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Research paper

Catalyzing the Circular Economy: Socio-cultural and Spatial Trajectories in Industrial Ecosystems

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Abstract

This paper contributes to the existing body of research on integrating economic geography approach with circular economy (CE) research by exploring how socio-cultural and spatial trajectories shape industrial CE ecosystems. Conceptually, we address this question by identifying economic geography parameters that catalyze the CE. Empirically, we conducted a qualitative case study on the regional electric vehicle battery metal ecosystem in Finland. Our findings reveal how complex regional factors govern the circulation of resources and materials. Two main implications are discussed: first, a deeper understanding of the contextual factors shaping CE development; second, a comprehensive view of the interplay between economic geography parameters that drive local CE implementation.

Keywords: Circular Economy · Economic Geography · Industrial Park · Spatial Dynamics · Sustainability Transition

1. INTRODUCTION

In response to the triple planetary crisis of climate change, pollution and biodiversity loss, sustainability transition literature advocates for novel approaches to replace current production and consumption systems (Ossio et al., 2023). One such transition is the circular economy (CE), which offers an alternative to the linear take–make–waste extractive consumption model (Calzolari et al., 2023; Pietrulla, 2022). The CE aims to keep materials and energy in continuous circulation while minimizing waste and pollution (Gatell & Avella, 2024; Geissdoerfer et al., 2017; Kanda et al., 2021). While the CE is a global phenomenon affecting value chains worldwide (Lehtimäki et al., 2024), it also involves local solutions and material flows (Jambou et al., 2022; Niang et al., 2023). This makes it essential to understand the regional parameters of CE transitions (Bianchi et al., 2023).

There is a call for research on the antecedents and consequences of local decisions on future material flows globally (Pietrulla, 2022) as well as for geographically sensitive analyses of how sustainability transitions and environmental innovation processes vary across regions and countries (Binz et al., 2020; Davies et al., 2024; Truffer et al., 2015). To address this call, we adopt an economic geography perspective on the CE, focusing on the socio-cultural and spatial trajectories of CE ecosystems.

Previous CE research has primarily focused on environmental sciences, green technology, engineering, and business (Davies et al., 2024; Kirchherr et al., 2017, 2023), yielding valuable insights into global industry value chains (Calzolari et al., 2023) and CE ecosystems (Aarikka-Stenroos et al., 2021). However, Davies et al. (2024) argued that this emphasis has marginalized critical social, cultural, and political factors affecting the CE. There is a growing body of recent literature on the geographical factors shaping the CE (Arsova et al., 2022; Bourdin et al., 2022; Chembessi et al., 2024; Marjanovic & Williams, 2024; Niang et al., 2023; Tapia et al., 2021). A growing body of research has indicated that socio-cultural and spatial dynamics influence the structure of production in territories in which ecosystem actors cooperate and coordinate their activities (Chembessi et al., 2024; Nijkamp et al., 2024;

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Pfotenhauer et al., 2023). Research on the geography of transition further suggests that sustainability transitions are influenced by a region's historical industrial traditions, resources, and capabilities (Coenen et al., 2012; Hansen & Coenen, 2015; Tapia et al., 2021; Tartaruga et al., 2024).

CE development is shaped by physical, socio-cultural, and institutional factors (Tapia et al., 2021). An economic geography approach in CE research facilitates the analysis of not only ecosystem actors and interdependencies (Aarikka-Stenroos et al., 2021) but also the hierarchical and institutional structures in which CE value networks are embedded (Kanda, 2023; Tartaruga et al., 2024). Economic geography provides valuable insight into where and how the CE transition takes place and how circular solutions are catalyzed in industrial ecosystems. This approach enhances systems thinking by integrating socio-spatial embeddedness, multidimensionality, and power relations in systemic change (Coenen et al., 2012; Truffer et al., 2015).

In this study, we address the following research question: “How do socio-cultural and spatial trajectories shape industrial circular economy ecosystems?” To do so, we present a qualitative case study of the Harjavalta Industrial Park (HIP), a regional electric vehicle battery metal ecosystem in the PoriHarjavalta region of Finland. This location has a history of over 80 years in chemical and industrial manufacturing. The ecosystem’s actors are interconnected through geographic proximity, material and energy flows, and shared knowledge and value creation networks. This case provides insights into how regional factors influence resource and material circulation. Industrial symbiosis in the area serves as a relevant example of the CE, as multiple stakeholders collaborate in close physical proximity to close energy and material loops (Aarikka-Stenroos et al., 2021).

Our research draws on eight in-depth interviews as primary data, supplemented by an industry workshop and publicly available documents as secondary material. We employ an abductive methodology (Timmermans & Tavory, 2012) to provide a rich contextual analysis of socio-cultural structures and spatial variables. This approach enables a theory-elaborating analysis (Ketokivi & Choi, 2014) of how these factors drive CE transitions in industrial ecosystems.

This paper contributes to the CE transition literature in two key ways. First, by integrating the economic geography approach with CE research, it enhances our understanding of CE transition systems (Kanda, 2023). Our findings refine existing theories at the intersection of economic geography and the CE by developing a framework of six economic geography parameters relevant to CE transitions. This framework strengthens general theory by grounding theoretical insights in the specific context of industrial symbiosis, making them more robust and contextually relevant (Ketokivi & Choi, 2014). Understanding regional parameters is essential for grasping the complex dynamics governing resource and material circulation (Bianchi et al., 2023; Chembessi et al., 2024). Second, our holistic analysis of a CE ecosystem advances understanding of socio-spatial embeddedness, multidimensionality, and power relations in CE transitions (Coenen et al., 2012; Truffer et al., 2015). This responds to calls for expanding theoretical perspectives to incorporate technological and governance factors in developing CE transition strategies for local governments (Rajaonson & Chembessi, 2024).

The paper is structured as follows. We first review literature on CE ecosystems and economic geography to examine CE implementation in regional contexts. We then describe the empirical setting and methodology. Following this, we present our findings and discuss the regional parameters of CE ecosystems, study limitations, and suggestions for future research. Finally, we conclude with a summary and practical implications.

2. THEORETICAL BACKGROUND

2.1 Circular Economy Transition

The CE represents a systemic sustainability transition involving multiple actors and multidimensional processes aimed at material, institutional, and socio-cultural changes (Zolfagharian et al., 2019). Circularity is a property of a system rather than a property of an individual product or service (Konietzko et al., 2020). It requires a paradigm shift across the supply chain, replacing end-of-life thinking with strategies for reducing, reusing, recycling, and recovering materials (Kirchherr et al., 2023). The geographical reach of CE value chains and ecosystems extends from local and regional levels to a global scale (Pietrulla, 2022).

The CE ecosystem literature has explored the roles and interactions of ecosystem actors, interdependencies among them, and the flows within these ecosystems (Aarikka-Stenroos et al., 2021; Thomas & Ritala, 2021). Prior research adopting a systems perspective on the CE has examined global value chain integration (Calzolari et al.,

2023), the interplay between global and local economies in the CE (Skene & Oarga-Mulec, 2024), national industrial ecosystem renewal toward the CE (Harala et al., 2023), CE acceleration in urban regions (Jokinen et al., 2023), and public sector involvement in regional industrial CE systems (Uusikartano et al., 2022).

CE innovations rely on both local and global resources and material flows, making regional networks and institutions critical to the CE transition (Schlaile et al., 2024). Previous studies on the geography of the CE have explored the impact of territorial factors (Bourdin et al., 2022; Chembessi et al., 2024; Tapia et al., 2021), local governance, and institutional structures (Bolger & Doyon, 2019; Deutz et al., 2024; Rajaonson & Chembessi, 2024) on the CE. Additionally, Niang et al. (2023) discussed the economic impact of the CE at the sub-regional level. Studies have highlighted that the territorialization of CE practices is key to their effectiveness and sustainability. Furthermore, they have emphasized the significance of proximity theory and the role of regional governments in fostering collaborative networks essential for CE success (Bourdin & Torre, 2024). However, limited attention has been given to ecosystems as crucial regional actor networks for innovation. Therefore, there is a need for a more explicit consideration of geography and the multiple contexts that shape regional specificities in CE ecosystems (Bianchi et al., 2023; Rajaonson & Chembessi, 2024).

2.2 Economic Geography Approach to the Circular Economy

Economic geography is an integrative paradigm that combines economics, geography, and urban and regional planning to study the spatial distribution of economic activity and the forces that shape it (Nijkamp et al., 2024). It focuses on the location and spatial organization of economic activities, analyzing the drivers of change across different scales and institutional contexts (Hassink & Gong, 2017). It also considers the social and cultural dimensions of economic activity. Regions and cities, as geographical entities, are shaped by their available resources, capabilities, and opportunities. These characteristics—ranging from historical heritage and resource endowments to policy measures and global trends—drive spatial dynamics that influence regional development (Nijkamp et al., 2024).

Economic geography has five major schools of thought (Chu et al., 2023). First, evolutionary economic geography emphasizes path dependencies in industrial dynamics and the relevance of proximity, local knowledge, routines, and capabilities (Boschma & Frenken, 2006, 2018; Hansen & Coenen, 2015). Second, relational economic geography focuses on the social construction of space through interactions between actors (Hansen & Coenen, 2015; Rantisi & Boggs, 2020; Yeung, 2005). Third, institutional economic geography highlights the importance of formal and informal institutional frameworks that evolve in specific places over time, shaping local cultures and influencing regional innovation (Getler, 2018; Martin, 2000; Truffer et al., 2015). Fourth, the geographical political economy examines labor processes, wage relations, regulatory structures, and technological systems, analyzing how these factors enable or constrain regional development as well as the dynamics of companies, industries, labor markets, and institutions (Sheppard, 2011, 2018). Fifth, alternative economic geographies emphasize alternative economic, social, and environmental practices in different sectors of the economy, incorporating feminist and post-structuralist approaches (Chu et al., 2023).

This study draws from the evolutionary, relational, institutional economic geography, and geographical political economy perspectives to examine socio-cultural and spatial trajectories in the CE (Table 1).

Table 1. Economic Geography Approaches (Table Compiled by Authors)

School of thought	Authors	Focus	Topics
Evolutionary economic geography	Beynon et al. (2024); Boschma & Frenken (2006, 2018); Corradini & Vanino (2022); Chembessi et al. (2024); Hansen & Coenen (2015); Tapia et al. (2021); Williams (2020, 2023)	Path dependencies, industrial dynamics, proximity, local knowledge, routines, capabilities, land, space	The development of economic activity.
Relational economic geography	Coenen et al. (2012); Hansen & Coenen (2015); Rantisi & Boggs (2020); Schlaile et al. (2024); Tartaruga et al. (2024); Yeung (2005)	Networks, power relations, embeddedness	The interactions and relationships between various actors and their impact on economic activities.
Institutional economic geography	Getler (2018); Heiberg et al. (2020); Martin (2000); Truffer et al. (2015)	History, formal and informal institutions	The impact of the institutional framework on economic performance.
Geographical political economy	Baumgartner et al. (2024); Sheppard (2011, 2018); Tartaruga et al. (2024)	Labor processes, wage relations, regulatory structures, technological systems	The interactions between the state, labor, and capital as well as uneven spatial development under capitalism.

These approaches provide analytical frameworks for analyzing how local technological and industrial specialization fosters the innovations necessary for sustainability transitions (Davies et al., 2024; Hansen & Coenen, 2015). Evolutionary economic geography research highlights the relevance of spatial analysis in studies on innovation and sustainability transitions (e.g., Beynon et al., 2024; Hansen & Coenen, 2015). In examining the CE, this perspective focuses on path dependencies in industrial dynamics (Corradini & Vanino, 2022), geographical and organized proximity (Chembessi et al., 2024), and the impact of territorial factors such as local knowledge and capabilities (Tapia et al., 2021). It also considers the role of land in facilitating experimentation and CE implementation as well as strategic and collaborative planning processes and regulatory aspects (Williams, 2020, 2023). Relational economic geography emphasizes the social construction of space through interactions between actors (Coenen et al., 2012; Schlaile et al., 2024; Tartaruga et al., 2024). From the CE perspective, this enhances understanding of networks and multi-stakeholder relationships (Blomberg et al., 2023), power relations (Tukker et al., 2024), and regional embeddedness (Schlaile, et al., 2024). Institutional economic geography focuses on the evolution of formal and informal institutional frameworks, which shape locally distinctive cultures and influence regional innovation and economic performance (Getler, 2018; Heiberg et al., 2020). Geographical political economy, which partly overlaps with institutional economic geography, examines regulatory, normative, and cultural-cognitive structures within regions, offering insights into factors that support or hinder sustainability innovation in complex socio-technical systems (Tartaruga et al., 2024). In the context of the CE, these perspectives contribute to understanding the uneven playing field created by institutional capacities (de Abreu & Ceglia, 2018), the variability of policy approaches across different regions (Rajaonson & Chembessi, 2024), and the role of public-sector planning in CE activities in urban settings (Baumgartner et al., 2024).

3. METHODOLOGY

This research employs a qualitative case study approach, focusing on single research setting to further develop theory (Eisenhardt, 1989; Eriksson & Kovalainen, 2016). The case study method is particularly suitable for analyzing understudied phenomena where there is an opportunity to contribute to theoretical and knowledge-building efforts (Yin, 2009), such as the CE transition from the perspective of economic geography in this study. It

also enables a rich contextual description, which is essential for understanding the phenomenon and contributes to both theory development and practical applications (Ketokivi & Choi, 2014). By examining the interplay between theory and empirical phenomena, we aimed to derive theoretical interpretations regarding the empirical tendencies observed in this study (Mantere & Ketokivi, 2013).

The focal regional industrial ecosystem for this research is HIP, located in the Satakunta region of South-Western Finland. The industrial park employs approximately 1,200 people and houses 20 organizations operating within the park and its immediate vicinity. Figure 1 illustrates how the different actors on the site are organized and how the industrial park functions. At the core of the ecosystem, there are two industrial manufacturing companies specializing in nickel and copper production, a precursor plant, a recycling plant, and variety of service companies offering production commodities, maintenance, logistics, engineering, security, and cleaning services. These actors are interconnected by infrastructure, regional proximity, and flows of materials, energy, knowledge, and value. Regional governance participates in the ecosystem through city governance and city development activities, such as development projects and land-use planning. National government and European Union (EU) participation in the ecosystem is realized through legislation, policymaking, and regulatory guidance.

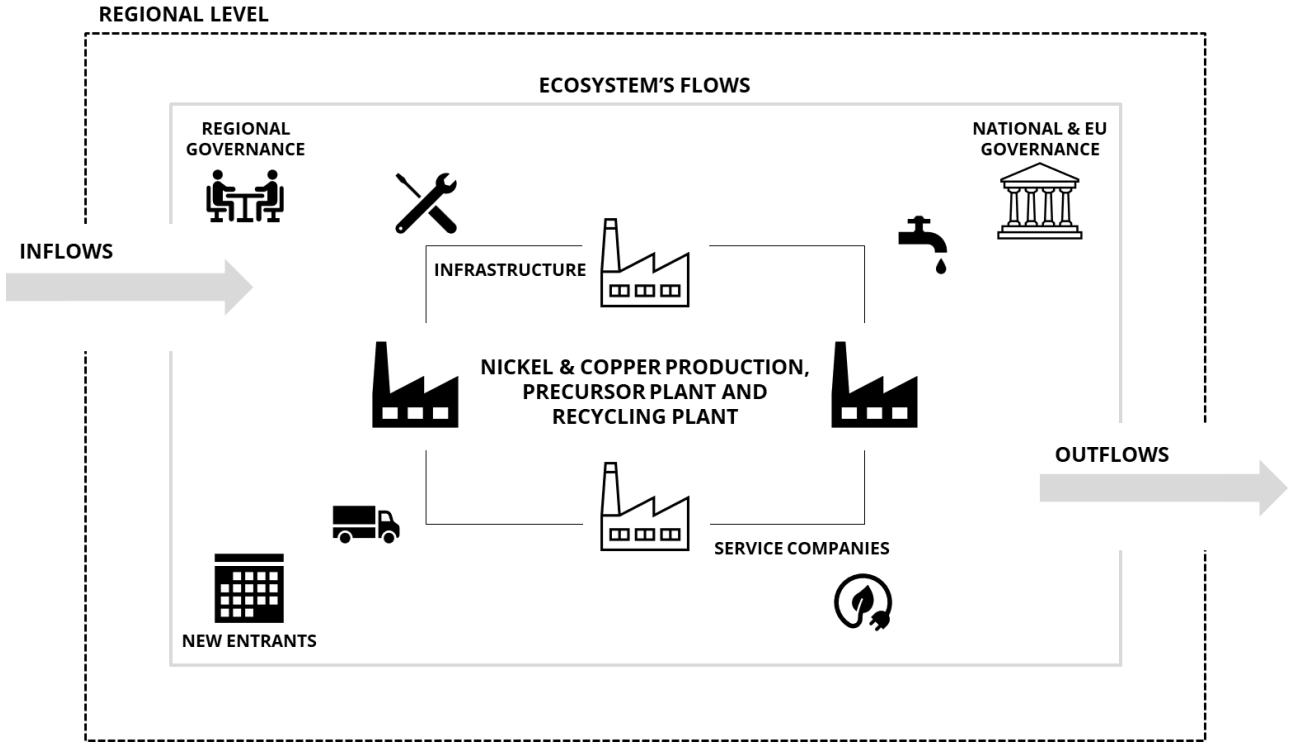

Figure 1. HIP Ecosystem Actors. (Figure Created by Authors)

HIP was chosen for its rich context for studying the geographical parameters of the CE. The industrial symbiosis between chemical and industrial manufacturing companies has a long operational history and plays a critical role in the economic viability of the region. The site features an ecosystem where key industrial manufacturing actors are complemented by service companies and new entrants. The actors are located geographically close to each other, providing an empirical setting for exploring the complex regional characteristics. Moreover, the significance of the site lies in the importance of the battery metal industry for sustainability transitions, with the EU's strategy for critical raw materials outlining the need to significantly increase European production of these materials in the coming years. The industrial symbiosis with chemical and manufacturing companies offers an interesting context for studying the CE, with material, knowledge, and economic flows (Aarikka-Stenroos et al., 2021).

The research material was collected by the second and third authors. The primary data comprise eight in-depth semi-structured interviews with respondents representing different actors from the HIP ecosystem (Table 2). The following themes were addressed during the interviews: (i) the role of the organization in the value chain,

ecosystem, and industry; (ii) regional embeddedness in terms of (tangible and intangible) resources; (iii) regional synergies and how they are organized; (iv) CE; (v) and future directions in the industry. All interviews were recorded, transcribed, and anonymized in accordance with academic and ethical guidelines. The interviews provided detailed descriptions of the site, the actors, governance, regional connectivity, interdependencies, and resource flows. Secondary data consist of recordings and transcriptions from a workshop as well as publicly available documents. The second and third authors were part of the organizing team for a workshop in Pori, which invited officials responsible for regional business development in municipalities with a battery metal industry in Finland to discuss future visions and current challenges in regional development. A total of 23 actors from five municipalities participated in the workshop. The publicly available documents include regional and national policy and strategy documents, strategy and sustainability reports from ecosystem actors, news related to HIP, and social media posts. These secondary materials were used to structure the case description and enhance the researchers' understanding of the local context in comparison to other similar regions in Finland.

Table 2. Overview of Interview Data Gathered from the Case Research (Table Compiled by Authors)

Organization	Sector	Position of interviewee	Identification code	Type	Length (minutes)	Month-year
Industrial actors						
Company 1	Recycling and second life use of batteries	R&D	PHD-1	Teams	50	Jan-2024
Company 1	Recycling and second life use of batteries	Top Management	PHD-2	Teams	64	Mar-2024
Company 2	Industrial manufacturing	R&D	PHC-2	Teams	55	Feb-2024
Company 2	Industrial manufacturing	Top Management	PHC-1	Teams	54	Feb-2024
Company 3	Industrial manufacturing	R&D	PHA-2	Teams	50	Feb-2024
Company 3	Industrial manufacturing	Top Management	PHA-1	Teams	56	Feb-2024
Public sector actors						
Public sector actor 1	City government	Official (×2)	PHB-1	Teams	49	Feb-2024
Public sector actor 2	Regional business development	Official	PHE-1	Teams	62	Feb-2024

To analyze the research material, we employed an abductive content analysis (Tavory & Timmermans, 2014), a qualitative method that generates theory by addressing anomalous and surprising empirical findings (Timmermans & Tavory, 2012). We followed an iterative analytical process that involved a continuous dialogue between theory and data (Figure 2). This approach was particularly suited to our study, as it enriched the analysis by emphasizing the diversity and depth of the data, guided the identification of the socio-cultural and regional trajectories shaping the industrial CE ecosystem in the empirical setting, and facilitated the development of insights related to the research question (Timmermans & Tavory, 2012; Vila-Henniger et al., 2022).

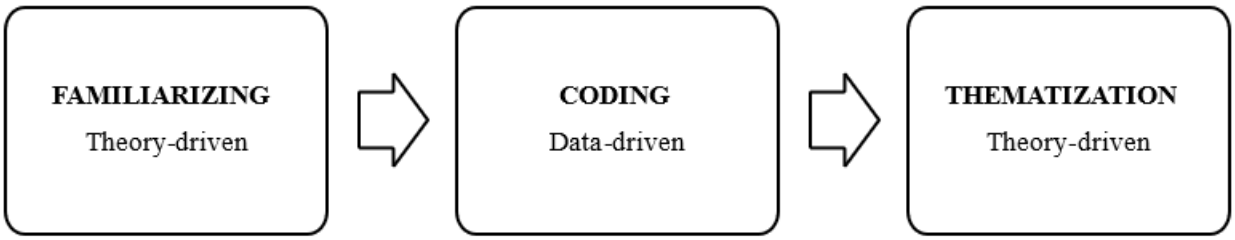

Figure 2. The Abductive Analysis Process

The abductive analysis process included three phases. The first involved theory-driven familiarization with the empirical research material to identify sections that were relevant to the research question. A close reading of the research material was performed by all authors. Second, data-driven coding was performed by the first author. This phase consisted of three rounds (Thompson, 2022): (1) The relevant data were analyzed through open coding to maximize understanding of the empirical site. This resulted in a large number of initial codes; (2) Coding was refined by focusing on sentences and paragraphs to detect the richness of meaning in the text; and (3) The codes were consolidated by identifying similarities between them. Codes that were deemed irrelevant to the research question were removed. These three rounds of coding ensured that each respondent's perspective on the issues discussed was accurately accounted for. In the third phase, a theory-driven thematization of codes was conducted. Themes were derived from the economic geography literature. All authors participated in this phase to ensure the reliability and credibility of the thematization. The abductive analysis process ensured that the themes were firmly rooted in empirical data, thereby enhancing their trustworthiness. While these themes are informed by recent literature, they also reflect the unique aspects of our data, capturing the specific dimensions that shape the local context effectively.

4. FINDINGS

Our empirical findings on the industrial park, with a focus on battery metals, highlight key economic geography parameters relevant to the CE in regional industrial ecosystems. These parameters include geographical proximity, industrial dynamics in the ecosystem, the history of the industrial park, powerrelated issues, the role of the municipality in the ecosystem, and regulation and multilevel governance. In the following, we elaborate on each parameter and illustrate how the socio-cultural and spatial context unfolds from the perspectives of those operating in the region.

4.1 Geographical Proximity

The actors were in close physical proximity with each other, which they considered a strength. The short distances were described as allowing for knowledge and resource sharing, innovation capacity building, and shared infrastructure. A nearby industrial research center and another industrial park with downstream copper processing enabled product development and increased the regional utilization of raw materials, as illustrated in the following excerpt:

> In our sector, having a large technology company with a research center in Pori is very important regionally.
>
> Additionally, the industrial park in Pori is significant. Our downstream processing of copper line products
>
> is located there, so they can be considered local customer. (PHC2)

Additionally, the park benefited from important logistical transport infrastructure, such as a railway, a highway, and a port, all closely connected to the park. The excerpt below highlights the importance of access to logistical transport infrastructure for material and resource mobility. It also provides insight into the role of a nearby river as an important natural asset for the further development of the industrial park, which relies on water resources for industrial processes.

> There are logistical aspects to this industrial area along the Kokemäenjoki River, which are perhaps the strongest ones. So, there is Highway 2, the railway, and the ports in Pori and Rauma, which are easily and conveniently accessible by railway. Then there is one of the biggest rivers in Finland. A lot of thought has now been given to green hydrogen and the associated fuel production. It needs a lot of water, and this industry needs a lot of water, so it has been noticed that this river is an important element for the industry. This has not even been realized before. (PHE1)

4.2 Industrial Dynamics in the Ecosystem

The industrial ecosystem in Harjavalta comprises battery chemical production, a precursor plant, and a recycling plant. In other words, it involves primary production, processing, and recycling. The excerpt below describes the ways in which a long-term industrial experience enabled the creation of a closedloop system for battery materials and energy, with side streams available as resources for operators in the park:

> In fact, Harjavalta is the first such complete ecosystem with battery chemical production (nickel sulphate, cobalt sulphate), a large precursor plant, and a battery recycling plant in operation. At the moment, we have a kind of closed-loop capability, where we can ensure that there is enough recycled nickel and cobalt in the battery materials. (PHA1)

Actors in the industrial park have developed mutual benefits and synergies by working with shared resources and raw materials (battery and technology metals). The following excerpt outlines the advantages of joint knowledge development and the ability to utilize equipment, infrastructure, and material flows within the area. It also emphasizes the importance of openness among the actors to address difficulties that may arise.

> We all work around the same raw materials and metals, so there's knowledge, experience, machinery, and infrastructure around, for example, recycling nickel. If we produce nickel that is a bit impure, another operator can process it into a purer product, and there is an open discussion with everyone about what the problems are and how we, they, and others, have solved them. (PHD1)

The industrial park offers regional accessibility to side streams through built infrastructure, such as pipeline bridges. The long experience of the main actors in the park also contributes knowledge capital in material refining (e.g., nickel) that benefits all other actors in the park. In addition, the park offers a range of commodities and services. One company provides logistics and storage in the area while another company produces water, energy, and heat for industrial use. Dialogue between different actors on commodities and services is often subcontracted and ad hoc, as expressed in the excerpt below. The lack of a jointly owned organization responsible for coordinating operations was perceived as problematic because although there was considerable cooperation in the area, it was seen as somewhat disorganized or concentrated among powerful actors.

Researcher: How is the dialogue with other actors in the Harjavalta region organized?

Well, in this area, there are a lot of operators who do subcontracted work for us, meaning that someone produces a commodity or service for our needs. With them, we have relatively active daily practices, where things are discussed. Then there are operators with whom there may have been a customer-supplier relationship, but not necessarily at the moment. It's a bit ad hoc. (PHC2)

4.3 History of the Industrial Park

The industrial park has been strongly influenced by the area's long industrial history. One operator had established its operations decades ago, making it a central actor in the ecosystem. This operator owns land and manages some of the common infrastructure in the area. Over the years, other actors in the same industrial sector have established operations in the area, building connections, networks, infrastructure, and logistics around them to attract new actors. The excerpt below describes the area as "an industrial knowledge pocket," common in Europe, emphasizing the significance of a long industrial history:

Europe has many 'knowledge pockets' that are largely based on traditional industries. There is a lot of metal processing industry here and Finland is a good example of relying on such existing players and companies with experience in the sector. (PHD2)

The long-term industrial experience of actors in the park has made the exploitation of material and side streams economically viable. While there are business opportunities for CE startups, the sector also presents its own challenges, as described in the following extract:

We do have all kinds of commodities available here. Perhaps in many respects, there is also a circular economy potential if there are small companies that want to start developing something special, but it is a difficult industrial sector. (PHC1)

4.4 Power-Related Issues

The historical development of the region has shaped the ecosystem and generated issues of power among the actors. As mentioned above, one operator is the dominant player in the area due to its ownership of land, infrastructure, and material production. The dominant position of this operator was described as a hindrance to establishing a joint operator to manage services in the industrial park. Establishing a joint operator would require a shift in the current top-down power structure and a more active approach from actors in the park to take responsibility for the joint operations. The current situation, with one central actor, was considered problematic due to the lack of power and sense of ownership by other actors to influence park operations. However, the interviewees generally agreed that a change in structure was not imminent.

It (co-owned external actor providing services in the area) would be necessary, but on the other hand, it would, in a way, mean that this leading actor would relinquish that role and, in a way, hand over the top-down role to an external organization. I think there is something like a fear of losing that dominant position.

> There should be some kind of ownership by these stakeholders if some kind of organization were to be built there to serve in such collective matters, a bit like there is in Kokkola. Then the stakeholders would really have a say in how it (the actor producing the commodities) operates, and not, as now, on commercial principles and exploiting its monopoly position in the area. (PHE1)

4.5 The Role of the Municipality in the Ecosystem

The role of the municipality was depicted as supportive. Harjavalta was described as having a proindustry atmosphere. The city had purchased and zoned land for industrial use to support the entrance of new companies and facilitate the expansion of the industrial park. In the following excerpt, the city is depicted as an important enabler of the industrial park's continuous development:

> The city of Harjavalta has had a rather aggressive land policy, in that they have bought up large areas of land on the other side of the highway, near the Harjavalta Industrial Park, because there is a shortage of land here. But the city of Harjavalta has acquired new land there, which is to be planned for industrial use, so there will also be opportunities for new operators there. (PHA1)

The city's compact organization, with few hierarchical structures, was described as agile and able to react quickly to the needs of the industrial park. Similar to other industrial areas in Finland, the city and the park have developed a strong regional tradition of cooperation between the private and public sectors. The good relationships between the industrial park and the public sector are also reflected in collaborations with regional educational institutions, which have jointly developed curricula relevant to the knowledge and skills needed in the industrial park.

4.6 Regulation and Multilevel Governance

Regulation was depicted as playing a major role in the battery and technology metals industry. It was seen as a driving force behind the transition to electric mobility and was considered crucial for ensuring the efficient recycling of materials. The following excerpt describes regulation as essential for creating the market for electric mobility and the demand for battery metals. Regulation was also considered important for directing the use of materials to ensure that all extracted materials remain in use as long as possible. According to the interviewees, legislation is necessary to create a level playing field enabling long-term investments in CE solutions.

> I find it hard to see that without legislation and EU policy objectives, e-mobility would have taken off. But again, it is clear that it takes a lot of primary metal in relation to what is produced, so none of it should be wasted. It must be recycled. The ecosystem cannot grow at the rate that the political will in Europe is, because there is not enough primary metal available. It has been seen from the beginning that the amount that the EU targets for electrification of transport have been completely unrealistic. (PHA2)

> The second is that when the projects are technically very risky, i.e., product development takes time and financial investment in a new field, few are willing to take the full risk if there is no protection through

> legislation. It comes in many forms through battery directives, legislation, and whatever else. It's a complex web that builds up around that, and you cannot underestimate the impact of the legislation that supports the creation of this type of (recycling/circular economy) business. (PHD2)

Regulation was also discussed in terms of the slowness of environmental permitting processes nationally and regionally. The following excerpt elaborates the concern within the industrial park about losing important investments due to the unpredictability and length of these permitting processes:

> If this kind of legal proceeding were to go through, the court should have given clear instructions on what to change in the permit conditions. What is sufficient that it is then complete. Then there should be no more opportunities for another round of appeals. If the first round has identified what was wrong and what needs to be corrected, it would also be said that when these are corrected, it is OK and then there should be no further round of appeals as has happened now. This delays projects for many years, and even Business Finland has said that Finland has failed to attract a billion euros in investment. (PHB1)

The green energy transition was expected to exponentially increase the demand for battery metals in the coming years. The following excerpt highlights the importance of regulation in ensuring that industrial actors are incentivized to build recycling capacity for the recovery and reuse of critical materials:

> In the light of this knowledge, recycling of batteries, for example, will be vital if the metals needed to electrify cars are to be in short supply. It is not that either primary or secondary, but both will be needed, and these recycling systems should be organized at the planning stage on the basis of the views of several operators in order to maximize the amount of metals that can be recovered. Legislative guidance is almost certainly needed to force operators to adopt a certain type of model. (PHC2)

Table 3 summarizes the economic geography parameters, illustrating how each contributes to the CE in the industrial park. The table also describes the interplay between the parameters, highlighting the dynamic nature of the geography of the CE.

Table 3. A Framework of Economic Geography Parameters Catalyzing the Industrial CE (Table Compiled by Authors)

Parameter	Catalyzing mechanisms for the CE	Examples of interplay between the parameters
Geographical proximity	**Initiate the CE change** through knowledge and resource sharing and innovation capacity building, and **sustain change** through a shared infrastructure.	*Creates the conditions for a coherent industrial dynamic and cooperation.*
Industrial dynamics in the ecosystem	**Enhance the understanding of the CE** through joint knowledge development, and **sustain change** by supporting the ability to utilize local equipment and infrastructure as well as through closed-loop material and energy cycles.	*Hierarchical dynamics between actors build power relations and issues of power.*
History of the industrial park	**Maintain the momentum of the CE change** by attracting new actors to benefit from established connections, networks, infrastructure, and logistics.	*Influences the industrial dynamics and how they have evolved over time and creates a cultural identity for the region.*
Power-related issues	**Govern CE development** through the concentration or distribution of power and a sense of ownership among actors in the ecosystem.	*Evolves from the combined effects of industrial dynamics and history.*
The role of the municipality in the ecosystem	**Enable CE investments** through effective interaction and communication between private and public sector actors locally.	*The city can offer and zone land in the vicinity of an activity, which reinforces or, conversely, undermines the benefits of geographical proximity, which also affect industrial dynamics.*
Regulation and multilevel governance	**Initiate and sustain CE implementation** through establishing an equitable investment environment and ensuring a balance between social, environmental, and economic sustainability.	*Influences the distribution and use of resources, reinforcing the benefits of geographical proximity.* *Steers municipal development activities in a top-down way.*

5. DISCUSSION

Our answer to the research question is that socio-cultural and spatial trajectories shape industrial CE ecosystems through context-specific parameters. Using empirical evidence, we highlight various economic geography parameters that are relevant and demonstrate the interrelationships between them within the regional context of our study. The findings detail how interactions among these parameters drive the implementation of the CE in a specific

region. Our study employs abductive reasoning by integrating empirical data with theoretical insights to provide context-sensitive explanations for the development of the CE. The significance of factors affecting CE implementation differs across regions. Therefore, relying solely on theoretical frameworks is inadequate. It is essential to empirically identify and thoroughly understand the specific parameters that are influential in each region.

First, as a contribution to research on geography of the CE (Bourdin & Torre, 2024; Chembessi et al., 2024; Tapia et al., 2021), our study elaborates on the interplay between economic geography parameters and deepens our understanding of the contextual circumstances that create the conditions for triggering and maintaining the CE transition (Jokinen et al., 2023). Further, the study enhances the systems understanding of the CE transition (Kanda, 2023) and responds to the call for research that goes beyond exploring the ways in which territorial specificities impact CE development (Tapia et al., 2021).

Second, the study contributes to literature on CE development in local governments (Rajaonson & Chembessi, 2024) by providing insights into the ways in which economic geography parameters accelerate and sustain CE development. It also elaborates on the complexities involved in the physical, socio-cultural, and institutional factors in the region. Thus, it provides a more comprehensive understanding of the mechanisms that drive CE implementation (Chembessi et al., 2024).

This study is not without limitations. While a single-case study can provide an in-depth contextualized understanding of a specific phenomenon, it also poses a risk of overemphasizing geographical specificities in a particular region (Hansen & Coenen, 2015). A study involving multiple cases would allow for multi-case theory building and broaden the understanding of the impact of economic geography on the industrial CE transition across different settings.

6. CONCLUSION

Economic geography in the CE transition represents a topical and expanding research subject (Bianchi et al., 2023; Davies et al., 2024; Pietrulla, 2022). Our research presents an empirically grounded analysis of the socio-cultural and spatial trajectories that shape industrial CE ecosystems. The results of this paper have theoretical and practical implications for the ongoing discussion on the role of economic geography in the CE transition. As a theoretical contribution, our study deepens the understanding of how industrial CE is socio-culturally and spatially constructed in regions. The policy implications of our study include valuable insights into the governance of the industrial CE transition. We recommend that policymakers adopt a place-based approach, grounded in a deep understanding of region, when implementing CE strategies.

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AUTHOR CONTRIBUTIONS

Mikko Lampinen: Conceptualization, methodology, analysis of the data, writing original draft, editing
Hanna Lehtimäki: Conceptualization, writing, editing, reviewing, supervision, project administration, funding acquisition
Nuppu Mielonen: Data collection, methodology, visualization, reviewing

DECLARATIONS

Competing interests The authors declare no competing interests.

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