this approach helped us position IE research in relation to previous ecosystem research in management and identify critical BCs (see Section 4.1 for a detailed discussion).

To answer RQ2, "What are the factors driving fragmentation and perplexity in IE research?", we observed and mapped three perplexity-driving patterns: (1) non-existent or incoherent use of definitions causing *definitional confusion*, (2) a large mix of terminologies/concepts employed in IE studies sharing many features, leading to fuzzy sub-conceptual boundaries and causing *inter-conceptual confusion*, and (3) four contextual factors (industrial geographic scope, industrial context, industrial dimensions, and industrial features) driving perplexity in the form of *contextual fragmentation*. The combination of these three perplexity drivers revealed unclear IE BCs (see Section 4.2 for a detailed discussion).

In an effort to bring clarity to the BCs of IE research, we executed a third analytical step aimed at answering RQ3, "How can IE research be amalgamated into an integrative framework clarifying the relationship between disparate IE studies?". Drawing on insights gleaned from the prior analyses conducted in response to RQ1 and RQ2, we recognized the need to construct an integrative framework consisting of several interdependent tiers. First, we learned that all ecosystem research originates from the field of industrial ecology. We labeled this insight, the "Philosophical Tier". Next, we observed that IE research followed two separate yet related streams: one adopting a sustainability perspective and the other adopting an organizational perspective. Both perspectives relied on distinct definitions of IEs. Consequently, we labeled this tier, the "Conceptual Tier". Following this, we identified a tier with four related key sub-concepts that significantly influence the discourses in the two research streams (sustainability vs. organizational): metabolism, symbiosis, architecture, and orchestration. This tier, labeled the 'Explicating Tier', helps to differentiate between the streams. Finally, based on our analysis of contextual fragmentation, we identified four application areas within IE research: industrial geographic scope, industrial context, industrial dimensions, and industrial features. We labeled this tier, the "Application Tier". This integrative framework clarifies IE BCs by illustrating the hierarchical relationship between various central main- and sub-concepts where synergies play a pivotal role.

In a fourth analytical step, we revisited the articles for an additional in-depth content analysis. While our previous analysis had identified the central role of synergy creation, we sought to understand how synergetic effects materialize, and what their antecedents and outcomes in IEs were (RQ4). However, in order to proceed, we first needed to define industrial transformation. We drew on Madsen and Szyliowicz (2016) who define industrial transformation as "a process of change that is triggered by an endogenous or exogenous event". Nevertheless, we consider this definition to be too limited in nature because it focuses on events only. Their definition pays attention to drivers of change but not to the outcomes or effects of change. In this paper, we therefore propose a broader definition of industrial transformation as a range of significant related endogenous micro-, meso-, and macro-level (qualitative and/or quantitative) changes in the organization (practices, structures. and processes) and performance of industries, and their business impact over time. Moreover, industrial transformation encompasses exogenous factors that drive change, such as political, legal, technological, economic, social, and environmental factors. We acknowledge the interplay between endogenous and exogenous factors driving change.

Thereafter, by employing a pattern-induced technique (Gioia et al., 2013), we were able to identify and explain the relationship between streams of disconnected studies. The first author studied, coded and categorized all articles. To ensure consistency, the second author studied, coded and categorized randomly selected articles (see Appendix 1). To compare and contrast articles (Charmaz, 2006; Burström et al., 2022), we drew on our integrative framework created in our third step of analysis. Thus, we were able to highlight the particularities of, and similarities between, different research streams in terms of how structure and action create synergies between firms and policymakers in IEs and how they are manifested in industrial renewal/transformation.

Then, in a fifth step, we performed an iterative analytical process to identify first-, second-, and third-order themes (see Fig. 4). First-order themes represent action and structural elements underlying second-order themes (sub-concepts). Here, we found that "symbiosis" as a second-order theme provides theoretical insights into both types of third-order themes ("transformative action" and "structures for transformation"). In contrast, "orchestration" and "metabolism", as second-order themes, provide theoretical insight into only "transformative action", while the second-order theme of "architecture" offers only theoretical insights into "structures for transformation". Additionally, we found that the third-order themes "transformative action" and "structures for transformation" are key antecedents of synergetic effects. Finally, our analysis shows that synergetic effects produce an outcome in the form of industrial renewal/transformation.

Based on this iterative analytical process, we developed ten propositions and related policy implications. We assert that our five-step analytical process helped us to clarify the BCs of the IE concept (Post et al., 2020).

4. Content analysis of IE research

In this first part of our content analysis, we position the IE concept in relation to other ecosystem types and identify IE key characteristics. Second, we identify and discuss what Busse et al. (2017) describe as perplexity drivers (Sub-section 4.2), which are issues contributing to the blurring of the IE concept. In the last part of Section 4 (Sub-section 4.3), an integrative framework is presented and discussed.

4.1. Four central IE key characteristics (boundary conditions)

There is a need to identify IE key characteristics (BCs). In this sub-section, we therefore address RQ1, "What are the key characteristics of IEs?" To create conceptual clarity, we establish a benchmark with previous streams of ecosystem research. This approach seems logical

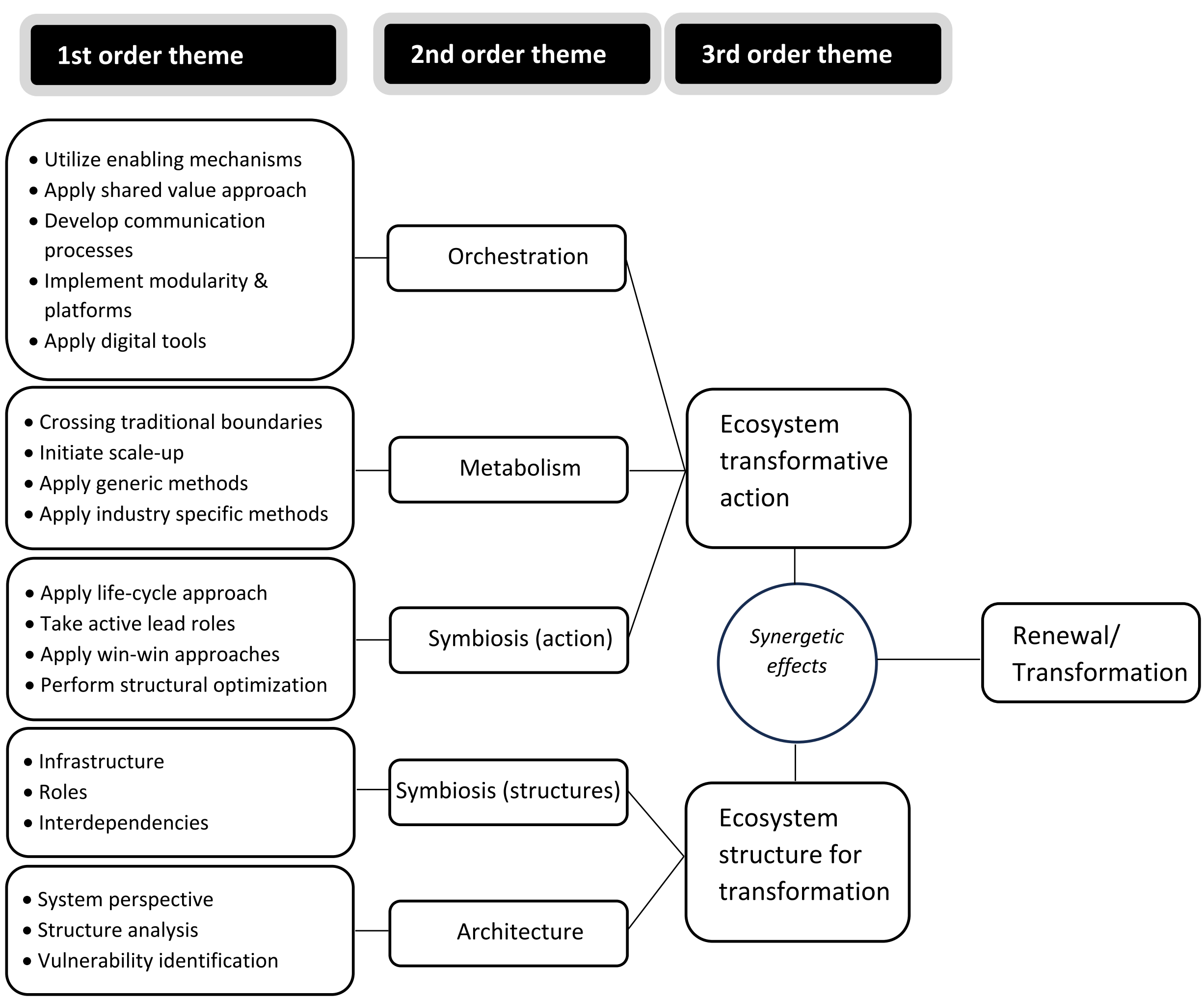

Fig. 4. Synergetic effects and IE transformation.

since (1) it is acknowledged that all forms of ecosystem concepts related to industries, business, and innovation are rooted in the field of industrial ecology (cf. Moore, 1993; Andrews, 1999, p. 366), and (2) previous studies of ecosystems in management research have already recognized the importance of identifying and clarifying ecosystem BCs (Jacobides et al., 2018; Autio and Thomas, 2022).

More precisely, we compare the characteristics of IEs with the key characteristics of the three most researched types of ecosystem in management research (i.e., business, innovation, and platform ecosystems). In this endeavor, we build on the work of Jacobides et al. (2018), which discusses the key characteristics of these three ecosystem types. Specifically, they draw on previous research (e.g., More, 1993; Adner, 2006; Jackson, 2011; Gawer and Cusumano, 2008; de Vasconcelos Gomes et al., 2018) to pinpoint key definitions and identify unique ecosystem BCs, such as shared key targets, focal point, ecosystem views, and units of interest (Table 1). We apply the same logic to clarify the BCs of IEs.

First, Jacobides et al. (2018) show that all three ecosystem types share the target of creating synergies. We find that creating synergies is of equal importance in IEs (e.g., Ayres, 1996; Baas, 1998; Bey, 2001; Adamides and Mouzakitis, 2009; Valackienė and Nagaj, 2021) (Table 1, column 1, row 2). Second, Jacobides et al. (2018) demonstrate that there are different focal points in the three ecosystem types: individual firms and the related business community (in business ecosystems), focal innovation (in innovation ecosystems), and a specific class of technologies – platforms (in platform ecosystems). Our analysis reveals that IE researchers commonly identify industrial processes as the focal point of IEs (e.g., Frosch & Gallapoulos, 1989; Bras, 2002; Casavant and Côté, 2004; Chavalparit et al., 2006; Andreoni, 2018) (Table 1, column 1, row 3).

Third, Jacobides et al. (2018) show that what actually comprises the system (system explanation) varies between the three types of ecosystem: economic community (in business ecosystems), system of innovations (in innovation ecosystem), and array of peripheral firms connected to a central platform (in platform ecosystem). In this context, we find that IE researchers typically explain that activities and processes evolve around the production system (e.g., Korhonen et al., 2001; Lyons et al., 2009; Ruth, 2009; Andreoni, 2018; Kim, 2019) (Table 1, column 1, row 4). Fourth and finally, Jacobides et al. (2018) propose that the unit of interest differs between ecosystems: interconnected activities (in business ecosystems), interconnected upstream and downstream innovations (in innovation ecosystems), and connections between the platform sponsor and complementors (in platform ecosystems). In IE research, we find that researchers commonly address the need for stakeholders to create networks of interconnected industrial partners. This element should, therefore, be seen as the unit of interest in IEs (e.g. Korhonen and Snäkin, 2005; Wolf et al., 2007; Tonn et al., 2014; Zaoual and Lecocq, 2018; Susur et al., 2019) (Table 1, column 1, row 5).

In essence, this study shows that IEs are characterized by four key distinguishing characteristics or BCs: synergy creation, industrial processes, production systems, and inter-connectedness between industrial partners. These key characteristics are also reflected in two often cited IE definitions (Frosch & Gallapoulos, 1989; Andreoni, 2018).

In this sub-section, we have enhanced the conceptual clarity by identifying four main IE characteristics (BCs) and positioned the IE in relation to business, innovation, and platform ecosystems. However, this clarification captures only IE key characteristics and does not mitigate the confusion caused by fragmented conversations in the extant IE literature.

4.2. IE confusion – three perplexity drivers

In this sub-section, an answer to RQ2, "What are the factors driving fragmentation and perplexity in IE research?" is provided. This analysis is illustrated in the sub-sections below where we identify and discuss three types of perplexity driver: definitional confusion, inter-conceptual confusion, and contextual fragmentation.

4.2.1. Definitional confusion

It is commonly agreed in the research community that perplexity may stem from the incoherent use of definitions. In other words, definitions matter because they clarify the conceptual BCs. Here, we applied inductive reasoning to derive explaining factors. First, we analyzed the extent to which researchers had used IE definitions, the IE definitions (or other ecosystem definitions) that were in play, and consistency in the use of definitions. Based on this inductive analysis, we contend that studies of IEs suffer from *definitional confusion*. In this review, three research behaviors have been observed that add to the definitional confusion: (1) a lack of IE definitions in studies, (2) casual use of IE or other ecosystem-related definitions, and (3) interchangeable use of IE or other ecosystem-related definitions.

In our sample, we find that 42 % (43/103) of the articles discuss IEs without providing an IE definition or any other ecosystem definition as the basis for their research. Rather, the concept is used as a buzzword. This means that the reader is left to accept the study as an IE study, without knowing what boundaries the researchers have placed around their study.

Second, the casual use of definitions comes about in different ways. For example, Adamides and Mouzakitis (2009) use a loose description – proposing that "geographically confined industrial ecosystems (eco-industrial parks and districts) should be seen as niches in a new industrial production paradigm". In another article, Best (2015) states that his IE study complements business ecosystem research, but he never defines IEs. In a third example, researchers (Lin et al., 2011; Kannisto et al., 2018; Parida et al., 2019; Burström et al., 2021) draw on a business ecosystem definition without reflecting on the differences/similarities between IEs and business ecosystems. In all of these cases, IE BCs remain unnoticed and, consequently, the IE concept is left to be understood intuitively.

Third, the interchangeable use of IE definitions is illustrated in different ways. For example, Kindcaid and Overchash (2001) propose that "This process of encouraging local exchanges is referred to as industrial ecosystem development or industrial symbiosis because it seeks to create a web of industrial relationships similar to an ecosystem found

Table 1
Ecosystem types and their key characteristics.

	Industrial Ecosystem	Business Ecosystem	Innovation Ecosystem	Platform Ecosystem
Definition	Frosch and Gallopoulos (1989), alternatively Andreoni (2018)	Moore (1993)	Adner, (2006), Jackson (2011), de Vasconcelos Gomes et al., 2018	Gawer and Cusumano (2008)
Shared key target	The creation of synergies between various ecosystem stakeholders			
Focal points	Industrial processes	Individual firms and the related business community	Focal innovation	Specific class of technologies – platforms
Ecosystem view	Production systems	Economic community	System of innovations	Array of peripheral firms connected to a central platform
Unit of interest	Interconnected industrial partners	Interconnected business activities	Interconnected upstream and downstream innovations	Connections between the platform sponsor and complementors

in nature". In a similar manner, Lou et al. (2004) state that an industrial ecosystem could be labeled as "industrial symbiosis". Indeed, these concepts are related, but they are not interchangeable. Symbiosis should rather be seen as a state of being (there is symbiosis), or a process of becoming (symbiosis is being created) within the context of an IE. Thus, interchangeable use of definitions should be avoided because the interchangeable use of concepts drives perplexity.

4.2.2. Inter-conceptual confusion

Here, we applied inductive reasoning as a way to derive a factor driving perplexity. While studying research articles, we observed that terminologies/concepts used in various studies share many features that make conceptual boundaries fuzzy. We therefore propose that studies of IEs suffer from what we label, *inter-conceptual confusion*. We contend that inter-conceptual confusion creates a cognitive boundary problem for researchers and practitioners trying to learn from IE studies. We observed a large number of similar concepts in use (Table 2, Examples of concepts in play). The relationship between these similar but yet diverse concepts is far from clear and adds to the problem of inter-conceptual confusion.

Table 2, Multiplicity of concepts in use in IE research.

Examples of concepts used in IE research			
eco-industrial parks (Lowe and Evans, 1995)	local industries symbiosis network (Wolf et al., 2007),	provincial industrial ecosystem (Wang et al., 2016)	urban-industrial ecosystem (Lu et al., 2020; Morris et al., 2021)
agricultural-industrial ecosystem (Fahim et al., 1995; Özyurt and Realff, 2001)	eco-industrial park (McManus and Gibbs, 2008)	resource-based industrial ecosystem (Fan et al., 2017)	post-industrial ecosystems (Spiering et al., 2020)
industrial ecosystem (Cote, 1997)	regional industrial ecosystem niches (Ashton, 2009; Susur et al., 2019)	eco-industrial ecosystem networks (Zaoual and Lecocq, 2018)	smart industrial ecosystems (Ali et al., 2021)
regional industrial ecosystem (Korhonen, 2001b)	web-based industrial ecosystems (Lin et al., 2011)	industrial ecology metabolism (Zhang et al., 2018)	industrial ecosystem oriented networked collaborative manufacturing platform (NCMP) system (Zhang et al., 2022)
industrial symbiosis (Lou et al., 2004)	reusable, recyclable, and renewable industrial ecosystem (Tonn et al., 2014)	hybridized industrial ecosystems (Kim, 2019)	industrial ecosystem for sustainable territorial development (Gamidullaeva et al., 2022)

All of these terms/concepts are, of course, created in good faith. However, the use of such tropes is not always beneficial. Analogies, metaphors, and images should be used with great care so that concepts serve a basic explanatory function (McManus and Gibbs, 2008). This is also supported by Cote (2009) who emphasizes the need for researchers to differentiate between IEs and other traditional industrial facilities, clusters, or parks. Similarly, we find that researchers need to use related concepts with greater care in order to create more distinct IE BCs.

One such distinction concerns the relationship between sub-concepts commonly referred to in IE studies: industrial metabolism (Chertow, 2000), industrial symbiosis (Wernik, 2001), architecture (Andreoni, 2018), and orchestration (Parida et al., 2019). These sub-concepts, which will be elaborated on and defined in subsection 4.3, serve as explanatory frameworks for understanding how transformations occur in IEs. They are employed to illustrate collective action, the emergence of synergies in IEs, and to address issues such as roles (Côté and Smolenaars, 1997; Levänen and Hukkinen, 2013), structures (Casavant and Côté, 2004), interdependencies (Zhu and Ruth, 2013), leadership (Kumari and Patil, 2019; Zaoual and Lecocq, 2018), life cycles (Shi and Li, 2019), and tools and methods (Singh and Lou, 2006; Korhonen and Baumgartner, 2009). However, since these sub-concepts concern overlapping elements, it is difficult to discern the interplay between these four sub-concepts and their importance for industrial transformation in IEs.

4.2.3. Contextual fragmentation

BCs do not only refer to definitions and concepts. There are other factors to take in consideration. Here, we apply an abductive reasoning as a way to explain how contextual fragmentation drives perplexity. Drawing on, and extending, the work of Korhonen and Snäkin (2005), we propose that four contextual sub-factors have an impact on understanding IE BCs: industrial geographic scope, industrial context, industrial dimensions, and industrial features.

First, when studying the papers in our sample, the issue of geographic scope became evident. This locality dilemma was also observed by Korhonen and Snäkin (2005) who argued that system boundaries as geographic scope (e.g., local vs. regional vs. national vs. global), should be clearly defined by IE researchers. Geographic scope can be characterized in various ways. In this study, we found that difficulties in defining geographic scope were most prevalent in local and regional studies. For instance, Adamides and Mouzakitis (2009) described "geographically" confined industrial ecosystems (eco-industrial parks and districts) as niches within a global industrial production system tied to regional development strategies. However, their study conflated small local IEs, consisting of only six firms, with larger regional IEs, one of which included twenty-one firms and another presumably larger region with an unspecified number of firms. We propose that examining these relationships from a symbiosis and metabolism perspective could be beneficial even in small industrial settings. Moreover, the appropriateness of characterizing a very small industrial setting as an IE is open to debate. In this particular case, the local IE (as in a tiny eco-industrial park) becomes equivalent to a regional ecosystem. Thus, understanding IE geo-scope boundaries becomes challenging when the relationship between the local ecosystem and the regional ecosystem is unclear.

Furthermore, in the spirit of Korhonen and Snäkin (2005), we find it essential to understand the type of industrial context in which studies have been performed. We reason that industrial boundaries are important to understand since findings and knowledge from one industrial context are not necessarily transferrable to another. For example, the fishing industry is very different from the coal mining industry. A clear industrial demarcation is, therefore, vital to understand the value of a study in a particular type of industry. In our sample, a large proportion of the studies (47) concern multi-industrial settings, but there are also industry explicit studies on, for instance, the agro-cultural industry (Fahim et al., 1995), the manufacturing industry (Malone et al., 2018), the coal industry (Wang et al., 2017), the metal industry (Reuter, 1998), the forest industry (Korhonen et al., 2001), the energy industry (Kim, 2019), the palm oil industry (Chavalparit et al., 2006), the chemical industry (Monteiro et al., 2010), the recycling industry (Lyons et al., 2009), and the pulp and paper industry (Côté and Smolenaars, 1997). Clear demarcations are needed in such studies because they act as guidelines for future research, enabling researchers to "catch on" and build on previous studies.

Moreover, researchers stress the importance of defining ecological, social, cultural, economic (Korhonen and Snäkin, 2005), and technological dimensions of an IE study. Communicating such dimensions (or combinations of dimensions) plays an essential role in demarking how research is applied to an IE and to communicate the expected outcome of a study. In our sample, there are, for example, optimization studies (mentioned in the article title). Here, the issue of "optimization of what?" surfaces. It would be easy to assume a close relationship between these studies. However, while Lu et al. (2020) studied a simulation of a local production flow model (technological dimension), Monteiro et al. (2010) considered the compromise between local profitability and environmental impact (a combination of dimensions) and Wang et al. (2016) took a national perspective on economic, environmental, and innovation subsystems. Thus, these studies share the features of optimization but yet they are different in the sense that they are complementary and loosely coupled.

Finally, we observe that communicating industrial features is an important element in setting boundaries around an IE study. Such features are commonly communicated in the article title. Here, features such as smart, renewable, networked, resource-based, or platform are often highlighted. For instance, local studies of IEs may be performed in a city (Jo et al., 2021). However, by adding that the study concerns "smart" cities or "low carbon" cities (Ma and Huang, 2020), a demarcation feature is created. This demarcation helps readers to understand the positioning of the study at hand in relation to other similar studies.

4.3. An integrative IE framework

In this sub-section, we address RQ3: "How can IE research be amalgamated into an integrative framework clarifying the relationship between disparate IE studies?" We propose a four-tier integrative IE framework (Fig. 5) that encapsulates the primary components of IE research and their respective interrelationships: the philosophical tier, the conceptualizing tier, the explicating tier, and the application tier.

4.3.1. The philosophical tier

This tier constitutes a philosophical standpoint recognizing the resemblance between ecological ecosystems and IEs. It is acknowledged that all forms of ecosystem concepts related to industries, business, and innovation are rooted in in the field of industrial ecology (cf. Moore, 1993; Andrews, 1999, p. 366). In addition, we maintain that any IE study should be understood in relation to four IE principles (Korhonen, 2001b; Kurhonen, 2001; Korhonen and Baumgartner, 2009): roundput (recycling of matter), diversity (variety of stakeholders, input and output, interdependency, and collaboration), locality (resources and stakeholders), and gradual change (gradual development of system diversity).

4.3.2. The conceptualizing tier

Here, we draw on the fact that all IE definitions stem from the area of industrial ecology. As reflected in Section 4.2.1, definitions matter because they may point researchers in different directions. It is therefore necessary to recognize that some dominating IE definitions are more streamlined towards a sustainability perspective (e.g., Frosch and Gallopoulos, 1989), while other IE definitions are directed towards an organizational perspective (e.g., Andreoni, 2018). We maintain that these definitions provide a base for two complementary streams of IE research – one stream of research placing emphasis on sustainability while the other stream of research emphasizing organizational issues. However, although the emphasis may be different, IEs in focus will still share key characteristics as described in Section 4.1 (synergy creation, industrial processes, production systems, and interconnected industrial partners).

4.3.3. The explicating tier

The main differences between the definitions taking a sustainability perspective versus an organizational perspective are further illustrated in what we label, the *explicating tier.* Building on the IE definition provided by Frosch and Gallopoulos (1989), researchers have shown that two sub-concepts play an essential role in explaining the direction of IE research – industrial symbiosis and industrial metabolism. Here, industrial symbiosis relates to the interaction of firms and the synergistic possibilities that may arise from such collaboration (Chertow, 2000). On the other hand, industrial metabolism concerns, for example, the flow of material and energy in the ecosystem (Wernik, 2001). This view coincides with Autio and Thomas's (2022) categorization of IEs as an ecosystem type concerned with the flow of energy and material. Consequently, these sub-concepts are fundamental to studies that adopt a sustainability perspective on IEs. In contrast, stemming from research

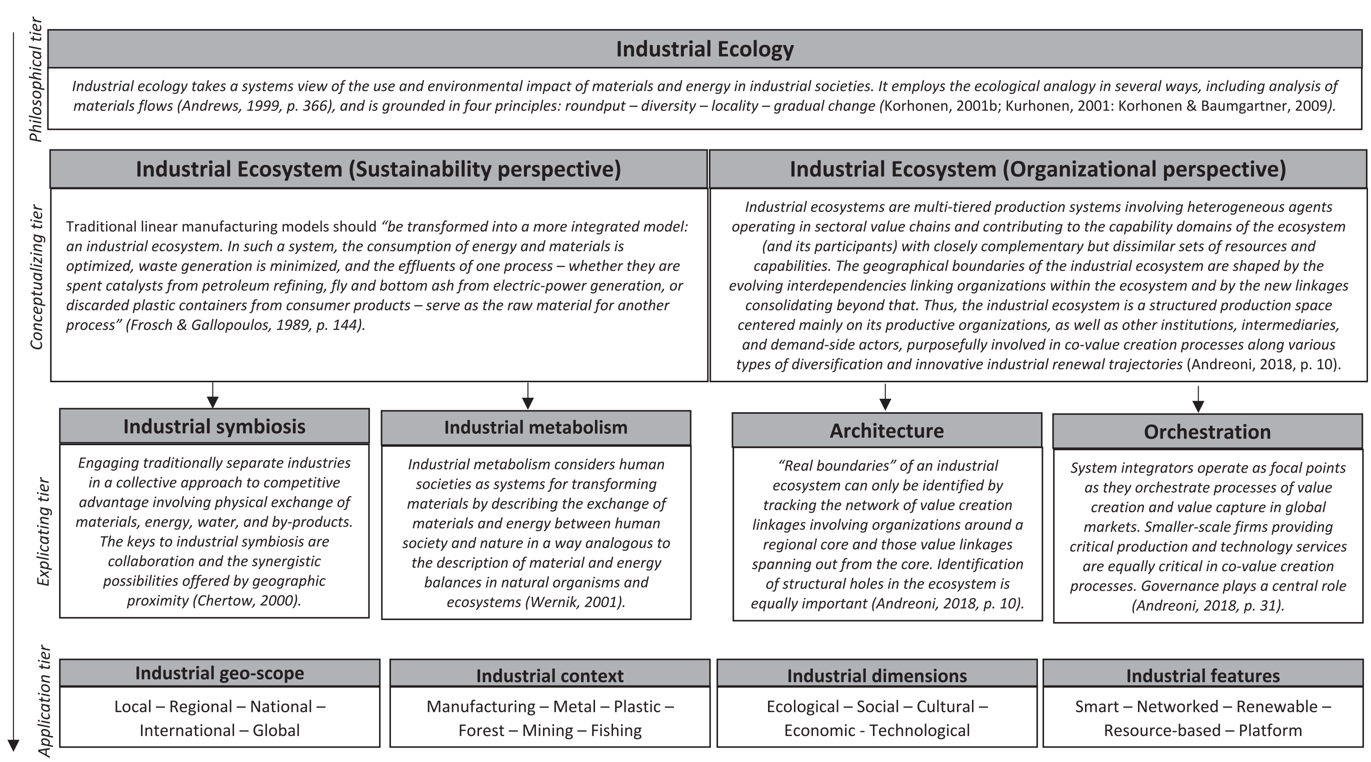

Fig. 5. Integrative Industrial Ecosystem Framework.

that adopts an organizational perspective on IEs, two other sub-concepts stand out as central – ecosystem architecture (IE structure, firms' roles, and how they relate to each other), and ecosystem orchestration (how firms take action and the way they compete/collaborate through various activities) (Andreoni, 2018).

4.3.4. The application tier

Finally, we propose a fourth tier, the *application tier*. Factors in this tier are fundamental for IEs that adopt a sustainability or an organizational perspective. Researchers propose that IE research needs to be explained and defined in relation to four central applied factors: industrial geo-scope, industrial context, industrial dimensions, and industrial features (cf. Korhonen and Snäkin, 2005). A clear explanation and definition of the industrial geo-scope helps authors and readers to understand how the study is positioned in terms of geography. Clearly, such definition is needed because it is very difficult, if even possible, to compare the findings of a study carried out locally (a city or eco-park) and one undertaken globally (global value networks). As a second factor, we contend that there is a need to clearly explain and define the industrial context where a study takes place. Such clarifications make it possible to categorize and compare various studies according to industry (manufacturing, plastic, metal, forest, fishing). Our third factor stresses the importance of understanding the industrial dimensions: ecological, economic, social, technological, and cultural – or any combination of the five dimensions (Korhonen and Snäkin, 2005). That is to say, these factors set the agenda for the study. The last factor to consider is that researchers should be clear on the industrial features that are at play in the studied industry. Here, we refer to qualities such as smart, renewable, networked, resource-based, and platform.

This four-tier framework guides researchers on how to communicate and define IE boundaries. Of course, the framework does not cover every possible type of IE definition, industry, dimension, or element. Therefore, it should be used in combination with the good judgement of researchers in the field.

5. Industrial ecosystems – a conceptual model

In this second part of our content analysis, we analyze and synthesize what the IE literature says about synergetic effects in IEs, and their antecedents and outcomes (RQ4). Here, we draw on our four-tier IE model (Fig. 5), where IE studies are divided into two streams of research: (1) studies drawing on a sustainability perspective (symbiosis and metabolism), and (2) studies taking an organizational perspective (architecture and orchestration). It is essential to understand that these research streams are complementary in contributing to knowledge on the relationship between synergetic effects, industrial renewal (Andreoni, 2018), and transformation (Frosch and Gallopoulos, 1989).

To clarify this relationship, we propose a model that connects antecedents and outcomes derived from IE research (Fig. 4). Our review revealed that both policymakers and firms are faced with the need to create synergies (excess value through complementarity) in IEs. However, while previous research has provided an understanding of isolated IE elements relating to how policymakers and firms can create synergies in IEs (Ayres, 1996; Adamides and Mouzakitis, 2009; Valackiené & Nagaj, 2021), a synthesized base of knowledge on what structures to create and which actions to take is lacking. To bridge this knowledge gap, we aim to create a holistic understanding by highlighting elements of ecosystem structure for transformation and ecosystem transformative action as key antecedents of synergetic effects.

Antecedents associated with ecosystem structure for transformation are found in architecture (Andreoni, 2018; Jo et al., 2021) and symbiosis (Cote, 1997; Ashton, 2008; Morris et al., 2021) studies, whereas antecedents belonging to ecosystem transformative action are identified in orchestration (Lyons et al., 2009; Parida et al., 2019; Burström et al., 2021), metabolism (Ayres, 1996; Korhonen et al., 2004a; Tonn et al., 2014), and symbiosis (Kurhonen, 2001; Layton et al., 2016; Gamidullaeva et al., 2022) studies. In Fig. 6, we use the following abbreviations: architecture (A), orchestration (O), symbiosis (S), and metabolism (M) to identify the origins of various elements. This shows that symbiosis researchers discuss matters relating to both structural frameworks and action-related issues, while metabolism researchers discuss items of a purely action-related nature. In comparison, architecture researchers address only structural elements, whereas orchestration research is action oriented.

In Fig. 6, the outcome explained by synergetic effects is industrial renewal/transformation in different forms. These effects may come in the form of sustainable industrial renewal/transformation (for example, cleaner production processes). However, research taking an organizational perspective (architecture and orchestration) contributes to the knowledge of industrial renewal and transformation in the form of digitalized production processes and other forms of business renewal/transformation (See Fig. 6).

To elucidate how different streams of research have contributed to understanding the mechanisms behind synergetic effects resulting in IE renewal/transformation, we perform an analysis based on factors in the application tier (Fig. 5, tier four): industrial geo-scope, industrial context, industrial dimensions, and industrial features. Drawing on the analysis in each sub-section, we advance ten propositions. Here, propositions 1, 6, and 7 relate to ecosystem structure for transformation, while propositions 2 to 5 and 8 to 9 concern ecosystem transformative action. The final proposition amalgamates propositions 1 to 9 connecting synergetic effects to outcomes in the form of renewal/transformation.

5.1. IE studies taking a sustainability perspective

The majority of the studies in our sample contribute to IE research by taking a sustainability perspective (64/103). Researchers in these articles typically refer to ecology-based IE definitions and draw on explicating factors such as industrial symbiosis (Chertow, 2000) and industrial metabolism (Wernik, 2001). These studies strongly relate to and contribute to an understanding of IE principles: roundput, diversity, locality, and gradual change (Korhonen, 2001b; Kurhonen, 2001; Korhonen and Baumgartner, 2009).

5.1.1. Industrial symbiosis and synergetic effects

Of the sixty-four (64) studies taking a sustainability perspective on IEs, forty-three (43) focused on symbiotic issues. A number of these studies adopted a local geo-scope (14/43) although, in some cases, the local geo-scope was mixed with regional or international aspects. The remaining studies were distributed across fifteen (15) regional, nine (9) international, and five (5) global studies. Moreover, twenty-six (26) of the symbiotic studies researched a multi-industrial context. The remaining studies were distributed across other contexts, such as manufacturing, energy, waste, forest, pulp and paper, chemical, sugar, construction, and a post-industrial setting. Additionally, the majority of papers (39/43) researched the sociological dimension of IEs, and the most common feature studied was networks.

These studies were grouped into three distinct research categories. First, it was clear that structural issues need to be resolved in order to achieve IE synergies. Therefore, a number of researchers focused on IE structural matters (Coté, 1997; Côté and Smolenaars, 1997; Ehrenfeld and Gertler, 1997; Lowe, 1997; Hardy and Graedel, 2002; Casavant and Côté, 2004; Harper and Graedel, 2004; Geng and Côté, 2007; Ashton, 2008; Liwarska-Bizukojc et al., 2009; Chertow and Ehrenfeld, 2012; Liu et al., 2012; Zhu and Ruth, 2013; Levänen and Hukkinen, 2013; Morris et al., 2021; Tolstykh et al., 2020; Agudo et al., 2023; Shmeleva et al., 2023; Tolstykh et al., 2023). These researchers typically assert the need to understand the networks of interdependent firms and the variety of complementary roles that these firms play.

Here, researchers emphasize the need for policymakers and firms to understand IE structures (Casavant and Côté, 2004; Harper and Graedel,

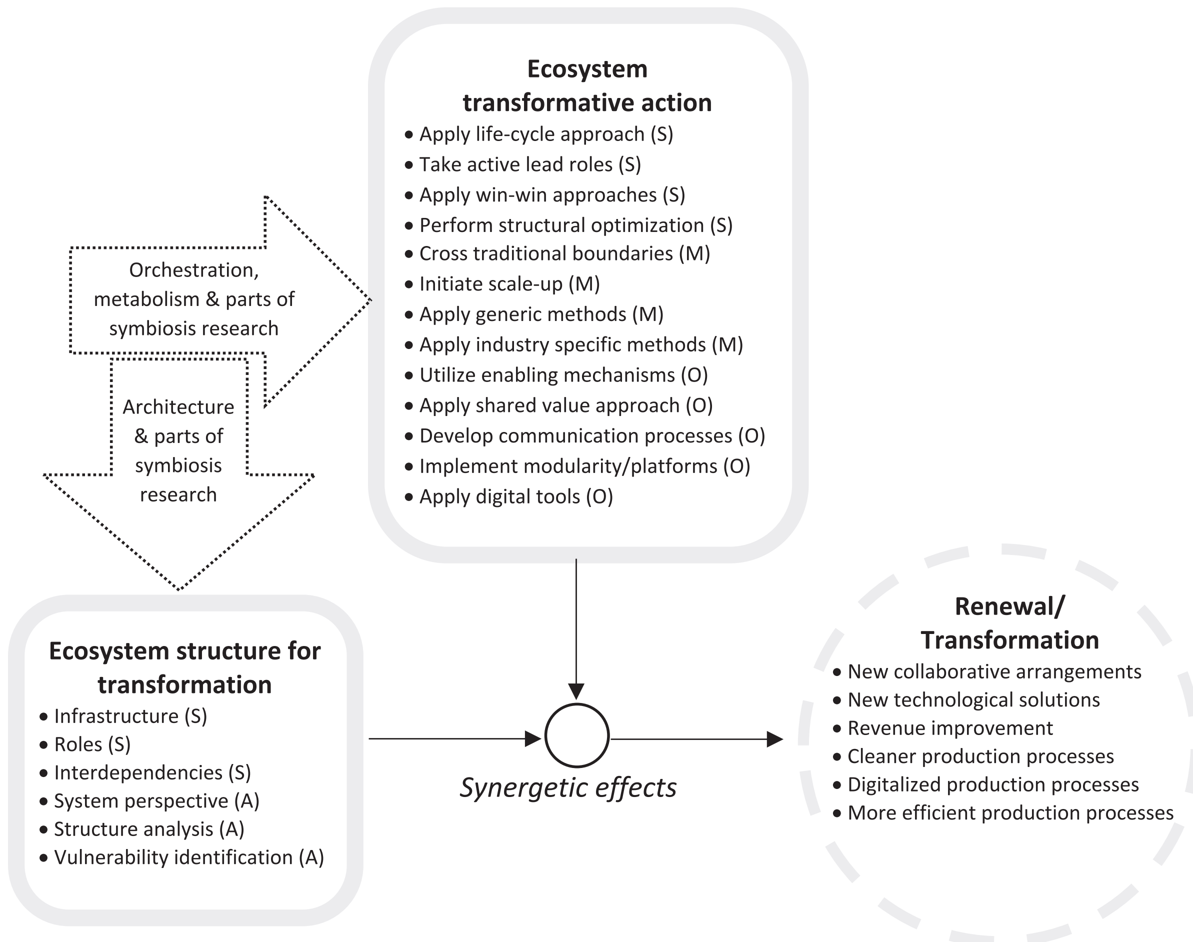

Fig. 6. A model of synergetic effects and industrial ecosystem renewal/transformation.

2004) and to configure structures so that they represent the best fit with various industrial symbiosis activities – for example, by-product exchanges, service sharing, and utility sharing (Lowe, 1997; Ashton, 2008; Agudo et al., 2023). Within these structures, the roles of firms need to be defined (Côté and Smolenaars, 1997; Chertow and Ehrenfeld, 2012; Levänen and Hukkinen, 2013) and diversity among members assured (Geng and Côté, 2007; Liwarska-Bizukojc et al., 2009). Moreover, interdependencies between various stakeholders need to be explicitly addressed and designed (Côté, 1997; Ehrenfeld and Gertler, 1997; Liu et al., 2012) so that firms can balance weak and strong dependencies (Zhu and Ruth, 2013). Nonetheless, the collaboration maturity among stakeholders must be understood (Tolstykh et al., 2020; Shmeleva et al., 2023; Tolstykh et al., 2023). Thus, researchers emphasize the importance of configuring structures, roles, and interdependencies to create synergies that achieve collective sustainability goals as part of industrial renewal/transformation. These structural elements are part of an ecosystem transformative framework (Fig. 6), constituting BCs for high-impact symbiotic collaboration. As an outcome of this discussion, we advance a first proposition:

P1: When policymakers and firms in industrial ecosystems plan for a) industrial ecosystem structures, b) role distribution, and c) symbiotic interdependencies, their likelihood of creating synergetic effects is increased.

Second, ecosystem leadership plays a central role. We found that large firms and public players can be well suited to play this IE leadership role (Kincaid and Overcash, 2001; Korhonen, 2001a; Lou et al., 2004; Wolf et al., 2007; Okkonen, 2008; Ashton, 2009; Liu et al., 2015; Ashton et al., 2017; Kumari and Patil, 2019; Zaoual and Lecocq, 2018; Susur et al., 2019).

The most successful networks are earmarked as those developed around a few leading critical firms (Ashton et al., 2017) who are capable of communicating/integrating collective (formal/informal) expectations, visions, and cognitive rules (Susur et al., 2019). Furthermore, leadership helps with conflict resolution between ecosystem members (Lou et al., 2004) and attaining win-win outcomes (Okkonen, 2008; Kumari and Patil, 2019). Here, public actors can play a role in facilitating collaboration among industrial actors (Korhonen, 2001a; Liu et al., 2015), while both private and public players can perform an orchestrating role in, for example, uncovering value in industrial ecology, generating trust, and activating/institutionalizing industrial ecology (Zaoual and Lecocq, 2018). Overall, IE leadership can positively impact the creation of synergies so that sustainability goals can be attained more quickly. These leadership elements form part of ecosystem transformative actions (Fig. 6). Drawing on the discussion above, we suggest the following proposition:

P2: When large private firms, or public players, in industrial ecosystems play a leading role in initiating symbiotic activities, their likelihood of creating synergetic effects is increased.

Third, in order to achieve synergetic effects in IEs, policymakers and firms should take a long-term view and adopt a systematic way of managing business problems (Bras, 2002; Korhonen, 2004; Zhu and Cote, 2004; Singh and Lou, 2006; Singh et al., 2007; Korhonen and Baumgartner, 2009; Layton et al., 2016; Kim et al., 2017; Shi and Li, 2019; Spiering et al., 2020; Gamidullaeva et al., 2022; Harala et al., 2023; Wang et al., 2023). These researchers typically emphasize the need to adopt a life-cycle perspective on IEs and recommend optimization methods as a way of addressing symbiotic challenges.

Here, symbiotic-based analytical life-cycle approaches (Korhonen, 2004; Zhu and Cote, 2004; Shi and Li, 2019) can provide a comparative evaluation of different IE design schemes (Singh et al., 2007), improve material quality control and assessment metrics (Bras, 2002) and support collective strategy creation and decision making (Shi and Li, 2019; Harala et al., 2023). Additionally, the use of optimization methods provides a systematic and flexible collective framework to solve multi-dimensional problems (Singh and Lou, 2006; Korhonen and Baumgartner, 2009; Kim et al., 2017), reducing the processing of natural resources and increasing the amount of production (Gamidullaeva et al., 2022; Wang et al., 2023). When combined, these measures improve assessments of environmental impact and provide collective guidance for improving sustainability. In implementing these solutions and methods, firms take transformative action (Fig. 6) that enables synergetic effects. Based on the arguments advanced, we offer a third proposition:

P3: When policymakers and firms in industrial ecosystems take a systematic a) life-cycle approach and b) use optimization methods to maximize the impact of symbiotic activities, their likelihood of creating synergetic effects is increased.

To summarize, studies on industrial symbiosis typically take environmental sustainability as a proxy and discuss how to organize industries in an environmentally friendly way. These studies provide critical knowledge on local and regional organizing issues to create synergies. However, they largely fail to adopt a global perspective on how to organize for environmental sustainability. Thus, IE researchers still have to solve the dilemma of how to create the transferability that will convert local managerial solutions into global solutions.

5.1.2. Industrial metabolism and synergetic effects

Of the sixty-four (64) studies taking a sustainability perspective on IEs, twenty-one (21) focused on industrial metabolism. These studies were dominated by researchers taking a local geo-scope (9), while other papers were distributed across six (6) regional studies, five (5) national studies, and one (1) global (conceptual) study. In terms of context, several types of industry were studied: multi-industrial (7), petrochemical (2), forest (2), chemical (2), agricultural (1), energy (2), construction (1), palm oil (1), mining (1), steel (1), and recycling (1). Most industries were studied on only a few occasions, and the majority of these studies examined a technological and/or ecological dimension of industrial metabolism. In addition, the industrial features in focus for the respective studies were widely distributed across different dimensions. All of these studies typically contribute detailed descriptions of *how* material flows can be managed in different industries and the output of such management.

We grouped these studies into two distinct research categories. First, we recognized that synergy creation is hampered if players stay within traditional industrial boundaries and remain small in scale. Hence, one category of researchers (Ayres, 1996; Andersen, 1997; Baas, 1998; Korhonen, 2001b; Kurhonen, 2001; Korhonen et al., 2004a; Sterr and Ott, 2004; Korhonen and Snäkin, 2005; Tonn et al., 2014; Lyu et al., 2023) study pre-conditions for achieving industrial metabolism and synergetic effects in IEs. These researchers recommend large-scale operations to address issues such as roundput, recycling, and the need to move beyond the boundaries of traditional systems.

Here, researchers (Korhonen, 2001b; Kurhonen, 2001; Korhonen et al., 2004a) propose that, in order to manage waste management flows, stakeholders must move beyond the boundaries of the traditional waste management system. Additionally, Baas (1998) emphasizes the need to optimize internal and external flows in parallel so that cleaner production is assured. Such optimization needs to be achieved in an expanding network of stakeholders (Baas, 1998; Korhonen and Snäkin, 2005). Other researchers stress that, in order to succeed in creating synergies and industrial metabolism, a fairly large-scale operation is required (Ayres, 1996; Andersen, 1997; Sterr and Ott, 2004; Tonn et al., 2014; Lyu et al., 2023). Taking such transformative action (boundary crossing and flow management) drives (Fig. 6) the development of economic and environmental sustainability in particular. These studies underline that it is vital to look beyond traditional industrial boundaries if synergies are to emerge and large-scale operations are to be created so that the shared sustainability goals in IEs can be achieved. Drawing on these findings, we advance a fourth proposition:

P4: When firms in industrial ecosystems a) expand networks beyond traditional industrial ecosystem boundaries and b) scale up industrial metabolism operations, their likelihood of creating synergetic effects is increased.

Second, in achieving metabolistic synergetic effects, flow management and related methods play a central role. Therefore, another category of researchers has studied particular methods for managing various types of material flows (Fahim et al., 1995; Bailey et al., 1999; Korhonen et al., 2001a; Özyurt et al., 2001; Basu and van Zyl, 2006; Chavalparit et al., 2006; Monteiro et al., 2010; Hollen et al., 2015; Malone et al., 2018; Zhang et al., 2018; Miao et al., 2020). These researchers typically adopt a practice-based approach describing the *management* of flows and the expected output from applying a certain method in a circumscribed local context.

For example, Hollen et al. (2015) describe how different *generic* policy instruments (e.g., investments in physical and knowledge infrastructure) can be used as a general method to foster industrial metabolism, while Bailey (1999) suggests that this can be achieved through simulations (e.g., the robust concept exploration method). Moreover, researchers demonstrate the good use of various industry-specific methods in the agricultural industry (Fahim et al., 1995), the forestry industry (Korhonen et al., 2001), the energy industry (Özyurt et al., 2001; Miao et al., 2020), the palm-oil industry (Chavalparit et al., 2006), the chemical industry (Monteiro et al., 2010), the mining industry (Basu and van Zyl, 2006), and the steel industry (Malone et al., 2018). However, Zhang et al. (2018) state that the methods in the construction industry are less effective in managing industrial metabolism. The collective evidence from the addressed studies indicates that generic and specific methods play a central role in creating synergies that enable shared sustainability goals to be reached. Use of these methods represents transformative action (Fig. 6), advancing the capabilities for creation and management of industrial metabolism by refining material and non-material flows. Based on these insights, we outline a fifth proposition:

P5: When policymakers and firms in industrial ecosystems utilize a) generic methods, and b) firms utilize industry specific methods for managing industrial metabolism, their likelihood of creating synergetic effects is increased.

To summarize, studies on industrial metabolism typically take environmental sustainability as a proxy and discuss how to arrange material flows to shape more environmentally friendly industries. These studies provide critical knowledge on how to create synergies and manage local and regional material flows. However, they fail, in the main, to adopt a global perspective on how to organize material flows for environmental sustainability.

5.2. IE studies taking an organizational perspective

In our sample, a minority of studies contribute to IE research by taking an organizational perspective (39/103). Researchers in these articles typically draw on organization-based IE definitions and on explicating factors, such as industrial architecture and/or industrial orchestration (Andreoni, 2018).

5.2.1. Industrial ecosystem architecture and synergetic effects

Of the thirty-nine (39) studies taking an organizational perspective on IEs, twenty (20) studies focused on structural issues – namely, discussing matters relating to IE architecture.

Here, several researchers took a national geo-scope (6). The other papers were distributed across three (3) local, two (2) regional, two (1) international, and seven (7) global studies. As for context, researchers studied a multi-industrial context (11), energy (2), integrated circuits

(1), blockchain (1), coal mining (1), semiconductors (1), silicon (1), and two (2) studies were of a conceptual nature. All of these studies took a sociological perspective (also in combination with other perspectives). In terms of industrial features, studies typically concerned roles and structural dilemmas. All of these studies contributed to an understanding of IE configuration.

These studies were grouped into two distinct research categories. First, policy initiatives are crucial in creating pre-conditions for synergetic effects in IEs. However, it is far from clear how policymakers should act to achieve synergies. Therefore, in the first category, researchers typically focus on the role of policymakers/authorities (Lowe et al., 1995; Bey, 2001; Korhonen et al., 2004c; Von Malmborg, 2004; Kim, 2019; Zhang et al., 2019; Ma and Huang, 2020; Yan et al., 2020). These researchers emphasize that policymakers cannot apply a one-size-fits-all solution, and IE structures should be configured from a systems perspective in accordance with contextual needs in order to generate synergetic effects that spur innovation and production.

For example, IE concepts provide a systemic context with tools for decision making that can enhance co-innovation (Lowe et al., 1995). Here, authorities/policymakers should exercise a governing role (Bey, 2001) by planning infrastructure (Kim, 2019; Zhang et al., 2019), creating feedback structures (with positive impact on technological innovation), initiating business development (Yan et al., 2020), playing a role as knowledge brokers in innovation networks (Korhonen et al., 2004c; von Malmborg, 2004), and adhering to normalized management models (Ma and Huang, 2020). These studies propose that, when policymakers take an appropriate role and support business development by planning infrastructures from a systems perspective, synergetic effects are enabled so that shared business goals can be attained through co-innovation in networks. These elements are essential parts of an ecosystem structure for transformation (Fig. 6). Building on these findings, we advance a sixth proposition:

P6: When policymakers in industrial ecosystems a) take a systems perspective and b) plan infrastructures that meet context-based needs, the likelihood of firms creating synergetic effects is increased.

Second, another category of researchers probes issues relating to structural quality. These researchers typically study the complexity and dynamics of systems and sub-systems (Ruth, 2009; Chen et al., 2010; Wang et al., 2016; Wang et al., 2017; Feng et al., 2018; Jo et al., 2021; Zhang et al., 2021; Lee and Kim, 2023), networks (Duan et al., 2022a; Duan et al., 2022b), power grids (Ali et al., 2021) and interdependencies (Andreoni, 2018) within the IE. They emphasize that IE boundaries are evolving and dynamic, and that structural renewal is vital to co-create value.

For instance, Ruth (2009) asserts the need to analyze structures in order to understand the dynamics in IEs because there is a lack of commonly agreed and followed protocols for dynamic modeling that span system hierarchies, space, and time. Moreover, there is a lack of institutional structures that enable stakeholder-guided adaptive management of IEs over the longer term. In addition, Wang et al. (2016) propose that IEs should be understood as based on three sub-systems: the economy sub-system, the environment sub-system, and the innovation sub-system. Each sub-system has its own curve shape that describes its economic–environmental relationship and reveals the effect of optimization degrees on the relationship between economic growth and environmental pollution. Similarly, Zhang et al. (2021) identified three sub-systems underlying the blockchain industry ecosystem.

Here, Wang et al. (2017) add that ecosystem vulnerability can be estimated and managed by using a special method (RS-TOPSISeRSR). Failing to understand vulnerabilities can lead to weak industry connectedness, hampering the possibility of achieving synergetic effects in IEs (Duan et al., 2022a; Duan et al., 2022b). IEs are less likely to crash when industries are tightly interconnected. Additionally, Chen et al. (2010) show that ecosystem analysis can provide company decision makers with a reference to restructure production chains and innovate technology. This restructuring can be seen as industrial renewal where interdependencies need to be shaped and re-shaped (Andreoni, 2018). Such restructuring of traditional industries leads to economic growth through synergetic co-value creation processes (Feng et al., 2018; Jo et al., 2021; Lee and Kim, 2023).

These studies show that the combined effect of analyzing structures and identifying vulnerabilities is to enable firms to generate synergetic effects in an attempt to co-create value. These elements constitute indispensable parts of an ecosystem structure for transformation (Fig. 6). This discussion leads us to the following proposition:

P7: When firms in industrial ecosystems a) analyze structures and b) identify vulnerabilities, their likelihood of restructuring interdependencies to create synergetic effects is increased.

To summarize, studies on IE architecture typically address questions concerning structures, roles, and interdependencies. These studies provide critical architectural knowledge on how relationships can be arranged to create synergies and encourage innovation and co-value creation.

5.2.2. *Industrial ecosystem orchestration and synergetic effects*

Of the thirty-nine (39) studies taking an organizational perspective on IEs, nineteen (19) studies focused on orchestrating topics – namely, discussing how IEs come about.

In this stream of research, four (4) articles took a global geo-scope, six (6) an international geo-scope and two (2) a national geo-scope. Other articles were distributed across three (3) local, and four (4) regional geo-scopes. Here, researchers studied multi-industrial contexts (6), manufacturing (6), biofuel (1), energy (1), recycling (1), the car industry (2), the consumer electronics industry (1), and the metal industry (1). These researchers typically adopt a sociological or socio-technological perspective on the studied contexts. In terms of features, these studies discussed the need for orchestration or how orchestration could come about. All of these studies contributed to an understanding of IE orchestration.

These studies can be grouped into two distinct research categories focusing on how to take ecosystem transformative action to make changes in an IE. First, one category of researchers discuss the need for orchestration and general pre-conditions for successful orchestration. Here, researchers examine orchestration processes and activities (Lyons et al., 2009; Parida et al., 2019; Hannibal, 2020; Burström et al., 2021; Suppipat and Hu, 2022; Sjödin et al., 2022), and elements enabling orchestration (Best, 2015; Tsvetkova et al., 2015; Valackienė & Nagaj, 2021).

For example, Lyons et al. (2009) describe how value chains in the recycling industry have been orchestrated to fulfill the needs of different countries. The development of such IEs is a product of historical co-adaptive processes (Best, 2015) where policymakers and firms must understand that organizational learning is a valuable capability aiding orchestration (Tsvetkova et al., 2015). Such learning leads to the development of enabling collaboration mechanisms, such as trust (Valackienė & Nagaj, 2021), standardization, nurturing, and negotiation (Parida et al., 2019). Moreover, to spur shared value creation (synergies), the business model should be used as a device to conceptualize orchestration activities (Hannibal, 2020; Sjödin et al., 2022; Suppipat and Hu, 2022). Here, Burström et al. (2021) propose that shared value creation is best managed in a situation where orchestrators try to balance development between exploitation (business goals related to cost efficiency and incremental innovation) and exploration (business goals related to new revenue flows and radical innovation). Based on the insights from the above studies, we find that orchestration is dependent on enabling orchestrating mechanisms, business models, and balancing diverse business goals as part of the process of creating synergetic effects (Fig. 6). Drawing on this discussion, we present our eighth proposition:

P8: When firms in industrial ecosystems a) learn to enable orchestrating mechanisms and b) use business models to identify shared value potential, their likelihood of creating synergetic effects is increased.

Finally, another category of researchers provides hands-on advice for orchestration and IE construction, which are vital in achieving synergetic effects. These researchers propose that strategic-niche management can be used to change technological regimes in IEs (Adamides & & Mouzakitis, 2009). In such circumstances, each IE has a set of constraint factors that have to be considered (Lu et al., 2020), where communication (Lin et al., 2011) and information processes (Kannisto et al., 2020) must be fine-tuned. Furthermore, IEs are typically built on complex networks. Here, it is noted that orchestrators can identify critical network nodes and interdependencies through an inference method to improve process efficiency (Fan et al., 2017). Moreover, orchestrators can manage complexity and increase revenue through modularity (Tsvetkova and Gustafsson, 2012) and/or platform approaches (Zhang et al., 2022). It is also pointed out that orchestrators can use digital twins for decision support (Meierhofer et al., 2021), and digital simulations (Reuter, 1998; Hooge and Le Du, 2016) can be used as ways to promote and govern IEs. Based on the above argumentation, we find that such transformative action is essential to create synergetic effects (Fig. 6). As a result of this discussion, we present our proposition as follows:

P9: When firms in industrial ecosystems orchestrate a) communication and information processes, b) modularity or platform approaches to manage complexity, and c) the use of digital tools for decision support and governance, their likelihood of creating synergetic effects is increased.

To summarize, studies on IE orchestration typically address preconditions for successful industrial renewal/transformation, and researchers discuss tools and processes to be used to create synergies and accomplish well-organized orchestrating activities in practice.

5.3. *IE synergetic effects and industrial renewal/transformation*

The core of ecosystem thinking is based on the idea of collective efforts and shared goal achievements (Frosch and Gallopoulos, 1989; Andreoni, 2018) where a win-win approach is the dominant logic (Okkonen, 2008). Therefore, we predict that, when policymakers and firms are capable of generating synergetic effects, they are more likely to instigate industrial renewal/transformation in IEs.

These synergetic effects occur when policymakers and firms can rely on system-level thinking, structure, and vulnerability analyses to define roles, interdependencies, and needs for infrastructure investments. In this sense, they can understand and explain who the members of the ecosystem are, their role distribution, relationships, and shared vision. These components form a structure for ecosystem transformation that is dynamic in nature, evolutionary, and open to change. However, structure alone is not enough to create robust synergetic effects.

Therefore, we find that transformative ecosystem action is central to creating synergetic effects and promoting change in the form of IE renewal/transformation. Here, it is essential that firms apply a life-cycle approach, look beyond traditional industrial boundaries, actively lead change, strive to optimize structures, initiate scale-up, take a shared value approach, employ enabling mechanisms, implement modularity/platform strategies and, on a functional level, utilize generic and specific methods, develop communication processes, and apply digital tools.

As policymakers and firms combine structures with action, the synergies that are generated produce an outcome in the form of new collaborative arrangements, new technological solutions, revenue improvements, and cleaner, digitalized, more efficient production processes. Here, there is a central source of differentiation between the IE research taking a sustainability perspective and the IE research taking an organizational perspective. Studies on IE symbiosis and metabolism typically aim to offer explanations on how synergies contribute to solving the triple-bottom line dilemma (economic, environmental, and social sustainability), primarily manifested in cleaner production processes. In contrast, researchers studying IE architecture or orchestration primarily focus on explaining how synergies generate new forms of cooperation, technological solutions, and revenue enhancements/cost reduction through digitalized processes, for instance. These outcomes represent aspects of industrial renewal/transformation. As a result of this discussion, we offer the following proposition:

P10: When policymakers and firms in industrial ecosystems create synergies among members in the IE collective, they are more likely to pave the way for industrial renewal trajectories and/or industrial transformation.

6. Discussion and Conclusions

The aim of this article was to review and synthesize existing IE research. Here, we initially reflect on the three first three questions that guided our research:

RQ1: What are the key characteristics of IEs?; RQ2: What are the factors driving fragmentation and perplexity in IE research?; RQ3: How can IE research be amalgamated into an integrative framework clarifying the relationship between disparate IE studies?

First, in this study, four IE key characteristics were identified and compared to key characteristics of three other types of ecosystem (business, innovation, and platform). One key characteristic is shared with other ecosystem types (synergy creation), while three others (industrial processes, production systems, and interconnected industrial partners) are unique to IEs. This achievement has clarified the fundamentals of IE BCs and allowed us to position IEs in relation to other ecosystem types.

Second, we identified three factors driving perplexity and fragmentation in IE research: (1) definitional confusion, (2) inter-conceptual confusion, and (3) contextual fragmentation. In relation to RQ3, our review revealed that IE research is bifurcated into two dominating complementary research streams: one adopting a sustainability approach, and the other adopting an organizational approach. The relationship between these research streams has been elucidated, and the issue of unclear BCs has been addressed through the creation of an integrative four-tier IE framework. This framework, encompassing philosophical, conceptualizing, explicating, and application tiers, enables IE researchers to make more informed decisions when designing future IE studies.

In response to our final research question (RQ4), "What does the IE literature say about synergetic effects in IEs, and their antecedents and outcomes?", our study revealed that there are antecedents derived from a combination of ecosystem structure for transformation and ecosystem transformative action. These antecedents enhance the likelihood of policymakers and firms creating synergetic effects. We found that antecedents related to ecosystem structure for transformation originate from literature focusing on architecture and symbiosis. In contrast, antecedents related to ecosystem transformative action originate from the orchestration, metabolism, and symbiosis literature. This body of work provides numerous examples of actions that policymakers and firms can undertake to instigate synergetic effects in IEs. However, it also identifies a division of responsibilities between policymakers and firms.

When both policymakers and firms undertake these responsibilities, the synergetic effects are amplified, leading to increased levels of industrial renewal/transformation. For instance, if the goal is to create industrial renewal/transformation on a global scale – as in the case of the recycling industry – coordination and synchronization across the IE must be meticulously designed by both policymakers and firms. As a result, these effects can be manifested in cleaner production processes, digitalized value chains, and new incremental and/or radical technological solutions.

6.1. *Policy implications and limitations*

Our analysis of synergetic effects in IEs enables us to formulate policy recommendations. First, we acknowledge that there is a challenge facing firms in scaling their operations from a local to a global level. There is a tendency for value chains and networks to stretch across nations and global regions. To help resolve this problem, policymakers should encourage studies (in firms and research institutions) on how to organize large-scale symbiotic networks in various types of IE so that global material flows can be managed in a synergetic way. In addition, this study highlights another challenge – critical interdependencies typically stretch across various IEs. Thus, in order to manage this challenge, policymakers could promote studies examining the relationship and interdependencies between various types of complementary IE (Auerswald and Dani, 2022). Such studies could reveal critical and complex IE structures that are vital to understand synergetic effects, their results, and their translation into industrial renewal/transformation.

Second, we advocate that governance and leadership demands special attention in the emergence of synergetic effects in IEs. There is a need for policymakers and industrial leaders to gain a deeper understanding of the micro foundations of collectively shared value-creating processes, enabling mechanisms, complexity-managing approaches, and the use of digital tools for governance and decision-making activities in various IEs. Therefore, we propose that policymakers and industrial leaders collaborate in developing best practices that can be implemented in the form of an IE governance toolkit.

Third, policymakers have a unique responsibility to establish infrastructure. This responsibility concerns both material and non-material infrastructure (Hannigan et al., 2022). Assuming such responsibilities involves investing in material infrastructure, such as electrical grids, airports, bridges, power plants, and waste management systems, enabling the development of various types of synergetic networks within the IE. Investments in non-material infrastructure relate to labor and market support in the form of events, knowledge brokering, regulators, interest organizations, and professional training. Through such investments, favorable market conditions can be established in IEs (cf. Wei, 2022).

Fourth, typically, IE creation begins in a small-scale fashion. Thus, policymakers can concentrate on creating synergies with firms and non-profit organizations on the local and regional levels. As a result, the network of policymakers and other stakeholders can be relatively simple, small, and dense. However, when IE business operations expand beyond local and regional borders, there is a need to grow a network of boundary-spanning policymakers (cf. Rocha et al., 2021) so that policymaking can be coordinated across local, regional, national, and global levels.

Finally, this study emphasizes that synergetic effects in IEs can amplify industrial renewal/transformation. Thus, there are societal benefits that warrant policymakers and governmental authorities prioritizing the development of an IE policy agenda where synergetic effects are emphasized. This agenda can play a key role in efforts to boost market resilience and revitalization by elaborating on global partnerships and strategic dependencies.

This study has the following limitations. First, our exploration of industrial ecosystems (IEs) is limited to their relationship with business, innovation, and platform ecosystems. We acknowledge that there are additional areas of ecosystem research that could be relevant for comparison. These could include, for instance, research on entrepreneurial ecosystems, software ecosystems, digital ecosystems, and regional ecosystems, all of which have been addressed in management and entrepreneurship research. Second, our approach to conducting a systematic review is narrative in nature. This means that our review does not include a section dedicated to patterns of bibliometric analysis. The inclusion of such a section would provide an alternative perspective on the evolution of the IE research field.

6.2. Future research

Our study leads us to make two assertions. First, there is a lack of studies taking a top-down perspective on the role and activities of large firms (hubs) in IEs. For example, in practice, we can observe that global companies, such as Hennes & Mauritz, assume an IE leading role in developing synergies for sustainable industrial transformation. H&M strives to create closed material loops in the fashion industry through cross-industry collaborative actions and investments in startups, which contribute to cleaner production processes (cf. Lahti et al., 2018). Thus, we encourage the IE research community to further investigate the role and behavior of hubs (Parida et al., 2019) in various IEs (fashion industry, recycling industry, steel industry, manufacturing industry).

Second, there is limited research that adopts a bottom-up perspective on IEs, examining their emergence and the complementary roles and interaction patterns between startups, incubators, accelerators, venture capitalists, and SMEs. While the current stream of IE research offers several contributions discussing smaller local/regional IEs – in the form of, for example, eco-parks – we have a limited understanding of how and whether these isolated examples of IEs expand to a larger scale through the creation of synergetic effects. Here, it would be of interest to understand which roles various players perform during such a collective renewal/transformation process. This type of growth would likely be based on some form of co-orchestrating efforts among a collective of stakeholders.

Third, our study identifies a gap in research knowledge regarding the role of venture capital investors in the emergence and development of IEs. Venture capital investments can assist firms in scaling their operations from a local to a global level, complementing the support provided by policymakers. These investments can cover costs related to internationalization and material infrastructure (e.g., digital platforms), thereby accelerating and facilitating the development of IE business operations. Long-term partnerships with venture capital investors, who typically have a valuable pool of social, human, and financial capital (Large and Muegge, 2008; Burström et al., 2023), can generate synergetic effects. Consequently, they can support firms and policymakers in IEs to generate industrial renewal/transformation. We encourage future research to explore the potential roles and responsibilities of venture capital investors in IEs.

Fourth, our study shows that collective efforts and synergies are necessary for industrial transformation to occur in IEs (Frosch and Gallopoulos, 1989; Andreoni, 2018). However, the creation of synergies in IEs depends on well-functioning partnerships. Despite this, there is limited knowledge on how firms in these collectives approach partner selection (i.e., attract, select, engage) and the criteria used for such selection (see van Vulpen et al., 2022; Burström et al., 2023). Future research should therefore investigate partner identification and selection mechanisms in IEs.

Finally, our study suggests that firms in IEs should aim to balance exploitation activities (business goals related to cost efficiency and incremental innovation) and exploration activities (business goals related to new revenue streams and radical innovation) to optimize innovation output. It would be of value to understand more about the differences/similarities in synergy creation in relation to exploitative/explorative activities. Additionally, as part of this process, it is vital for firms to balance such innovation targets with sustainability goals. Despite its central importance, this balancing act is under-researched in an IE context and should, therefore, be further investigated.

CRediT authorship contribution statement

Thommie Burström: Writing – review & editing, Writing – original draft, Visualization, Validation, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Tom Lahti:** Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Vinit Parida:** Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Formal analysis. **Joakim Wincent:** Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Formal analysis, Conceptualization.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used Enterprise Bing to language edit parts of the document. After using this tool/service, the authors reviewed and edited the content as required. They take full responsibility for the content of the publication.

Data availability

Data will be made available on request.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.techfore.2024.123656.

References

Adamides, E.D., Mouzakitis, Y., 2009. Industrial ecosystems as technological niches. J. Clean. Prod. 17 (2), 172–180.
Adner, R., 2006. Match your innovation strategy to your innovation ecosystem. Harv. Bus. Rev. 84 (4), 98.
Agudo, F.L., Bezerra, B.S., Gobbo Júnior, J.A., 2023. An Overview of Brazilian companies' Readiness to Implement Industrial Symbiosis. IN PRESS, Business Strategy and the Environment.
Ali, W., Din, I.U., Almogren, A., Guizani, M., Zuair, M., 2021. A lightweight privacy-aware IoT-based metering scheme for smart industrial ecosystems. IEEE Trans. Industr. Inform. 17 (9), 6134–6143.
Andersen, O., 1997. Industrial ecology and some implications for rural SMEs. Business Strategy and the Environment 6 (3), 146–152.
Andreoni, A., 2018. The architecture and dynamics of industrial ecosystems: diversification and innovative industrial renewal in Emilia Romagna. Camb. J. Econ. 42 (6), 1613–1642.
Andrews, C., 1999. Putting industrial ecology into place: evolving roles for planners. J. Am. Plann. Assoc. 65, 364–375.
Argenti, P.A., Berman, J., Calsbeek, R., Whitehouse, A., 2021. The secret behind successful corporate transformations. Harv. Bus. Rev.
Ashton, W., 2008. Understanding the organization of industrial ecosystems: a social network approach. Journal of Industrial Ecology 12 (1), 34–51.
Ashton, W.S., 2009. The structure, function, and evolution of a regional industrial ecosystem. J. Ind. Ecol. 13 (2), 228–246.
Ashton, W.S., Chopra, S.S., Kashyap, R., 2017. Life and death of industrial ecosystems. Sustainability 9 (4), 605.
Auerswald, P., Dani, L., 2022. Entrepreneurial opportunity and related specialization in economic ecosystems. Research Policy 51 (9), 104445.
Autio, E., Thomas, L.D., 2022. Researching ecosystems in innovation contexts. Innovation & Management Review 19 (1), 12–25.
Ayres, R.U., 1996. Creating industrial ecosystems: a viable management strategy? Int. J. Technol. Manag. 12 (5–6), 608–624.
Baas, L., 1998. Cleaner production and industrial ecosystems, a Dutch experience. J. Clean. Prod. 6 (3–4), 189–197.
Bailey, R., Bras, B., Allen, J.K., 1999. Using robust concept exploration and systems dynamics models in the design of complex industrial ecosystems. Eng. Optim. 32 (1), 33–58.
Basu, A. J., & van Zyl, D. J. (2006). Industrial ecology framework for achieving cleaner production in the mining and minerals industry. J. Clean. Prod., 14(3–4), 299–304.
Best, M.H., 2015. Greater Boston' s industrial ecosystem: a manufactory of sectors. Technovation 39, 4–13.
Bey, C., 2001. Changing economies of scale–synergies between implementation of an ecological tax reform and development of industrial ecosystems. Business Strategy and the Environment 10 (6), 383–393.
Bras, B., 2002. Material flow challenges in industrial ecosystems. Mater. Trans. 43 (3), 364–367.
Burström, T., Parida, V., Lahti, T., Wincent, J., 2021. AI-enabled business-model innovation and transformation in industrial ecosystems: a framework, model and outline for further research. J. Bus. Res. 127, 85–95.
Burström, T., Lahti, T., Parida, V., Wartiovaara, M., Wincent, J., 2022. Software ecosystems now and in the future: a definition, systematic literature review, and integration into the business and digital ecosystem literature. IEEE Trans. Eng. Manag. https://doi.org/10.1109/TEM.2022.3216633.
Burström, T., Lahti, T., Parida, V., Wartiovaara, M., Wincent, J., 2023. A definition, review, and extension of global ecosystems theory: trends, architecture and orchestration of global VCs and mechanisms behind unicorns. J. Bus. Res. 157, 113605.
Busse, C., Kach, A.P., Wagner, S.M., 2017. Boundary conditions: what they are, how to explore them, why we need them, and when to consider them. Organizational Research Methods 20 (4), 574–609.
Casavant, T.E., Côté, R.P., 2004. Using chemical process simulation to design industrial ecosystems. J. Clean. Prod. 12 (8–10), 901–908.
Cenamor, J., Frishammar, J., 2021. Openness in platform ecosystems: innovation strategies for complementary products. Research Policy 50 (1), 104148.
Charmaz, K., 2006. Constructing Grounded Theory: A Practical Guide through Qualitative Analysis. Thousand Oaks, California, Sage Publications, London.
Chavalparit, O., Rulkens, W.H., Mol, A.P.J., Khaodhair, S., 2006. Options for environmental sustainability of the crude palm oil industry in Thailand through enhancement of industrial ecosystems. Environ. Dev. Sustain. 8 (2), 271–287.
Chen, L., Wang, R., Yang, J., Shi, Y., 2010. Structural complexity analysis for industrial ecosystems: a case study on LuBei industrial ecosystem in China. Ecol. Complex. 7 (2), 179–187.
Chertow, M.R., 2000. Industrial symbiosis: literature and taxonomy. Annual Review of Energy and Environment 25, 313–337.
Chertow, M., Ehrenfeld, J., 2012. Organizing self-organizing systems: toward a theory of industrial symbiosis. Journal of Industrial Ecology 16 (1), 13–27.
Cote, R., 1997. Industrial ecosystems. Journal of Industrial Ecology 1 (3), 9–11.
Cote, R.P., 2009. New Way of Thinking about Industrial Systems with Nature as Model. Canadian Pollution Prevention Roundtable, Charlottetown, PEI.
Côté, R.P., Smolenaars, T., 1997. Supporting pillars for industrial ecosystems. J. Clean. Prod. 5 (1–2), 67–74.
Duan, W., Madasi, J.D., Khurshid, A., Ma, D., 2022a. Industrial structure conditions economic resilience. Technological Forecasting and Social Change 183, 121944.
Duan, W., David Madasi, J., Khurshid, A., 2022b. How network structure and exchange rate volatility drive the industrial ecosystem towards collapse: a global perspective. Economic Research-Ekonomska 36 (1), 1688–1707 (Istrazivanja).
Ehrenfeld, J., Gertler, N., 1997. Industrial ecology in practice: the evolution of interdependence at Kalundborg. Journal of Industrial Ecology 1 (1), 67–79.
European Commission. (2022). Annual Single Market Report, Brussels, SWD (2022). Retrieved at: https://ec.europa.eu/docsroom/documents/48877.
Fahim, F.A., Abdallah, A.M.A., Abdel Razek, T.A.M., 1995. Flow and accumulation of pollutants in an agro-industrial ecosystem. J. Afr. Earth Sci. 20 (3–4), 295–301.
Fan, J., Hu, S., Chen, D., Zhou, Y., 2017. Study on the construction and optimization of a resource-based industrial ecosystem. Resources, Conservation and Recycling 119, 97–108.
Feng, Y., Wu, J., He, P., 2018. Global M&a and the development of the IC industry ecosystem in China: what can we learn from the case of Tsinghua Unigroup? Sustainability 11 (1), 106.
Frosch, R.A., Gallopoulos, N.E., 1989. Strategies for manufacturing. Sci. Am. 261 (3), 144–153.
Gamidullaeva, L., Shmeleva, N., Tolstykh, T., Shmatko, A., 2022. An assessment approach to circular business models within an industrial ecosystem for sustainable territorial development. Sustainability 14 (2), 704.
Gawer, A., Cusumano, M.A., 2008. How companies become platform leaders. MIT Sloan Manag. Rev. 49 (2), 28–35.
Geng, Y., Côté, R., 2007. Diversity in industrial ecosystems. International Journal of Sustainable Development and World Ecology 14 (4), 329–335.
Gernsheimer, O., Kanbach, D.K., Gast, J., 2021. Coopetition research – a systematic literature review on recent accomplishments and trajectories. Ind. Mark. Manag. 96, 113–134.
Gioia, D.A., Corley, K.G., Hamilton, A.L., 2013. Seeking qualitative rigor in inductive research: notes on the Gioia methodology. Organ. Res. Methods 16 (1), 15–31.
Hannibal, M., 2020. The influence of additive manufacturing on early internationalization: considerations into potential avenues of IE research. J. Int. Entrep. 18 (4), 473–491.
Hannigan, T.R., Briggs, A.R., Valadao, R., Seidel, M.D.L., Jennings, P.D., 2022. A new tool for policymakers: mapping cultural possibilities in an emerging AI entrepreneurial ecosystem. Res. Policy 51 (9), 104315.
Harala, L., Alkki, L., Aarikka-Stenroos, L., Al-Najjar, A., Malmqvist, T., 2023. Industrial ecosystem renewal towards circularity to achieve the benefits of reuse-learning from circular construction. J. Clean. Prod. 389, 135885.
Hardy, C., Graedel, T.E., 2002. Industrial ecosystems as food webs. J. Ind. Ecol. 6 (1), 29–38.
Harper, E.M., Graedel, T.E., 2004. Industrial ecology: a teenager's progress. Technol. Soc. 26 (2–3), 433–445.
Hollen, R., Van Den Bosch, F.A., Volberda, H.W., 2015. Strategic levers of port authorities for industrial ecosystem development. Maritime Economics & Logistics 17 (1), 79–96.
Hooge, S., Le Du, L., 2016. Collaborative organizations for innovation: a focus on the management of sociotechnical imaginaries to stimulate industrial ecosystems. Creat. Innov. Manag. 25 (3), 311–330.
Jackson, D.J., 2011. What is an innovation ecosystem? National Science Foundation 1 (2), 1–13.
Jacobides, M.G., Cennamo, C., Gawer, A., 2018. Towards a theory of ecosystems. Strategic Management Journal 39 (8), 2255–2276.
Jo, S.-S., Han, H., Leem, Y., Lee, S.-H., 2021. Sustainable smart cities and industrial ecosystem: structural and relational changes of the smart city industries in Korea. Sustainability 13 (17), 9917.
Kannisto, P., Hästbacka, D., Marttinen, A., 2020. Information exchange architecture for collaborative industrial ecosystem. Inf. Syst. Front. 22 (3), 655–670.
Kim, S.Y., 2019. Hybridized industrial ecosystems and the makings of a new developmental infrastructure in East Asia's green energy sector. Rev. Int. Polit. Econ. 26 (1), 158–182.
Kim, E., Kim, S., Kim, H., 2017. Development of an evaluation framework for publicly funded R&D projects: the case of Korea's next generation network. Eval. Program Plann. 63, 18–28.
Kincaid, J., Overcash, M., 2001. Industrial ecosystem development at the metropolitan level. Journal of Industrial Ecology 5 (1), 117–126.

Korhonen, J., 2001a. Co-production of heat and power: an anchor tenant of a regional industrial ecosystem. J. Clean. Prod. 9 (6), 509–517.
Korhonen, J., 2001b. Four ecosystem principles for an industrial ecosystem. J. Clean. Prod. 9 (3), 253–259.
Korhonen, J., 2004. Industrial ecology in the strategic sustainable development model: strategic applications of industrial ecology. J. Clean. Prod. 12 (8–10), 809–823.
Korhonen, J., Baumgartner, R.J., 2009. The industrial ecosystem balanced scorecard. International Journal of Innovation and Sustainable Development 4 (1), 24–42.
Korhonen, J., Snäkin, J.P., 2005. Analysing the evolution of industrial ecosystems: concepts and application. Ecol. Econ. 52 (2), 169–186.
Korhonen, J., Wihersaari, M., Savolainen, I., 2001. Industrial ecosystem in the Finnish forest industry: using the material and energy flow model of a forest ecosystem in a forest industry system. Ecol. Econ. 39 (1), 145–161.
Korhonen, J., Okkonen, L., Niutanen, V., 2004a. Industrial ecosystem indicators-direct and indirect effects of integrated waste- and by-product management and energy production. Clean Techn. Environ. Policy 6 (3), 162–173.
Korhonen, J., Savolainen, I., Ohlström, M., 2004b. Applications of the industrial ecology concept in a research project: technology and climate change (CLIMTECH) research in Finland. J. Clean. Prod. 12 (8–10), 1087–1097.
Korhonen, J., Von Malmborg, F., Strachan, P.A., Ehrenfeld, J.R., 2004c. Management and policy aspects of industrial ecology: an emerging research agenda. Business Strategy and the Environment 13 (5), 289–305.
Korhonen, J., Honkasalo, A., Seppälä, J., 2018. Circular economy: the concept and its limitations. Ecol. Econ. 143, 37–46.
Kumari, S., Patil, Y.B., 2019. Enablers of sustainable industrial ecosystem: framework and future research directions. Management of Environmental Quality: An International Journal 30 (1), 61–86.
Kurhonen, J., 2001. Industrial ecosystems – some conditions for success. Int J Sust Dev World 8 (1), 29–39.
Lahti, T., Wincent, J., Parida, V., 2018. A definition and theoretical review of the circular economy, value creation, and sustainable business models: where are we now and where should research move in the future? Sustainability 10 (8), 2799.
Large, D., Muegge, S., 2008. Venture capitalists' non-financial value-added: an evaluation of the evidence and implications for research. Ventur. Cap. 10 (1), 21–53.
Layton, A., Bras, B., Weissburg, M., 2016. Industrial ecosystems and food webs: an expansion and update of existing data for eco-industrial parks and understanding the ecological food webs they wish to mimic. Journal of Industrial Ecology 20 (1), 85–98.
Lee, H.B.R., Kim, S., 2023. Borderless collaboration in materials chemistry for an industrial ecosystem in the semiconductor industry. Chem. Mater. 35 (11), 4117–4119.
Levänen, J.O., Hukkinen, J.I., 2013. A methodology for facilitating the feedback between mental models and institutional change in industrial ecosystem governance: a waste management case-study from northern Finland. Ecol. Econ. 87, 15–23.
Lin, W.W.K., Wong, J.H.K., Wong, A.K.Y., 2011. A novel real-time traffic sensing model to improve the performance of web-based industrial ecosystems. IEEE Trans Ind Electron 58 (6), 2147–2153.
Liu, C., Ma, C., Zhang, K., 2012. Going beyond the sectoral boundary: a key stage in the development of a regional industrial ecosystem. J. Clean. Prod. 22 (1), 42–49.
Liu, C., Côté, R.P., Zhang, K., 2015. Implementing a three-level approach in industrial symbiosis. J. Clean. Prod. 87, 318–327.
Liwarska-Bizukojc, E., Bizukojc, M., Marcinkowski, A., Doniec, A., 2009. The conceptual model of an eco-industrial park based upon ecological relationships. J. Clean. Prod. 17 (8), 732–741.
Lou, H.H., Kulkarni, M.A., Singh, A., Huang, Y.L., 2004. A game theory-based approach for emergy analysis of industrial ecosystem under uncertainty. Clean Technologies and Environmental Policy 6 (3), 156–161.
Lowe, E.A., 1997. Creating by-product resource exchanges: strategies for eco-industrial parks. J. Clean. Prod. 5 (1–2), 57–65.
Lowe, E.A., Evans, L.K., 1995. Industrial ecology and industrial ecosystems. J. Clean. Prod. 3 (1–2), 47–53.
Lu, C., Ji, W., Liu, Z., Dong, S., Xue, B., 2020. Synergistic evaluation and constraint factor analysis on urban industrial ecosystems of traditional industrial area in China. Complexity 2020, 3805454.
Lyons, D., Rice, M., Wachal, R., 2009. Circuits of scrap: closed loop industrial ecosystems and the geography of US international recyclable material flows 1995–2005. Geogr. J. 175 (4), 286–300.
Lyu, Y., Tian, J., Chen, L., 2023. Enabling sustainable chemical manufacturing from product to industrial ecosystem. Resources, Conservation and Recycling 192, 106915.
Ma, X., Huang, Y., 2020. Construction on industrial ecosystem of marine low carbon City based on composite ecosystem. J. Coast. Res. 107 (sp1), 61–64.
Madanaguli, A., Parida, V., Sjödin, D., Oghazi, P., 2023. Literature review on industrial digital platforms: a business model perspective and suggestions for future research. Technol. Forecast. Soc. Chang. 194, 122606.
Madsen, T.L., & Szyliowicz, D. (2016). Industry transformation. In: M. Augier, D. Teece, (Eds.) The Palgrave Encyclopedia of Strategic Management. Palgrave Macmillan, London. https://doi.org/https://doi.org/10.1057/978-1-349-94848-2_762-1.
Malone, S.M., Weissburg, M.J., Bras, B., 2018. Industrial ecosystems and food webs: an ecological-based mass flow analysis to model the progress of steel manufacturing in China. Engineering 4 (2), 209–217.
McManus, P., Gibbs, D., 2008. Industrial ecosystems? The use of tropes in the literature of industrial ecology and eco-industrial parks. Prog. Hum. Geogr. 32 (4), 525–540.
Meierhofer, J., Schweiger, L., Lu, J., Züst, S., West, S., Stoll, O., Kiritsis, D., 2021. Digital twin-enabled decision support services in industrial ecosystems. Appl. Sci. 11 (23), 11418.
Miao, Y., Song, J., Wang, H., Hu, L., Hassan, M.M., Chen, M., 2020. Smart Micro-GaS: a cognitive micro natural gas industrial ecosystem based on mixed blockchain and edge computing. IEEE Internet Things J. 8 (4), 2289–2299.
Monteiro, J.G.M.-S., Silva, P.A.C., Araújo, O.Q.F., Medeiros, J.L., 2010. Pareto optimization of an industrial ecosystem: sustainability maximization. Braz. J. Chem. Eng. 27 (3), 1917–1922.
Moore, J.F., 1993. Predators and prey: a new ecology of competition. Harv. Bus. Rev. 71 (3), 75–86.
Morris, Z.B., Weissburg, M., Bras, B., 2021. Ecological network analysis of urban–industrial ecosystems. Journal of Industrial Ecology 25 (1), 193–204.
Okkonen, L., 2008. Applying industrial ecosystem indicators: case of Pielinen Karelia. Finland. Clean Technologies and Environmental Policy 10 (4), 327–339.
Özyurt, D.B., Realff, M.J., 2001. Combining a geographical information system and process engineering to design an agricultural-industrial ecosystem. Journal of Industrial Ecology 5 (3), 13–31.
Parida, V., Burström, T., Visnjic, I., Wincent, J., 2019. Orchestrating industrial ecosystem in circular economy: a two-stage transformation model for large manufacturing companies. J. Bus. Res. 101, 715–725.
Podsakoff, P.M., MacKenzie, S.B., Bachrach, D.G., Podsakoff, N.P., 2005. The influence of management journals in the 1980s and 1990s. Strateg. Manag. J. 26 (5), 473–488.
Post, C., Sarala, R., Gatrell, C., Prescott, J.E., 2020. Advancing theory with review articles. J. Manag. Stud. 57 (2), 351–376.
Reuter, M.A., 1998. The simulation of industrial ecosystems. Miner. Eng. 11 (10), 891–918.
Rocha, A., Brown, R., Mawson, S., 2021. Capturing conversations in entrepreneurial ecosystems. Research Policy 50 (9), 104317.
Ruth, M., 2009. Dynamic modeling of industrial ecosystems. Journal of Industrial Ecology 13 (6), 839–842.
Shi, X., Li, X., 2019. A symbiosis-based life cycle management approach for sustainable resource flows of industrial ecosystem. J. Clean. Prod. 226, 324–335.
Shmeleva, N., Tolstykh, T., Dudareva, O., 2023. Integration as a driver of Enterprise sustainability: the Russian experience. Sustainability 15 (12), 9606.
Shrivastava, P., 1995. The role of corporations in achieving ecological sustainability. Acad. Manage. Rev. 20 (4), 936–960.
Singh, A., Lou, H.H., 2006. Hierarchical pareto optimization for the sustainable development of industrial ecosystems. Ind. Eng. Chem. Res. 45 (9), 3265–3279.
Singh, A., Lou, H.H., Yaws, C.L., Hopper, J.R., Pike, R.W., 2007. Environmental impact assessment of different design schemes of an industrial ecosystem. Resour. Conserv. Recycl. 51 (2), 294–313.
Sjödin, D., Parida, V., Visnjic, I., 2022. How can large manufacturers digitalize their business models? A framework for orchestrating industrial ecosystems. Calif. Manage. Rev. 64 (3), 49–77.
Spiering, D.J., Larsen, C.P.S., Potts, D.L., 2020. Modelling Vegetation Succession in Post-Industrial Ecosystems Using Vegetation Classification in Aerial Photographs. Buffalo, New York, Landscape and Urban Planning, p. 198.
Srivastava, S.K., 2007. Green supply-chain management: a state-of-the-art literature review. Int. J. Manag. Rev. 9 (1), 53–80.
Stam, E., 2015. Entrepreneurial ecosystems and regional policy: a sympathetic critique. Eur. Plan. Stud. 23 (9), 1759–1769.
Sterr, T., Ott, T., 2004. The industrial region as a promising unit for eco-industrial development – reflections, practical experience and establishment of innovative instruments to support industrial ecology. J. Clean. Prod. 12 (8–10), 947–965.
Suppipat, S., Hu, A.H., 2022. Achieving sustainable industrial ecosystems by design: a study of the ICT and electronics industry in Taiwan. J. Clean. Prod. 369, 133393.
Susur, E., Hidalgo, A., Chiaroni, D., 2019. The emergence of regional industrial ecosystem niches: a conceptual framework and a case study. J. Clean. Prod. 208, 1642–1657.
Tolstykh, T., Shmeleva, N., Gamidullaeva, L., 2020. Evaluation of circular and integration potentials of innovation ecosystems for industrial sustainability. Sustainability 12 (11), 4574.
Tolstykh, T., Shmeleva, N., Gamidullaeva, L., Krasnobaeva, V., 2023. The role of collaboration in the development of industrial enterprises integration. Sustainability 15 (9), 7180.
Tonn, B., Frymier, P.D., Stiefel, D., Skinner, L.S., Suraweera, N., Tuck, R., 2014. Toward an infinitely reusable, recyclable, and renewable industrial ecosystem. J. Clean. Prod. 66, 392–406.
Tranfield, D., Denyer, D., Smart, P., 2003. Towards a methodology for developing evidence-informed management knowledge by means of systematic review. Br. J. Manag. 14 (3), 207–222.
Tsujimoto, M., Kajikawa, Y., Tomita, J., Matsumoto, Y., 2018. A review of the ecosystem concept –towards coherent ecosystem design. Technological Forecasting and Social Change 136, 49–58.
Tsvetkova, A., Gustafsson, M., 2012. Business models for industrial ecosystems: a modular approach. J. Clean. Prod. 29, 246–254.
Tsvetkova, A., Hellström, M., Gustafsson, M., Sjöblom, J., 2015. Replication of industrial ecosystems: the case of a sustainable biogas-for-traffic solution. J. Clean. Prod. 98, 123–132.
Valackienė, A., Nagaj, R., 2021. Shared taxonomy for the implementation of responsible innovation approach in industrial ecosystems. Sustainability 13 (17), 9901.
de Vasconcelos Gomes, L.A., Facin, A.L.F., Salerno, M.S., Ikenami, R.K., 2018. Unpacking the innovation ecosystem construct: evolution, gaps and trends. Technol. Forecast. Soc. Chang. 136, 30–48.
Von Malmborg, F., 2004. Networking for knowledge transfer: towards an understanding of local authority roles in regional industrial ecosystem management. Bus. Strateg. Environ. 13 (5), 334–346.

van Vulpen, P., Jansen, S., Brinkkemper, S., 2022. The orchestrator's partner management framework for software ecosystems. Sci. Comput. Program. 213, 102722.

Wang, W., Yang, Z., Lu, Y., Shi, Y., Zhang, B., 2016. The optimization degree of provincial industrial ecosystem and EKC of China – based on the grey correlation analysis. Journal of Grey System 28 (2), 1–12.

Wang, D., Zheng, J., Song, X., Ma, G., Liu, Y., 2017. Assessing industrial ecosystem vulnerability in the coal mining area under economic fluctuations. J. Clean. Prod. 142, 4019–4031.

Wang, J., Zhang, L., Zhang, H., Zhang, Y., 2023. Research on a coordination evaluation and prediction model of water use and industrial ecosystem development. Int. J. Environ. Res. Public Health 20 (3), 2381.

Wei, Y., 2022. Regional governments and opportunity entrepreneurship in underdeveloped institutional environments: an entrepreneurial ecosystem perspective. Research Policy 51 (1), 104380.

Wernik, K., 2001. In: Smelser, N.J., Baltes, P.B. (Eds.), International Encyclopedia of the Social & Behavioral Sciences, 11. Elsevier, Amsterdam.

Wolf, A., Eklund, M., Söderström, M., 2007. Developing integration in a local industrial ecosystem – an explorative approach. Business Strategy and the Environment 16 (6), 442–455.

Wurth, B., Stam, E., Spigel, B., 2022. Toward an entrepreneurial ecosystem research program. Entrep. Theory Pract. 46 (3), 729–778.

Yan, M.R., Yan, H., Zhan, L., Yan, X., Xu, M., 2020. Evaluation of technological innovations and the industrial ecosystem of science parks in Shanghai: an empirical study. Science, Technology and Society 25 (3), 482–504.

Zaoual, A.R., Lecocq, X., 2018. Orchestrating circularity within industrial ecosystems: lessons from iconic cases in three different countries. Calif. Manage. Rev. 60 (3), 133–156.

Zhang, Y., Lu, W., Tam, V.W.Y., Feng, Y., 2018. From urban metabolism to industrial ecosystem metabolism: a study of construction in Shanghai from 2004 to 2014. J. Clean. Prod. 202, 428–438.

Zhang, D., Shi, Y., Li, W., 2019. China's sharing economy of mobility industry: from perspective of industrial ecosystem. Sustainability 11 (24), 7130.

Zhang, H., Yi, J.B., Wang, Q., 2021. Research on the collaborative evolution of blockchain industry ecosystems in terms of value co-creation. Sustainability 13 (21), 11567.

Zhang, X., Ming, X., Bao, Y., Liao, X., 2022. System construction for comprehensive industrial ecosystem oriented networked collaborative manufacturing platform (NCMP) based on three chains. Adv. Eng. Inform. 52, 101538.

Zhu, Q., Cote, R.P., 2004. Integrating green supply chain management into an embryonic eco-industrial development: a case study of the Guitang group. J. Clean. Prod. 12 (8–10), 1025–1035.

Zhu, J., Ruth, M., 2013. Exploring the resilience of industrial ecosystems. J. Environ. Manage. 122, 65–75.

Thommie Burström Is working as assistant professor of Entrepreneurship at Hanken School of Economics in Helsinki, Finland. His academic interests are in entrepreneurship, ecosystems, innovation management, and platform research. Thommie has previously published papers in high ranked journals as Journal of Business Research, Industrial Marketing Management, and in Business and Information Technology and People.

Tom Lahti from Hanken School of Economics, Finland) is Associate Professor in Entrepreneurship and Management at Hanken School of Economics, Finland. His research interests include entrepreneurship, venture capital, neuroentrepreneurship and innovation in organizations. He has published in highly ranked journals, such as, Journal of Business Venturing, Journal of Business Research, International Small Business Journal and Human Brain Mapping.

Vinit Parida is a Chaired Professor of Entrepreneurship and Innovation at Luleå University of Technology. His research interests include digitalization transformation, business model innovation, organizational capabilities, servitization, industrial ecosystem formation, and circular economy. He has published 200+ international journal articles, conference papers and industry reports. He is the recipient of multiple awards for his research, such as Entrepreneurship Forum Young Researcher Award 2016 for his research on the digital business models innovation of Swedish industry.

Joakim Wincent is Professor in Entrepreneurship and Management at Hanken School of Economics, Finland, and a professor in Entrepreneurship and Innovation at University of St.Gallen. His-current research interests include technology, artificial intelligence, management, and innovation in organizations. Previous articles by him have been published in journals such as the Academy of Management Review, Strategic Management Journal, Harvard Business Review, Journal of Management Studies, Journal of Business Venturing, Entrepreneurship Theory and Practice and others.