THESIS FOR THE DEGREE OF LICENTIATE OF ENGINEERING

A Heroic Vision of Sustainability Transition: Adaptive Construction Business Network toward Electrification

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‘‘Doubt is not a pleasant condition, but certainty is absurd’’
- Voltaire, 1770

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ABSTRACT

Transport and excavation activities within the construction sector contribute approximately 4 –5 percent of Sweden's total CO_2 emissions. To meet the national climate targets for 2030 and 2045, the electrification of construction machinery and vehicles is gaining momentum. While several pilot projects have been carried out, large-scale implementation and integration into standard practice remain limited. This theis embarked on an exploration of the phenomenon, acknowledging the uncertainties encountered along the way, therefore sustainability transition was adopted as the guiding theoretical lens. Based in Sweden, empirical data were collected through expert interviews and a two-round Delphi survey, with 34 participants from government, academia, construction firms, OEMs, energy companies, consultancy firms, and NGOs. By integrating Industrial Marketing and Purchasing (IMP) perspective and the Multi-Level Perspective (MLP), this thesis proproses an adaptive cycle-inspired theoretical framework—Adaptive Business Network for Sustainability Transition. Beyond the individual papers, *Chapter 5 Conclusion and Discussion* depicts a more integrated "heroic vision" of sustainability transition, where the development of resource ties and actor bonds are conceptualized as the driving mechanisms leading to future alternative scenarios. Building on these insights, future study will employ simulation and optimization modelling to further generate managerial and policy-relevant implications, while remaining attentive to the inherent data limitations.

Keywords: emission-free construction site; electrification; construction business network; sustainability transition, adaptive cycle.

LIST OF APPENDED PAPERS

Paper I Ru Chen and Lisa Govik (2025), "A heroic vision for sustainability transitions: electrification through collaborative supply chain networks". *Supply Chain Management: An International Journal*, Vol. 30 No. 7 pp. 116–130, doi: https://doi.org/10.1108/SCM-12-2024-0796

Paper II Ru Chen and Lisa Govik, The Future of Swedish Emission-Free Construction by 2030 and 2045: A Choice between Hope and Fear. *Earlier version presented at conference NOFOMA 2025*

ACKNOWLEDGEMENTS

"It is sometimes easier to make the world a better place
than to prove you have made the world a better place"
— Michael Lewis, The Undoing Project: A Friendship That Changed Our Minds

It is time to step out of my writing bubble and recall the vivid people and moments that have shaped this journey so far. It all began with an email I wrote to Lisa in July 2022. Two months later, she invited me to her office, became my master's thesis supervisor, and is now my PhD supervisor. As we call tell, Lisa, you are an incredibly decisive person — a quality much needed in this journey full of choices. Your strategic thinking and management skills are truly inspiring (*"choose your battle,"* as you would say). As a result, our meetings and email exchanges are always efficient yet full of laughter, and your feedback — clear, specific, and often with smiley faces — never fails to motivate me. Your encouragement, trust, and reminders — *"this is your project," "it doesn't have to be perfect," "let's test it,"* and *"it is an iterative process"* — have guided me toward becoming a more independent, open-minded, daring, and patient researcher (and person). The journey is ongoing, so let's keep moving forward, stay positive, and remain adaptive!

I would also like to thank the many others who made this journey meaningful:

- My family and friends —Xia, Luo, Yao, Simin, Nastya and Natasha — our connection is timeless; Lilly and Iris, my wonderful Kung Fu mates, let's keep punching with purpose! Sage, for the beautiful time we've shared, I hope there are many more to come <3
- My officemates — Luciana (my hugs supplier), Mandana, Carolin, Tayana and Chami — for the surprises of sweets, cards, small gifts, and energizing conversations.
- IMA seminar group, host by Anna and Kajsa, for those discussion and opportunities to present my work. Frida, I'll never forget your immediate tears (and soft heart) when I shared my difficulty saying goodbye to my mom everytime when I left China. Sandra, for your firm hug last time and our deep talks — *"emotions come and go", "we should abandon all the models and just live."*
- Ala, Dawid and Ivan for the fun in teaching and discussions.
- Catarina, for organizing social activities that brought so much joy.
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Finally, I would like to thank all the experts who participated in my studies for generously sharing your time and insights. Your interest and care for the topic have greatly motivated me to continue exploring the construction industry and its sustainability transition toward electrification. At the end of the day, it was the vividness of your observations and words that kept me going and reminded me that those voices deserve to have their scientific story told.

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1.Introduction

The United Nations Environment Programme (UNEP) highlights that the buildings and construction sector is not on track to meet its 2050 decarbonization goals **(**Hamilton *et al.,* 2022). The sector continues to be a major driver of the climate crisis, accounting for 32% of global energy consumption and 34% of global CO_2 emissions (UNEP, 2024). To contribute to emission reduction goals by 2030 and 2045 within the construction industry, Scandinavian countries are initiating efforts to electrify construction machinery and vehicles. As one of the pioneers, Norway seeks to lead this transition, supported by an electricity grid powered by 98% renewable energy (Tutton, 2021).For instance, the City of Oslo aims for all municipal construction sites to be zero-emission by 2025 (C40 Cities Climate Leadership Group, 2021). In Sweden, ten municipalities, including Stockholm and Gothenburg, have also signed a declaration of intent to ensure that the majority of construction vehicles and machinery used in city procurements are electrified by 2030 (Fossilfritt Sverige, 2025). Although emission-free construction sites are still in their infancy, early implementations have demonstrated both environmental and social sustainability benefits (KlimaOslo, 2024; Volvo CE, 2024). Environmentally, these projects contribute to lower greenhouse gas emissions, improved air quality, and reduced noise levels. Socially, they foster healthier working conditions and cleaner, quieter surroundings for nearby residents, enhancing public perceptions of construction activities.

A few studies have primarily focused on mapping the current state of the transition toward emission-free construction site (Fufa *et al.,* 2021; Høyli *et al.,* 2023), identifying key knowledge gaps and research needs in this emerging field (Ólafsson *et al.,* 2024). These studies highlight several challenges in scaling up the adoption of electric construction equipment, particularly related to the high upfront cost of electric machinery and vehicles, infrastructural constraints regarding charging capacity and electricity access, and unclear responsibilities and coordination among actors.The slow adoption of new technologies and practices in the construction industry is often attributed to cost concerns, resistance to change, and the sector's fragmented structure (Alsofiani, 2024). From a sustainability transition perspective, deeper barriers can be understood as stemming from dysfunctional social interactions (Martek *et al.,* 2019), including complacency, passive governmental engagement, vested interests, and lack of leadership. Moreover, such a "collective good" emission free transition does not provide obvious immediate benefits for business customers, while complementary assets are needed to be introduced (Geels, 2011). These imply a long-term change that involves multiple actors and entails co-evolution and multi-dimensional interactions between technologies, industry structures, markets, policies, and culture (Köhler *et al.,* 2019).

As encapsulated by Hallin *et al.* (2021, p. 1948), "transition towards sustainability always involves the transition of sustainability", it suggests that open-endedness, uncertainty, and disagreement are inherent in sustainability transitions. This understanding resonates with Gunderson & Holling's (2002) undestanding of sustainability as the capacity to adapt. From this standpoint, the goal of electrification is understood not as a linear process of technological substitution, but as a collective and adaptive journey of sustainability transition. By tracing the development of the Swedish construction industry throughout the electrification, the thesis seeks to deepen understanding of how a sustainability transition unfolds. Rather than starting from a predefined research question, this thesis adopts an exploratory orientation and an adaptive mentality in its aim. As elaborated in Chapter 2 Theoretical Framework, **the aim of this thesis is to investigate the electrification as a sustainability transition through the lens of adaptive business networks.**

2.Theoretical Framework

Drawing on three theoretical streams—the conceptualization of construction as a meta-industry, adaptive business networks, and sustainability transitions—an integrated framework, Adaptive Business Network for Sustainability Transition, is proposed to bridge the Industrial Marketing and Purchasing (IMP) perspective and the Multi-Level Perspective (MLP). The metaphor of the adaptive cycle in panarchy is employed to illustrate this integration.

2.1Construction as A Meta-Industry

The phrase “forgotten developments” was first used as an editorial title in *Building* magazine and later cited by Ofori (2015). Although Ofori’s analysis focused on developing countries, the term has broader resonance: it underscores a persistent neglect in the need to enhance the capacity, capability, and performance of construction industries globally (Barbosa *et al.,* 2017). As Ofori (2015) emphasized, construction industries must be “rescued” and enabled to contribute actively to the adjustment of national economies, while also building the capability and resilience required to adapt to future transformations. To this day, the sector is still largely characterized as fragmented and project-based, frequently overshadowed by technologically intensive industries that attract more attention in innovation and industrial transformation studies. The consequences of this neglect are evident for researchers entering the field, who often struggle with the absence of its own body of theories and database. As Koskela and Vrijhoef (2001) argued, the persistent efficiency gap between construction and other industries can be attributed partly to the absence of well-developed theoretical frameworks in construction research.While considerable research has concentrated on project-level management practices and operational tools, broader investigations into the construction industry’s systemic role, structural change, and long-term development trajectories remain underdeveloped (Glass *et al.,* 2022; Costa *et al.,* 2023; Ochoa, 2025; Mazher*,* 2025). The development of theory requires robust empirical data. Yet this ambition is entangled with the pervasive issue of data availability, quality, and integration (Atuahene *et al,*. 2023; Li *et al.,* 2023). Fragmented project environments, inconsistent reporting practices, and the absence of standardized data infrastructures often constrain efforts to generate reliable datasets, thereby limiting theory-building and systemic analysis.

The lack of theory and fragmented data are not random shortcomings; rather, they reflect the inherent complexity of the construction industry. The complexity is well captured by the observation that “construction often behaves less like a conventional industry and more like a ‘conglomerate of industries’, an ‘industry of industries’, or a ‘meta-industry’.” (Fernández-Solís, 2008, p.33). The construction industry draws heavily on different industries (Hillebrandt, 2000) including manufacturing for materials and components, logistics and transportation for supply and delivery, services for design, consultancy, and facilities management, finance for project funding, regulation and governance for compliance, and diverse labour markets for skilled and unskilled work. Such meta-industry are inherently characterized by paradoxes, inefficiencies and contradictions, yet they also contain significant potential for adaptation and innovation. In this vein, Dubois and Gadde (2002) described construction industry as a loosely coupled system composed of many independent actors—including clients, contractors, subcontractors, and suppliers—whose relationships are largely temporary, project-based, and weakly coordinated. This loose coupling constrains knowledge transfer, learning, and sustained innovation, while at the same time offering a degree of flexibility and adaptability. Fredriksson and Huge-Brodin (2022) also illustrate the meta-industry character by showing that construction logistics is not an isolated function but deeply entangled with multiple subsystems, including urban land use, construction sites, supply chains, transport and infrastructure. Their study highlights the multi-actor character of construction logistics and the resulting challenges of coordination across fragmented responsibilities, particularly when implementing sustainable practices such as green logistics. However, the authors wrapped their study in a positive tone: ‘‘to realise change, the temporary nature of each construction project can be twisted into something positive. Each new project opens up new opportunities to alter or add policies and to apply demands through procurement criteria’’ (Fredriksson & Huge-Brodin, 2022, p.10).

Although the complexity of construction can be captured through the preliminary concept of a meta-industry, there is not yet widely established framework that can be systematically applied to the industry. The complexity becomes evident when attempting to exam its individual components, particularly construction transport, which serves as the connective tissue between industries supplying inputs and the construction site where buildings take shape. The circulation of materials, machinery, and labor is not simply an operational concern; it structures the feasibility, rhythm, and performance of projects, shaping both time and cost outcomes (Vrijhoef & Koskela, 2000). However, construction transport cannot just rely on standardized, repeated flows, but must be continuously reconfigured around project-specific conditions. The need for *construction logistics centres (CLCs)* has therefore emerged as an important response, enabling coordination across multiple actors and projects, reducing site congestion, and facilitating more sustainable logistics solutions (Janné & Fredriksson, 2019). Apart from off-site flows (materials, prefabricated elements, equipment delivered to site), construction transport also encompasses on-site flows (the movement of materials, machinery, and workers within the site). While off-site flows might be measured using freight systems, on-site transport remains highly variable, context-dependent, and inefficient. This segmentation underscores why construction transport has long resisted clear categorization within national transport statistics, and why it has often been excluded from freight transport accounts despite its economic, environmental and social significance (Lundesjö, 2015, Huang *et al.,* 2021).

2.2 Adaptive Construction Business Network

2.2.1 ARA model: The Atoms of Business Networks

The Industrial Marketing and Purchasing (IMP) Group emerged in the 1970s as a collective of European scholars seeking to understand industrial markets not as isolated, price-driven exchanges but as long-term, interdependent relationships between organizations (Håkansson, 1982). Their early *Interaction Model* was a milestone in moving away from the transactional paradigm of marketing toward a relational and network-based perspective. The model conceptualized business exchanges as interactive processes between two organizations, emphasizing that the outcomes of these exchanges depend on both partners’ activities, resources, and actors, as well as on the broader network context in which the dyad is embedded. It introduced key dimensions of interaction, such as the short term exchange episodes (products, information, financial, and social exchanges), and long term relationship via adaptation and atmosphere (power, closeness, expectation, etc.), showing how industrial relationships evolve over time rather than occurring as isolated market transactions (Håkansson, 1982; Snehota & Håkansson, 1995). Building on this foundation, ARA (Actors—Resources— Activities) model was proposed as a simplified yet powerful way of describing the structure and dynamics of business networks. Business networks thus are seen as configurations of actor bonds, resource ties and activity links, where change in one dimension inevitably affects the others (Snehota & Håkansson, 1995). In this sense, the ARA model provides a conceptual entry for analysing the “atoms” that make up industrial networks and how they interact to form complex structures.

In the ARA model, actors consist of individuals, individual companies and groups of organisations, having control over a certain resources and activities. Different actors can utilize their resources in various ways, leading to diverse activities falling into two main categories:

transfer activities and transformation activities. Resources are changed in transformation activities whereas transfer activities are merely to give the direct control over resource to other actors. The resources involved can vary widely, including tangible assets like factories or production equipment, as well as intangible resources such as knowledge (Sundquist & Melander, 2021).The activities that actors undertake include production, logistics, administration, deliveries, information handling, services, innovation, and so on. Actors can also act and establish business relationship with each other, in turn, actors are considered powerful with the support of business network. The establishment of business relationship or network is an essential achievement through the mobilisation of resources and activities, providing a mutual development and learning environment for each actor involved in the network (Snehota & Håkansson, 1995). The importance of individual actors is even considered proportional to the significance of business network which they are part of (Håkansson *et al.,* 2002).

The IMP perspective assumes that actors collaborate with one another within the business landscape, forming networks (Snehota, 2011; Snehota & Håkansson, 1995). These networks and relationships evolve as actors enter or exit the network and as the motivations and willingness of the involved actors change (Guercini & Runfola, 2012). As the network evolves, the roles of actors also change; for example, an actor may assume one role during an innovation phase, which then transforms into another role during the implementation phase. In networks, relationships are built through interaction, often through long-term collaborations. Actors engage in networks because no single actor controls all the resources necessary to perform the activities required to operate a business (Gadde *et al.,* 2010; Snehota, 2011). Innovation can be viewed as a result of interactions among multiple actors within the network, rather than the work of a single company (Hakansson & Johanson, 2016). It can be examined as shifts in relationships, connections, and affiliations, or as novel configurations of actors, resources, and activities. Interaction and resource combining are often considered important enablers of innovation in networks (Landqvist & Lind, 2019), as actors need to combine knowledge to develop new sustainable products, services, or processes (Melander & Arvidsson, 2022).

Despite their enduring influence in understanding business relationships, the IMP perspective are not without limitations. First, scholars have noted that it tends to offer a static representation of networks, focusing more on structural description than on processes of change, emergence, or dissolution, including the issue of network boundaries, network complexity, the role of time and case comparisons (Halinen & Törnroos, 2005). Second, while the model effectively decomposes network structure into three analytical layers, critics argue that it underplays the role of agency, power, and institutional context in shaping network dynamics (Araujo & Easton, 2012). Third, its abstraction level can make empirical application difficult, with many studies reverting to overly descriptive case studies. Reflecting on these limitations, the 2025 IMP Conference theme, "Learning from the Past – Interacting for the Future," calls for renewed theoretical and methodological innovation. Notable examples include the special issue "It's a SIN! Simulating Industrial Networks," proposed by Enrico Baraldi *et al*. (2025), which explores the use of simulation approaches to better understand industrial network dynamics; and "Combining Human and Nature as Equal Actors in the Industrial Network," proposed by Ilkka *et al.* (2025), which challenges the traditional objectification of nature as an passive agency through human decision-making.

2.2.2 Construction Business Network: Formed Rather than Found

Viewing construction as a meta-industry underscores its multi-layered structure, where interactions and relationships can be conceptualized as business networks operating at multiple transitory scales, including individual projects, project networks, and the broader industrial networks (Wikström *et al.,* 2010). This understanding aligns with recent observations that construction business networks emerge and evolve dynamically through ongoing interactions and reorganizations across scales rather than existing as fixed structures (Wang *et al.,* 2023; Liu *et al.,* 2024; Havinga *et al.,* 2023). Earlier, Gadde & Dubois (2010) also characterized construction relationships as having longevity yet being noncontinuous, marked by low stability and high independence. The one-off nature of construction projects often maintain multiple interchangeable suppliers to reduce uncertainty, avoid dependence on single solution providers, and stimulate competition for better pricing. Such features aligns with what has been described as “low-involvement relationships” or “arm’s-length relationships” (Hoyt & Huq, 2000) within the construction industry

Due to the ever-changing coalitions formed around unique projects (Holmen *et al.,* 2005), the construction industry demonstrates high adaptivity. On the one hand, this flexibility enables “hidden innovations” that emerge from unforeseen engineering challenges and are realized through temporary collaborative efforts across firms (Ozorhon, 2013). On the other hand, such project-based organization makes it difficult to accumulate and transfer learning from previous experiences. Surveys conducted in Norway and Sweden reveal that the main drivers of innovation are the internal staff and the own personal network within the organisation (Orstavik, *et al.,* 2015). In contrast, external networks and supplier relationships remain underutilized, as suppliers and subcontractors are not highly valued as strategic partners (Bygballe *et al.,* 2014). Furthermore, markets operating under public procurement rules, which encompass large segments of the construction industry, face additional barriers to collaboration because regulatory frameworks limit opportunities for interaction and early conversations

Despite the fragmented structure of the construction industry (Alsofiani, 2024), various efforts have been made to strengthen its integration. Recent initiatives include the introduction of construction logistics setups (CLSs) to improve coordination and move beyond the traditional ad hoc approach (Janné & Fredriksson, 2019). To foster flexibility and innovation among Swedish small and medium-sized enterprises (SMEs), horizontal collaboration has proven effective in promoting resource and knowledge sharing (Björnfot & Torjussen, 2012). The ongoing shift toward an emission-free construction sector further necessitates the formation of new inter-firm relationships to support sustainability-oriented collaboration.This has motivated studies on circular economy (CE) strategies aimed at enhancing resource utilization within the construction industry (Moscati *et al.,* 2023). Moreover, it has been suggested that the sector could evolve toward strategic partnering by extending collaboration across both time and space (Sundquist *et al.,* 2018), enabling actors to deepen relationships with suppliers over time and broaden their networks through continued collaboration across multiple projects.

2.3 Sustainability Transition

Sustainability transition is “a grand socio-technical imagination of our time projecting an infinite future of human and earth” (Beck *et al.,* 2021, p143). The imaginaries of sustainability transition are not merely strategic and action-forcing representations of the world as it is, but also concurrent representations of how collectives want that world to be (Beck *et al.*, 2021). Such a vision necessitates long-term transformation across economic, environmental, and social dimensions, involving multiple stakeholders and require the co-evolution and interaction of technologies, industry structures, markets, policies, and culture (Köhler *et al.,* 2019). However, as highlighted by Geels *et al.* (2023), a central tension exists between the pace and depth while deep transitions are inherently complex and slow, global climate targets demand faster action. This calls for addressing ‘how’ questions focusing on scaling up niche innovations, destabilizing unsustainable regimes, and understanding potential tipping points to accelerate progress toward sustainability. At the same time, principles of equity and justice must guide transition processes to ensure that workers, communities, and regions are not left behind, aligning with the broader idea of a “just transition” (Healy & Barry*,* 2017, McCauley & Heffron*,* 2018). Given the inherent uncertainty and complexity of sustainability transitions, continuous monitoring, evaluation, and adaptive strategies are necessary (Schandl *et al.,* 2025).

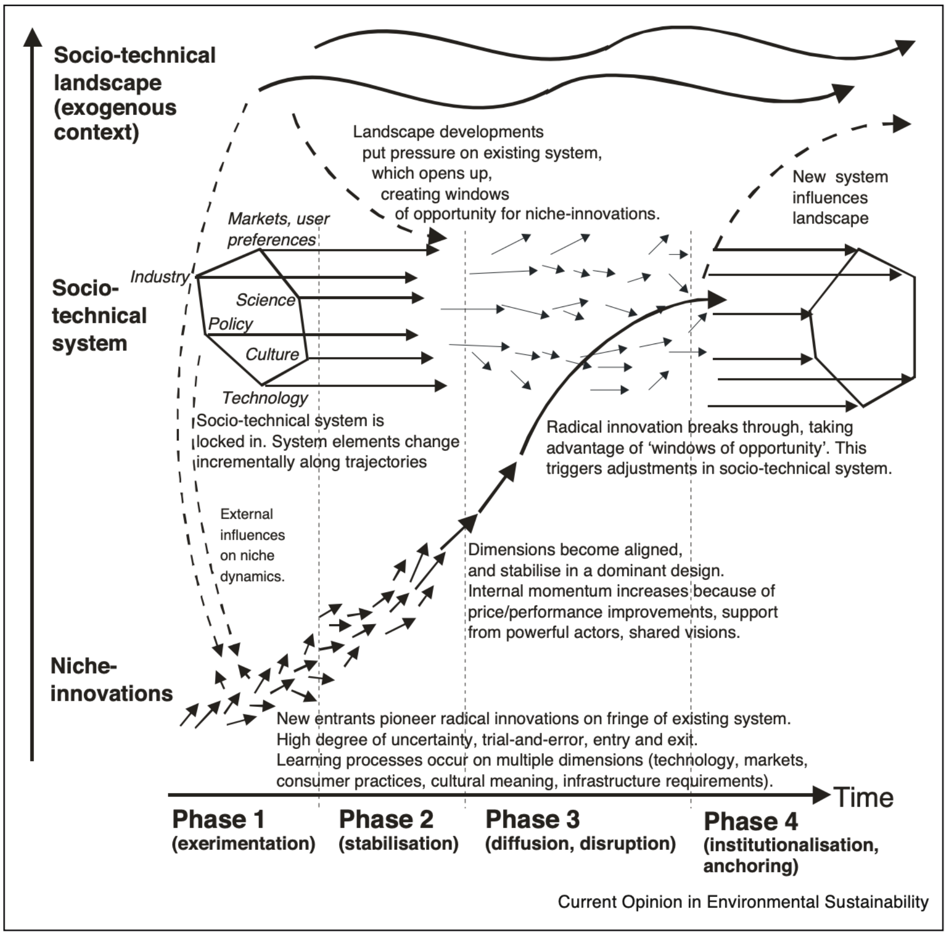

Figure 2.1 Multi-level perspective on socio-technical transitions, from Geels (2019).

One dominant approach to understanding sustainability transitions is the Multi-level Perspective (MLP), which conceptualizes social-technical transitions as dynamic interactions between three analytical levels: niches, regimes, and landscapes (Geels, 2019). As illustrated in Figure 2.1, at the niche level, radical innovations emerge within protected spaces where actors experiment with new technologies, business models, and social practices. Niches represent the seeds of potential change—sites of learning and adaptation that may challenge existing systems. The regime level constitutes the dominant socio-technical system, including technology, industry, market preference, policy and cultural norms. Regimes provide stability and continuity, but they also create inertia that resists disruptive change. At the landscape level, broader exogenous factors, such as climate change, geopolitical shifts, demographic trends, and societal values, shape the context within which regimes and niches evolve. Landscape pressures can destabilize existing regimes, opening windows of opportunity for niche innovations to scale up. In turn, the new formed regimes will influence landscape. Together, the three levels illustrate how sustainability transitions unfold through multi-level interactions over time. When landscape pressures align with maturing niche innovations and internal tensions within regimes, systemic transformation becomes possible.

While MLP perspective is useful for explaining how socio-technical systems evolve (e.g., from horse-drawn carriages to automobiles), it is less effective in addressing whether or why such changes lead toward sustainability. There are also other critics toward MLP, including lack of agency, unclear operationalization in the concept regime, and bias toward bottom-up change models. Therefore, Geels (2011) suggests dropping the notion of hierarchy in favor of flat ontologies, where outcomes are shaped by actors who combine and reproduce different elements such as technology, meaning, and skills. This is where IMP perspective can come into play.The emphasis on actors and more microdynamics aligns with the performative perspective of sustainability transition, seeking to develop a deeper and more inclusive understanding: "the actual dynamics of sustainability transition, not as defined theoretically or envisioned politically, but as they are shaped by the everyday practices of individuals and organizations" (Hallin *et al.,* 2021, p.1950). This perspective requires the actors to respond and adapt to a wide range of potential uncertainties, which is central to resilience thinking that has rarely been integrated into discussions on sustainability transitions (Scordato & Gulbrandsen, 2024).

Furthermore, resilience thinking brings attention to issues of fairness in the transition, shifting from technology to a more holistic perspective encompassing broader social and environmental considerations (Scordato & Gulbrandsen, 2024). In practice, diverse actors can align their visions as a collective network in the transition. Farla *et al.* (2012) examined sustainability transitions from the perspectives of actors, strategies, and resources, demonstrating that these processes do not arise from unintentional interactions among players pursuing their own agendas. Instead, they tend to be strategically shaped by actors with a broader vision. Corazza *et al.* (2022) illustrate how a network of smaller actors can exert influence by developing policies that support these smaller entities in engaging in sustainable innovations. Furthermore, pro-renewable actors, such as NGOs and local governments, are not entirely passive during periods of political instability caused by the central government's actions; they actively seek opportunities to move forward together, albeit on a smaller scale (Aguiar-Hernandez & Breetz, 2024).

2.4 Adaptive Business Network for Sustainability Transition

Building on the aforementioned concepts, the electrification of construction transport (offsite and onsite) is understood not merely as a technological substitution—replacing diesel engines with electric ones—but as a systemic transformation that involves how networks of actors, resources, and activities interact, evolve, and co-create pathways toward an ongoing sustainability transition**,** where the destination remains emergent rather than predefined. By focusing on its fundamental building blocks—actors, resources, and activities—the ARA model moves beyond linear and static supply chain representations**,** revealing the complex, interdependent, and emergent nature of construction business networks.While the MLP perspective provides a valuable heuristic for further structuring socio-technical change, yet it lacks the depth required to capture the adaptive, resilient, and fairness-oriented dimensions of sustainability transitions. To address this gap, an integrated framework is proposed and inspired by the metaphor of the adaptive cycle from panarchy (Gunderson & Holling, 2002). **The aim of this thesis is therefore to investigate the electrification as a sustainability transition through the lens of adaptive business networks,** aligning with the call for a paradigm shift toward more flexible and responsive supply chains—what Wieland (2021) terms "dancing the supply chain".

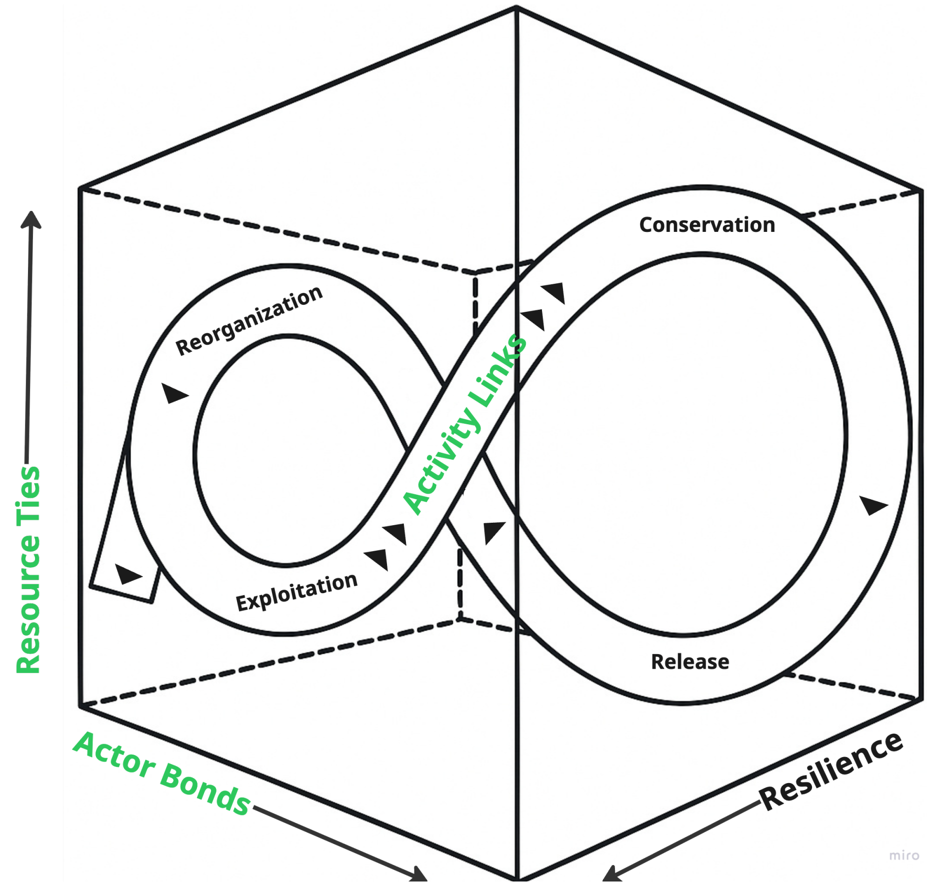

Figure 2.2 Theoretical Framework: Adaptive Business Network for Sustainability Transition (Developed based on Håkansson & Snehota, 1995 and Gunderson & Holling, 2002)

As illustrated in Figure 2.2*,* the proposed framework integrated the fundamental dimensions of the IMP perspective: resource ties represent the business network's potential and material base; actor bonds capture connectedness, interdependence, and institutional relationships; and the infinity loop ∞ at the center—symbolizing activity links—depicts the continuous flow of interaction, through which actors recombine resources and realign relationships. These activities constitute the engine of adaptation*,* propelling the network through different phases of the adaptive cycle, including exploitation (innovation and expansion), conservation (stabilization and efficiency), release (disruption and resource reallocation), and reorganization (renewal and transformation). Notably, a greater number of arrows indicates a longer duration within that phase, while exiting the cycle represents a stage in which resources may leak away, potentially leading to a shift into a less organized and productive cycle (Gunderson & Holling, 2002).This framework acknowledges the dynamic, cross-scale nature of sustainability transitions while moving beyond the static, hierarchical systems of the MLP. Moreover, by introducing the axis of *ecological resilience*, the framework emphasizes the capacity of business networks to absorb shocks and reorganize without losing their essential functions. Sustainability transitions are thus reimagined not as linear progressions toward a fixed or "better" sustainable end state where new regimes simply replace old ones, but as managing to identify and ride an adaptive cycle, where networks grow, collapse, reorganize, and renew through the continuous interplay of actor, resource, and activity dynamics—*the gist is to carry on*.

3.Methodology

This chapter first provides an current overview of the research design, including the nature of the study, the rationale for the chosen methodology, and a brief outline of future research. To ensure transparency, the methods of data collection and analysis are presented separately, followed by a reflection on the experience of applying these methodologies.

3.1 Overview of Research Design

The research context is Sweden, one of the leading countries in this field. Given the emerging phenomenon of electrifying construction transport, both on-site machinery and off-site vehicles, this study adopts a sequential exploratory design involving mixed methods (Creswell *et al., 2006*). As illustrated in Figure 3.1, Study 1 began by investigating the phenomenon without predefining the nature of the issue. Paper I employed expert interviews to explore the challenges and facilitators shaping the phenomenon, with the data analysed using the Gioia methodology (Gioia *et al.,* 2013). The uncertainty and complexity revealed through this initial inquiry led to the conceptualisation of the phenomenon as a sustainability transition. Building on this theoretical foundation, Paper II expanded the analytical focus to examine the wider transition toward emission-free construction sites, with particular emphasis on electrification—a still promising direction evidenced by emerging initiatives across the Nordic countries (e.g., in the city of Oslo, Stockholm, and Gothenburg). Among the uncertainty, the Delphi survey was chosen to facilitate a structured communication process characterized by anonymity, expert iteration, controlled feedback, and consensus-building (Paliwoda, 1983; Woudenberg, 1991), aimed at developing future scenarios. Overall, as shown in Figure 3.1, the choice of methodology evolved from qualitative exploration toward more quantitative methods, in response to the emerging empirical contexts. Given the current limitations in data availability, the future study will seek to simulate sustainability transitions using agent-based modelling. While this is not the focus of the present work, it will be briefly discussed as a direction for future research. More details regarding data collection and analysis are provided in the following sections, while the practical steps for each method are presented in the attached papers and therefore are not repeated here.

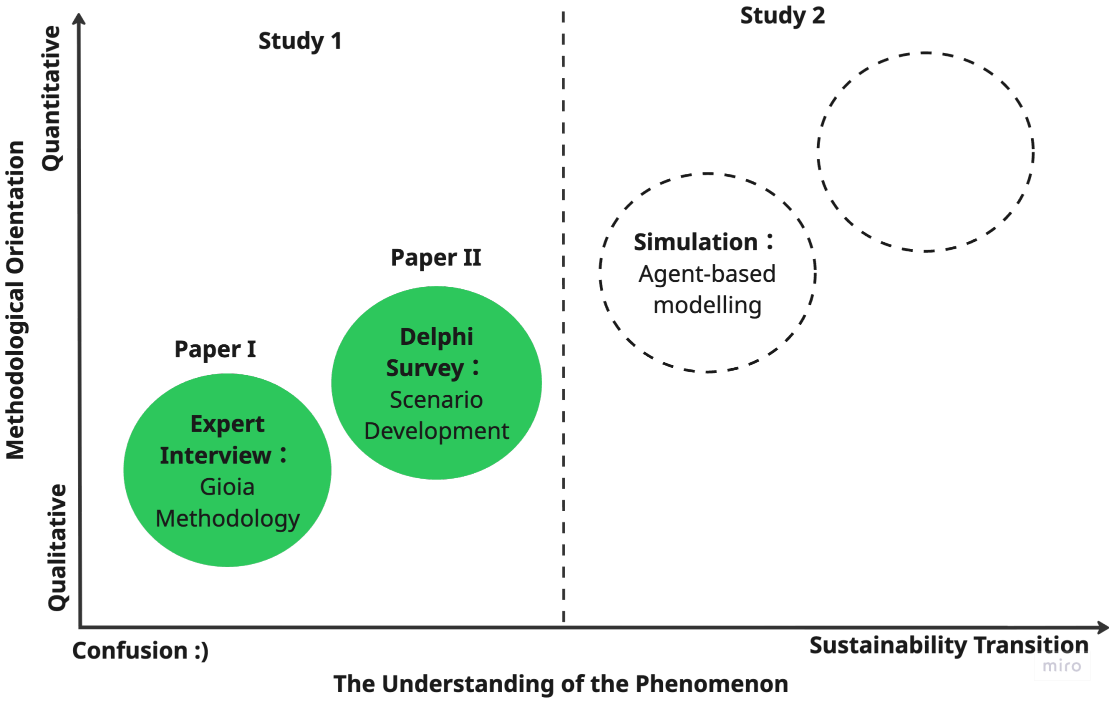

Figure 3.1 Overview of Research Design (A snapshot for now)

3.2 Data Collection: Expert Sampling and Composition

Initially, relevant organizations were identified through their official webpages, published reports, and LinkedIn posts. Experts were contacted with the assistance of these organizations and through networking events, thereafter a snowballing approach was employed. As outlined in Paper I, 18 experts were interviewed between March 2023 and October 2023, with each interview lasting approximately one hour (the interview guide is provided in the appendix of Paper I). Following the interview study, research updates were shared via emails, and four interview participants joined again the Delphi survey for Paper II, also recommending new contacts. In total, 20 experts participated in the first round and 18 in the second round of the survey, conducted between February 2024 and May 2024. The survey was sent using the SurveyMonkey platform, allowing participants to evalute 15 future projections using the scale of probability (0-100%), impact(1-5), and desirability(1-5), in either Swedish or English. Prior to the main survey, a pre-test was conducted with four participants selected for their academic and industry expertise in construction and transportation. At this early stage of promoting emission-free construction sites and electrification, knowledge was dispersed across multiple stakeholders, resulting in a diverse pool of experts in both studies representing government bodies, academia, construction companies (including main contractors and subcontractors), OEMs, energy companies, consulting firms, and NGOs. Figure 3.2 and Table 3.1 present the backgrounds of all 34 experts, along with their participation in the interview and survey indicated by one or two expert codes.

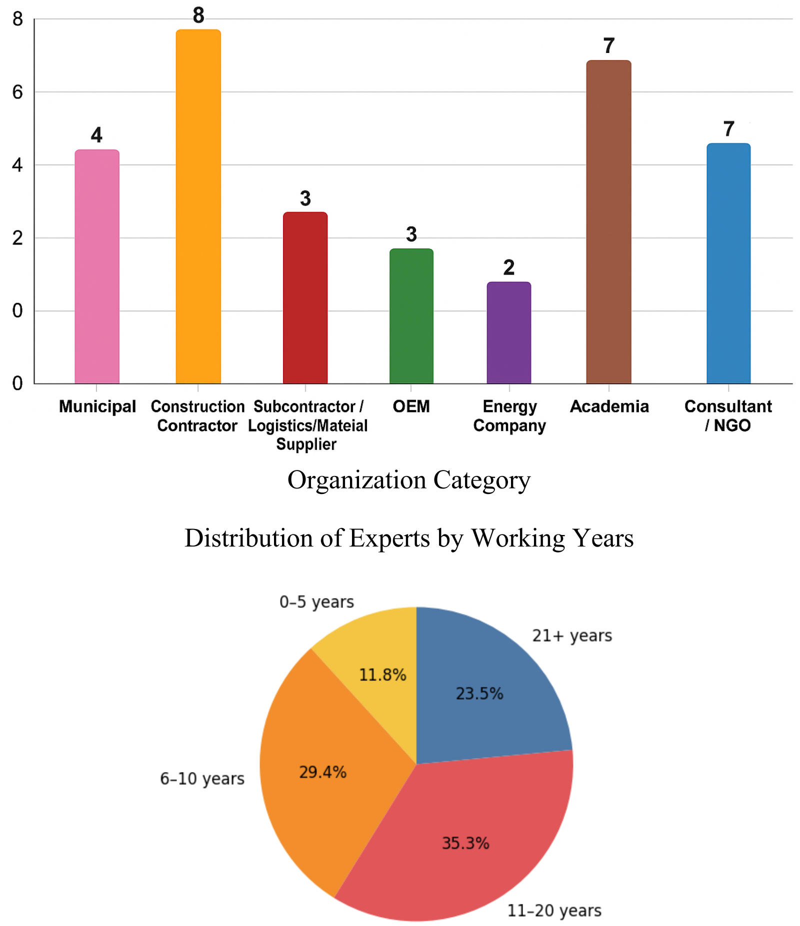

Figure 3.2: The Distribution of the Experts (34 participants in total)

Table 3.1: The Background of Experts

	Organization	Expert Code	Current Position	Relevant Experience
Municipal	National Innovation Department	R3, E2	Innovation Division Director	Worked one year as a part-time researcher in innovation capacity; five years as director of the innovation management division for sustainable mobility systems, future innovation, and ecosystems for innovative companies; fourteen years on innovation capability in a construction equipment manufacturer company.
	City A	R2, E1	Project Leader in the Climate-Neutral Construction Sector.	Worked seven years as a management controller in the Department of City Environment Administration; two years as a city sustainability coach.
		R4, E3	Project Manager in Electromobility	Worked five years as project manager for city electromobility; 3.5 years as project manager in the Department of City Environment Administration.
		R1	Electrification Strategist	Has been working for six years in project management and R&D, focusing on electric vehicles and charging infrastructure.
Construction Company	Construction Main Contractor A	R9	Vice Innovation President	Over 20 years in the company, mostly involved in enabling financial safety and operations of construction materials.
		R10	Project Manager	Has been working on an exclusive project to investigate electrifying construction transport for one year when interviewed.
		R11	Project Developer	Worked for seven years on sustainable development for road and construction regions. Has been working on an exclusive project to investigate electrifying construction transport for one year when interviewed.
		E4	Construction Project Manager	Worked five years in construction site management; six years in construction project management.
		E5	Construction Project Leader	Worked twenty years as a construction project leader.
	Construction Main Contractor B	R12	Project Manager	With over five years of experience addressing urban environmental issues, now focuses on electrification and mobility.
		R13	Project Manager	Has been working for nine years in the company, mainly responsible for planning stages of construction projects. Participated in some pilot tests of electric machines on-site.
		R14	Site Manager	Worked 20 years in the company, mainly responsible for the groundwork of construction projects, and participated in some pilot tests of electric machines on-site.
	Logistic Provider A	R15,E6	Sales Manager in Project Logistics	Worked two years as sales manager in project logistics; two years as block manger and on-site construction engineer.
	Building Material Supplier A	E7	Global Category Manager in Heavy Mobile Equipment and Quarry Decarbonization	Worked four years as head of sales and marketing for off-road solutions in the OEM autonomous solutions division; twelve years on pilot projects and advanced engineering in a construction equipment manufacturer.
	Individual Construction Subcontractor A	R16	Individual Business Owner	Over 10 years in the industry to help construction sites network with providers of construction machines, trucks, and materials.

Vehicle Manufacturer	OEM A	E8	Segment Leader in Off-Highway Heavy Equipment	Worked twenty-three years in marketing and sales, both globally and regionally.
		E9	Segment Leader in Off-Highway Heavy Equipment	Worked twenty-five years in emerging technologies and future solutions management.
	OEM B	E10	Expert Research Engineer	Worked six years in data analytics for electrification of transport, electromobility, and energy systems, nineteen years as a senior technology specialist, and nine years in PhD studies on energy-efficient working machines.
Energy Company	Energy Company A	R17	Senior Project Manager for R&D	Worked 19 years in a large OEM company and six years so far for R&D projects related to the electrical grid and electrification of transport.
	Energy Company B	R18	Head of Charging Infrastructure	Has 15 years of experience in sustainability transformation and one year in the current position.
Academia	University A	E11	Associate Professor in Construction Logistics	Worked ten years as a researcher in the Department of Communications and Transport Systems.
		E12	Senior researcher in Zero-emission Construction Logistics	Worked eight years researching the impact of off-site construction transport.
	University B	E13	Associate Professor in Construction Production and Management	Worked seven years as a researcher in construction production and management.
	University B & Research Institute A	E14	Industrial PhD student in low-carbon transport systems	Worked nine years researching low-carbon transport and pathways to net-zero emissions.
	University C	E15	PhD Student in Planning and Operation of Autonomous Mobile Charging	Worked five years researching urban mobility.
	University C & National Transport Administration	E16	PhD Student in System Dynamics and Freight Electrification	Worked six years of using system dynamics modeling to understand the impact of electrification on the road freight transport system.
	Research Institute B (National Road and Transport)	E17	Research leader in freight transport	Worked seven years researching logistics and sustainability.
Consultant Company and NGOs	Innovation Hub A	R5	Senior Project Manager in Mobility	Worked 10 years related to sustainable transport and energy systems and one year so far in the current position.
	Innovation Hub A	R6	Program Manager	Has been working for 10 years in actively initiating and managing projects within electrification, automation, and digitalization in the mobility sector.
	Systems Lifecycle Management Consulting	E18	Consultant within complex technical systems	Worked five years in PhD research on sustainable road freight transport systems; three years as a system dynamics modeler in the national transport administration.
	Energy Technology innovator	E19	Consultant for ISCC (International Sustainability and Carbon Certification)	Worked twenty-five years as founder and CEO of two environmental accounting consulting companies.
	International Green Building Council	E20	Secretary of the Building Standards Board	Worked three years on the standardization of Nordic sustainable construction projects.

Networking Agency A	R7	Expert in E-mobility	Worked in an energy agency for three years and two years in the current position.
Networking Agency B	R8	Project Leader	Has been working for six years on the transition to fossil-free transport by providing expert support to municipalities, regions, and companies and facilitating cooperation across municipal and county borders.

(Note: R# denotes experts who participated in the interview study, and E# denotes experts who participated in the Delphi survey. The code numbers are consistent across the two papers to facilitate cross-referencing.)

3.3 Data Analysis

The interviews were coded using the Gioia methodology (Gioia *et al.,* 2013), complemented by the coding guidelines outlined in Corbin and Strauss (2014). During the development of first-order codes—kept as close as possible to the interviewees' own words—the data largely reflected two overarching categories: challenges (expressed as feelings of being stuck) and facilitators (reflecting a can-do attitude). From these, second-order themes were derived to capture more abstract patterns. At this stage, the ARA framework was applied, focusing on the interrelations between actors, resources, and activities (see *Figure 1 Data Structure* in Paper I). Apart from the Data Structure, representative expert quotes are also displayed in *Table II* and *Table III* of Paper I to enhance the transprancy. The analysis of the survey results included consensus analysis and scenario analysis (Leypoldt *et al.,* 2024; Peppel et al., 2022). Comparisons were made across two timelines by 2030 and 2045. In consensus analysis, each projection was assessed using the total IQR (interquartile range), which aggregates the IQR across probability, impact, and desirability. For the scenario analysis, clustering methods were employed to support scenario development. As detailed in *Appendix A* of Paper II, three clustering method including Fuzzy C-Means (FCM), K-Means, and Hierarchical Analysis (HA) were combined to analyze the second-round Delphi results. Without the need to predefine the number of clusters, HA was used to identify three suitable clusters. Based on the three-cluster solution, FCM approach provided greater interpretability for scenario development than K-means, which resulted in a more polarized pattern (see *Appendix A* of Paper II). FCM was therefore chosen for clustering analysis leading to three distinct scenarios, driven by policy, technology and niche technology. In this thesis, both data analyses were combined to produce an overall mapping in the theoretical framework, leading to *A Heroic Vision of Sustainability Transition: Adaptive Construction Business Network toward Electrification* in *Chapter 5 Conclusion and Discussion*, supported by interview quotes, Delphi survey comments, and FCM-based scenario development.

3.4 Methodological Reflection: *''Do not Be a Slave to the Process''.*

I would like to conclude with a personal reflection on my experience of applying the aforementioned expert-based interviews and Delphi survey. During one academic conference, a peer commented that "as a qualitative researcher, you can be challenged on every aspect of your work—from the research question, theory, to the methodology, result and discussion — whereas in quantitative research, you will only be asked about your dataset." This remark stayed with me because it exposes how ambiguity in qualitative methodologies is often underestimated and framed as a weakness, while the apparent certainty of quantitative approaches is overvalued as a strength. I find this distinction or the "methodological hierarchy'' (Creswell *et al.,* 2006, p.1) worth challenging.

The Power of Thinking Qualitatively: unfortunately or fortunately, the lens of quantitative rigour remains prevalent in academia, often pushing researchers to defend the nature and strength of qualitative methodologies (*Gioia et al., 2013)*, like they must justify their value beyond a merely supportive or auxiliary role within mixed methods research (Creswell *et al.,* 2006). This tendency is most visible in the persistent demand for quantitative criteria in qualitative data collection. As one of the journal reviewers for Paper I commented (though kindly): "Under research methodology, I would like to know how the authors determined data saturation." Some would argue that saturation is reached when themes begin to repeat—a logic I find only partly satisfying, since it still impose quantitative measuring on qualitative inquiry which focuses on understanding meanings, experiences, and perspectives. On the one hand, I understand the concern that "Does it deserve the name of 'research' or is it just based on trend searching and arbitrary interpretation in a 'closed shop' and in no transparent way?" (Kuusi *et al*., 2015, p.22). On the other hand, I fail to see why a compelling story, supported by expert backgrounds and quotations, should lose its credibility simply because it involves ten rather than twenty participants. Adding more experts may produce a longer book, but *"*a shorter one can still be a very good book*"* (Lewis, 2016). With these thoughts in mind, I replied to the journal as follows:

Especially, we would like to thank you for giving us the opportunity to reflect on the concept 'data saturation'. The reason we didn't involve any criteria at the first place is due to a struggle to describe the indescribable 'stop point', while we acknowledge prior efforts to operationalize data collection by recommending specific interview counts to achieve data saturation. However, as motivated by your question, we get inspired by several previous works. So, we would like to answer you using the same texts we have added under the research methodology:

''In terms of the sample size, Guest et al. (2006) suggest that saturation often occurs within the first 12 interviews, with basic themes emerging as early as six interviews. Similarly, Hennink and Kaiser (2022) found that code saturation can be achieved with 9–17 interviews. However, recent methodological discourse has challenged the traditional notion of data saturation (Braun and Clarke, 2019). By abandoning the concept of data saturation, we acknowledge that data collection in this study could, in principle, continue indefinitely to generate new insights. This openness does not compromise the rigour of our qualitative analysis, which follows the transparent and structured approach advocated in the Gioia methodology (Gioia et al., 2013). Given the interviewees' background in Table I and the representative quotations in Tables II and III, we think that readers are well-equipped to assess the quality of the data and the robustness of the theoretical model depicted in Figure 2. This approach resonates with the principles of information power (Malterud et al., 2016) and theoretical sufficiency (Charmaz, 2006), which prioritize the depth and relevance of data over the pursuit of number of participants.''

The Ambiguity in Quantitative Methods: when reading about scenario analysis, I anticipated that there would be no universal definition of scenario as a qualitative concept. However, I did not expect to encounter what some authors have described as *"methodological chaos" (*Amer, 2013, p.26), a reflection of the vast number of scenario development techniques proposed in the literature.For example, there is no consensus on which clustering method best suits scenario development, as Tapio (2003, p.92) notes, "the deeper one gets into this discussion, the less agreeable criteria one gets". Commonly used methods include K-Means, Fuzzy C-Means, and Hierarchical Analysis (HA).Yet, the rationale behind these methodological choices is sometimes weak or even misleading, as illustrated by several examples in Table 3.2.

Table 3.2 The Rational of Clustering Choice in Previous Studies

#	Paper	The Claimed Rationale	My Reflection
1	The future and social impact of Big Data Analytics in Supply Chain Management: Results from a Delphi study (Roßmann *et al.,* 2018, p.141)	''A non-hierarchical approach was chosen since the validity of clustering outcomes computed by hierarchical methods (e.g. average or complete linkage) is limited for small sample sizes, as in the present case (Ketchen and Shook, 1996).'' ''The fuzzy c-means (FCM) algorithm was therefore applied, as this fuzzy clustering technique outperforms hard clustering methods (e.g. k-means) if the boarders of the clusters cannot be clearly separated (Bezdek, 1981; Budayan et al., 2009; Dunn, 1973).''	This study serves as a reference point for the subsequent studies.
2	The impact of COVID-19 on the European football ecosystem – A Delphi-based scenario analysis (Beiderbeck *et al.*, 2021, p.6)	''In this context, Roßmann et al. (2018) have noted the benefits of the non-hierarchical fuzzy c-means algorithm (FCM) to create clusters of Delphi projections. Hence, we followed this approach.''	Although Roßmann et al. (2018) present a sound rationale for adopting Fuzzy C-Means within their specific context, the reasoning given of uncritically following the same approach in the current study remains doubtful.
3	How will last-mile delivery be shaped in 2040? A Delphi-based scenario study (Peppel *et al.*, 2022, p.8)	''We select the fuzzy c-means clustering method using R since this non-hierarchical method yields a higher validity for small sample sizes than hierarchical methods such as k-means clustering.''	K-Means is a non-hierarchical method also, its distinction from Fuzzy C-Means appears to be misunderstood in this study.
4	Lessons Learned from a Two-Round Delphi-based Scenario Study (Schmalz *et al.,* 2021, p.10)	''Fuzzy k-means and HC clustering generated the same clusters. We decided on HC, as Akman, Comar, Hrozencik, and Gonzales [2] argue that it is a suitable cluster algorithm for a small data set'. Hence, hierarchical clustering with Euclidean distance and using the Ward [57] method provided the best and most feasible results for our study.''	The suggested suitability of Hierarchical Clustering (HC) for small datasets contradicts what has been stated in the first study
5	Disaggregative Policy Delphi: Using Cluster Analysis as a Tool for Systematic Scenario Formation (Tapio, 2003, p.92)	''The only obvious agreement seems to be, that the nearest neighbour (i.e., single linkage) method should not be used unless the clusters are supposedly of chain shape [48,49] .''	This conclusion does not provide any constructive basis for informing the choice among alternative clustering algorithms.

It is understandable that the application of clustering methods in scenario-based studies may not always achieve full methodological rigor, as the primary focus often lies in exploring and discussing potential scenarios. However, a critical yet rarely mentioned issue in the literature is an underlying qualitative question that alternative clustering methods poses as *'what is a group?':*

- K-Means: A group is a bunch of points close to a center; each point in one cluster only.
- Fuzzy C-Means: A group is a soft membership; a point can belong partially to multiple groups (probabilistic).
- Hierarchical Analysis: A group is a nested set of mergers that minimize variance (based on distance and structure).

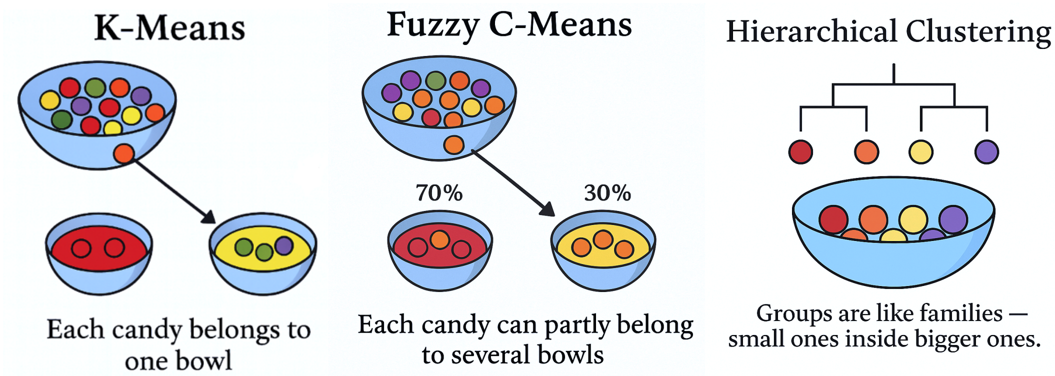

Figure3.3 The Difference Between Clustering Methods
(An illustration "Does the orange candy belong to the red or yellow bowl?", allegedly understandable for kids and created with ChatGPT)

The difference between clustering methods is not only technical — it's *ontological* (what we think a "group" is) and *epistemological* (how we think we can know it). At a deeper level, the philosophical choice of a clustering technique reflects an implicit commitment to how the researcher believes order, similarity, and diversity exist in the world (Yoon, 2009). The consicious choice of worldview in the methdology is especially vital in the age of artificial intelligence. As technology increasingly mediates our ways of knowing, there is a growing risk of losing our reflective engagement with the assumptions that underlie the tools we use. When we follow computational processes uncritically, without questioning the foundamental assumptions embedded within them, we risk weakening the very connection between scientific inquiry and our humanity (Yoon, 2009).

Why the Choice of Mixed-Method Research Design: apart from ensuring transparency in each method, the recognition of the strengths and weaknesses in both qualitative and quantitative approaches further motivated the adoption of a mixed-method research design in this thesis. This design enables a more comprehensive understanding of the phenomenon by integrating the depth of qualitative insights with the generalizability of quantitative findings. As stated in the data analysis, a combination of insights from expert interviews and a Delphi survey was employed in this thesis, to capture both individual perspectives and collective consensus.

4. Summary of Papers

The following summarizes the two attached papers, highlighting the motivation, the methodology, the main results and contribution, see in Table 4.1

Table 4.1 The Summary of Papers

Paper	A Heroic Vision for Sustainability Transitions: Electrification Through Collaborative Supply Chain Networks (Published on SCM:An International Journal)	The Future of Swedish Emission Free Construction Site by 2030 and 2045: A Choice between Hope and Fear (Earlier version presented at conference NOFOMA 2025)
Methodology	Expert interviews, Gioia methodology.	Two-round Delphi survey, clustering analysis, Scenario development.
Findings	Challenges: a negative resource loop includes lack of physical asset- lack of knowledge-lack of motivation Facilitators: a positive activity loop includes initiate collaborative network-share for fair transition-aim for common practice	Three future scenarios for the development of Sweden's emission-free construction sites by 2030 and 2045 are developed: *No Surprises Ahead?, Where Fear Draws the Line, and Inescapable Scepticism.*

4.1 Paper I: A Heroic Vision for Sustainability Transitions: Electrification Through Collaborative Supply Chain Networks

Emission-free construction sites are gaining increasing attention in urban development and has shown to provide both environmental and social sustainability. Paper I presents a expert interview study that integrates the Industrial Marketing and Purchasing (IMP) and Multi-Level Perspective (MLP) perspective to analyze the challenges and facilitators within the context of electrifification. 18 experts are intervieweed representing municipalities, innovation hubs, networking agencies, energy companies, and construction firms in Sweden. The paper explores the emergence of a "heroic vision" of sustainability transition. It is observed in the efforts to address the 'chicken-and-egg' dilemmas in the early stages of electrification, where actors need to navigate interlinked challenges of limited physical resources, low motivation, and insufficient knowledge. Those who demonstrate a balanced, resilient, and collaborative long-term orientation are recognized as the 'heroes' in this transition. Their practices include initiating collaboration, promoting fairness, and striving for common practices. The study's main contribution lies in providing operational insights for fostering sustainability transitions through collaborative supply chain networks, particularly during the pre-development phase. By complementing macro-level frameworks such as the MLP, the paper offers a more granular understanding of how actors and their interactions shape the business networks, and influence the unfolding transition process.

4.2 Paper II: The Future of Swedish Emission Free Construction Site by 2030 and 2045: A Choice between Hope and Fear

Furthermore, Paper II investigates the potential future development of the transition through a Delphi-based scenario analysis for the years 2030 and 2045 in Sweden. 15 projections were developed across five key dimensions: market demand, policy and regulation, technological

feasibility, infrastructure feasibility, and economic viability. A two-round Delphi survey was conducted involving 20 experts from government, industry, and academia. By combining the clustering results and expert reflections from the survey, three future scenarios for the development of Sweden's emission-free construction sites were outlined: *No Surprises Ahead?*, *Where Fear Draws the Line*, and *Inescapable Scepticism*. The study's main contribution lies in unpacking the future of emission-free construction sites through the dynamic interplay between these scenarios. Scenario 1 (*No Surprises Ahead?*) illustrates how the construction industry's conservative and hierarchical characteristics sustain a normative transition path, where governments and major clients guide practices primarily through financial incentives. However, concerns about stagnation open space for a more radical, technology-driven pathway in Scenario 2 (*Where Fear Draws the Line*). The diminishing fear of deep disruption in Scenario 2 sets the foundation for Scenario 3 (*Inescapable Scepticism*), where disproportionate resistance persists toward niche technologies such as battery-swapping, compared with more mainstream technology like AI and automation. Beyond offering managerial and policy insights to navigate the transition, the findings also contribute by reconceptualizing scenarios as dynamic and interconnected processes rather than fixed endpoints. Each secnario is understood as components of an evolving system shaped by social factors including perceptions, attitudes, and worldview choices.

5. Conclusion and Discussion: "*This Too Shall Pass*"

This chapter builds upon and extends the two papers, offering a more integrated understanding of electrification as a sustainability transition through the lens of adaptive business networks, thereby addressing the aim of this thesis. As illustrated in Figure 5.1, the transition is conceptualized through variations in the scales of resource ties and actor bonds, illustrated by the differing sizes of the circles along the axes. Within the construction sector—understood as a meta-industry—each actor's perception of the "transition state" is inherently partial, situated, and evolving. The varying understandings of resource ties and actor bonds observed in the data reflect implicit, recursive, and often intangible motivational dimensions. Starting from different interpretations of the present, or "nows," actors mobilize resources and relationships at diverse scales, generating alternative yet interconnected future trajectories. This highlights that the transition is not orchestrated through centralized coordination but emerges through plural mobilizations across these relational scales. Within this dynamic, resilience emerges as a critical managerial dimension, emphasizing the capacity of networks to reorganize amid shifting perceptions, resources, and relationships. This view recognizes that any dominant configuration or overlooked condition is inherently transitory, subject to continuous adaptation and renewal.

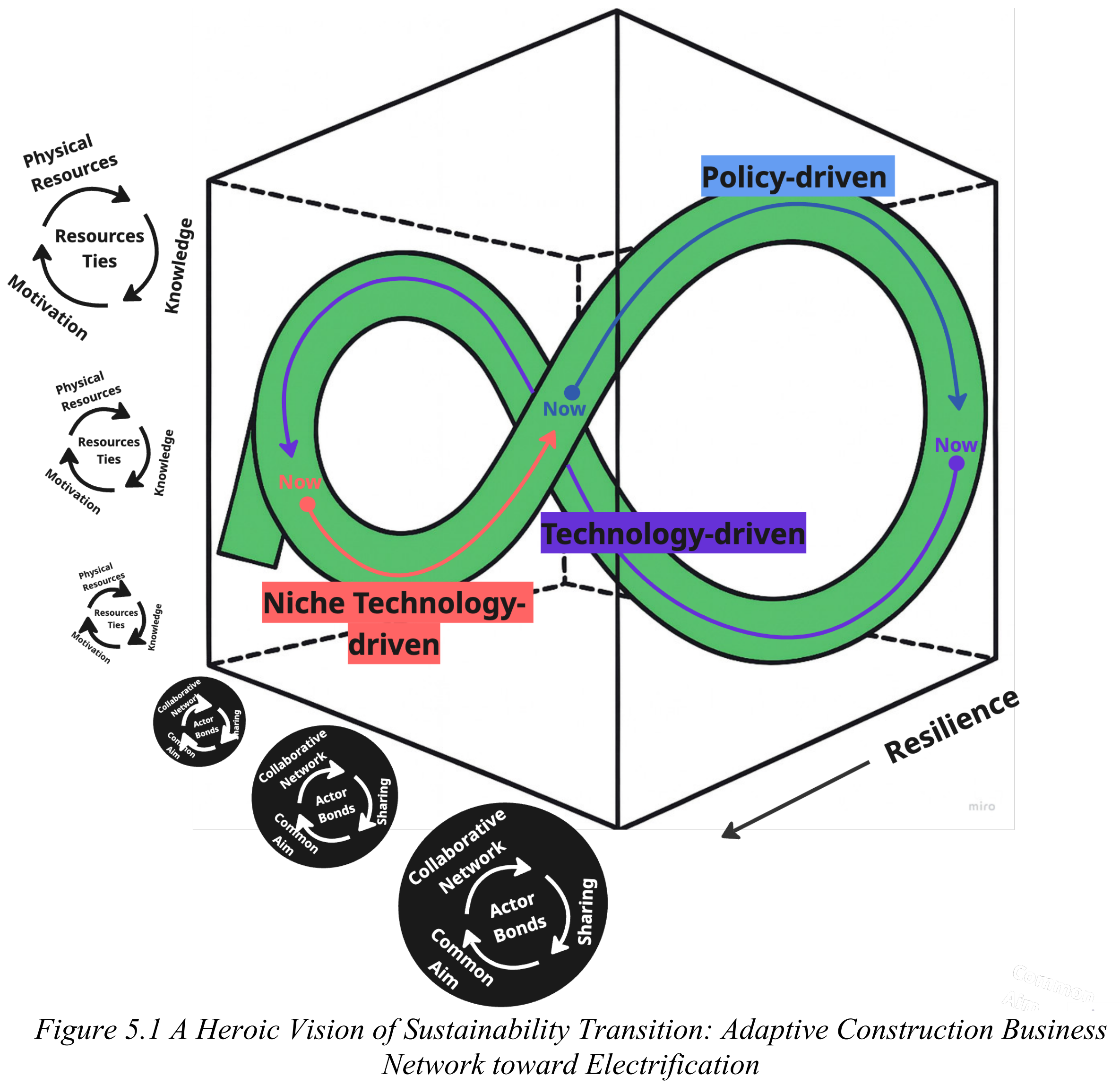

Figure 5.1 A Heroic Vision of Sustainability Transition: Adaptive Construction Business Network toward Electrification
(developed based on Håkansson & Snehota, 1995, Gunderson & Holling, 2002)

5.1 Where are we ''nows''?

Construction business networks are too complex to be captured by a single reality, where actors position themselves reflects their unique perceptions of available resource ties and actor bonds, forming their own "virtual realities" (Wieland, 2021, p. 63). In the context of promoting electrification, diverse perceptions give rise to different starting points at this early stage of transition, as illustrated by the multiple "nows" in Figure 5.1. As conceptualized in Paper I, the challenges reflect an industry-wide perception of resource scarcity—a "chicken-and-egg" dilemma that forms a negative feedback loop among limited physical resources, insufficient knowledge, and low motivation. These challenges persist across all "now" perspectives, as changes in the scale of resource ties constitute a fundamental driving mechanism of the transition. However, resource heterogeneity exists, meaning that actors differ in what they possess and can do. As Gibson (1993) commented, "The future is already here, it's just not evenly distributed". For example, OEMs hold greater technical knowledge of electric construction equipment, while contractors specialize in site management and subcontractors act as expert pilots. Even between the competing construction *Main Contractor A* and *B*, differences in motivation toward adopting electric equipment are evident (innovation opportunity versus investment burden). This asymmetry creates dependence leading to a "righteous stagnation" dynamic, where everyone can blame everyone, and everyone can wait for everyone else: *"If our client, the company that we are building for, if they demand it, then we will demand it from our subcontractors. But we don't demand it. Subcontractors are the ones owning the machines, maybe to start with them or someone else? not necessarily us, but someone else might need to have the storage of electric machines that we could employ" (R12).*

Despite the challenges, some actors are demonstrating strong awareness and striving to initiate collaborative networks, share for a fair transition, and work toward common practices at different scales. For instance, the interviewee *R3* highlighted that the construction industry often misses funding opportunities and lacks representation at higher policy levels, questioning whether this reflects a sense of exclusion. *Main Contractor A* is developing an internal knowledge base for electric construction sites by engaging subcontractors across different projects, while broader concerns persist regarding the survival of small subcontractors whose livelihoods depend on conventional construction equipment. Meanwhile, other actors such as government agencies are considering assuming multiple roles: creating shared charging infrastructure and pools of electric vehicles, setting procurement requirements, and promoting supportive policies. By forging new actor bonds, such networking initiatives across scales can help mobilize and integrate essential resources. The heroism embedded in these actors' initiatives does not arise from domination or disruption, but from their capacity to connect, empower, and adapt. It is a quiet, relational courage to collaborate, share, and co-evolve toward a fair sustainability transition. These practices also resonate with the everyday realities of the infrastructure industry, like construction, transport, and logistics, characterized by cognitively demanding work and a daily spirit of "firefighting" amid noise, dust, and heavy labour.

5.2 ''*All Roads Lead to Rome*''

Starting from diverse perceptions of the current situation, the transition unfolds through a continuous balancing act between resource dilemmas and networking initiatives, shaping multiple future pathways toward electrification. As discussed in Paper I's *Section 5.3 Beyond Acceleration to Destination: "Sustainability transitions require moving beyond target-driven approaches toward a shared, meaningful destination shaped by the continuous interplay of challenges and facilitators. This destination should reflect resilient, inclusive change and reconnect with the core purpose of sustainability — a process we refer to as a heroic vision of* *sustainability transition."* Figure 5.1 further positions the future scenarios identified in Paper II as a outcome of mobilizing resource ties and actor bonds across scales.

In the policy-driven scenario (*No Surprises Ahead?)*, the promotion of electrification is viewed as mainly reinforcing resource ties and actor bonds at larger scales, where governments and major clients play a central role in steering practices among smaller actors. This reflects the *conservation stage* in the adaptive cycle (Gunderson & Holling, 2002), where the construction industry's hierarchical structure sustains a normative transition pathway by strengthening existing business networks. Examples include government-led emission-free megaprojects and financial incentives aimed at reducing the cost of electric equipment. These could create early "islands" of collaboration between machine suppliers and contractors. However, this pathway—stablizing established networks during change—can progress slowly and is not without risks: *"Unfortunately, I think we need to see more climate disasters before political priority will be in place. I guess Trump and others are slowing this down, but climate change is not slowing down, so it is very likely that this will not be policy-making slowness but crisis management in a few years" (E2).*

The concerns about stagnation reflect a prevailing perception that the construction industry has already reached a level of maturity that limits its adaptability. The continuous reinforcement of existing resource ties and actor bonds may, in turn, weaken network resilience, as illustrated in the "now" of the technology-driven scenario in Figure 5.1. This perspective opens the space for a more radical pathway—*Where Fear Draws the Line*—in which a faster electrification is envisioned through the integration of advanced technologies such as automation and artificial intelligence. However, the disruptive potential of this pathway demands extensive *release* and *reorganization* across multiple scales, from revising regulatory frameworks (e.g., safety standards for automated construction equipment) to terminating established commercial construction projects and restructuring the labor market. Ultimately, the main barrier lies not in technological capacity but in the fear of destabilizing the entrenched networks. Reducing this fear could also faciliate the adoption of more diverse solutions, such as battery-swapping—the focus of the niche technology-driven scenario (*Inescapable Scepticism*). This scenario begins with the mobilization of new resource ties and actor bonds at smaller scales, which may eventually reshape broader business networks by enabling new business models (e.g., battery-sharing, on-site energy management platforms) and fostering cross-project, cross-site, or even cross-sector partnerships. Yet, despite their practicality and visibility, niche technologies facing persistent resistence tend to follow conservative trajectories rather than scaling up independently. This dynamic ultimately feeds back into the normative, policy-driven pathway—*No Surprises Ahead?*—where new actors eventually join or 'surrender' to reinforce existing networks: *"It is natural that one actor moves first. Status quo is strong and if nobody moves first the industry will be stagnant, but of course one leader needs to have a bunch of fast followers. It is also possible that because of all the new technology completely new value constellations will occur that will break the traditional paradigm with strong incumbents. Nevertheless, regulated markets will always have friendship corruption so it is most likely that this will continue but the giants will accept and include more of the young entrepreneurial firms as partners" (E2).*

The awareness of alternative scenarios is significant, as it invites critical reflection on what is often taken for granted in sustainability transitions—*questioning who defines the boundaries of possibility, whose interests are centered, whose fears or ambitions are amplified, and which forms of change are rendered invisible.* The diverse perceptions and pathways demonstrates that there is no single route toward sustainability; rather, multiple trajectories can coexist and interact, each reflecting different priorities, resources, and temporalities. This plurality of visions can be seen not as fragmentation but as a sign of vitality—a proof of ongoing reflection, negotiation, and experimentation among actors seeking to promote the transition. It represents a necessary stage leading to decisive actions and responsibility-taking, where actors test ideas, confront uncertainties, and gradually align around shared directions. While the paths may differ in pace and emphasis, their convergence toward the common goal of sustainability is promising—an infinite (∞) process symbolized by the adaptive cycle.

5.3 Ride the Adaptive Cycle

As shown in Figure 5.1, each scenario represents a moment within the adaptive cycle, where effective management requires attunement to its rhythm—recognizing when resilience is waning and when renewal becomes possible. Here, resilience is not about preserving stability, but about sustaining a shared sense of purpose and direction through the change. The four phases—growth, conservation, release, and reorganization—illustrate recurring dynamics of change that demand ongoing resource mobilization and actor bonding across scales. To ride the adaptive cycle is to cultivate adaptive capacity—the wisdom to discern when to hold on and when to let go; to sense when networks become overconnected, to allow for necessary release, and to nurture renewal through experimentation, learning, and cross-scale linkages. In this sense, the management of transitions is less about control and more about reaction through impermanence, acknowledging that every phase, whether expansion or collapse, will eventually pass. This understanding resonates with Wieland's (2021, p.69) notion of "Managing In, Through, Out, Up, and Beyond", which calls for the collective wisdom and reflexivity of construction business networks to navigate the transition:

- "Managing In" calls for actors to identify their positions and roles within evolving business networks, understanding how actors, resources and activities connect and influence one another: *"At this stage, we are trying things in collaboration projects, there are different actors who are either new or changing offerings that they are presenting. They're also sort of finding their roles: am I going to be a direct supplier to a main contractor or am I going to supply my solutions to a subcontractor?" (R5). "While I think regulations could eventually be put in place, it's important that companies feel policy stability, so that regulations don't shift every four years with changes in government" (E16).*
- "Managing Through" involves embracing disruptions as opportunities for learning and creativity rather than seeking immediate fixes: *"There is a huge operation efficiency waste that we can take away. The electric machines added to the management system can be much more efficient than one with a combustion engine. It becomes even more interesting for us to use and that's why we tested this solution of autonomous electrified equipment. I would say that you need to look at it from different angles" (R9). "Utilize the full benefit and connectivity, automation and electrification as well as redesigning processes to get the job done, then the industry will reach the desired productivity, predictability and sustainability targets that are desirable. This needs to be a stepwise approach, but it can't be an approach where incumbents get the power to slow legislation down for their profitability's sake"(E2).*
- "Managing Out" emphasizes the importance of engaging with external networks: *"When we approached suppliers, as far as they tell us, we are the only one doing this (aggregating knowledge of electrification), now in Sweden at least. I have the same opinion, and they also appreciate that we take these meetings, have all these questions, and want to accelerate the change of the market"(R10). "Although there are efforts for international collaboration, achieving a unified global standard takes time and is challenging. Differences in local construction regulations, regional capabilities,*

financial conditions, and cultural factors make it difficult to implement. As a result, the impact would be moderate and limited for now. However, having an international unified standard remains highly desirable" (E16).

- "Managing Up" encourages alignment with larger-scale resource ties and actor bonds: *"A knowledge maturing that needs to be done to make all actors in the industry realize how they need to shift their operation model, we are doing it, but we could improve" (R3). "I think that Sweden is a very small market. If you look at the whole machinery market in the world, we can't be alone in Sweden to have these incentives and drive the market. What's needed is more on the EU level" (R8).*
- "Managing Beyond" invites reflexivity—actors continually reassessing their own values, priorities, and power positions to balance competing interests and link short-term local actions to long-term shared sustainability goals: *"We use the electrical vehicles to transport the last mile delivery, that's good! But do you see the risks? it is somewhat of a green wash, for the long term, we transport machines and materials on the road that need more effort or charging stations. Installing charging infrastructure on the logistic hub probably will be an intermediate solution, in the long term we need to look at all the logistics" (R10). "So far most of companies are looking into how they can solve their charging issues. The problem is, for example, where we have these big logistics hubs, it will be the ones who apply it first to get the capacity. Then after a while, there will be no more capacities. The ones who have not been fast enough will not get anything; this might not be the most optimal way" (R18).*

6. Future Study and Implication

The thesis is limited by its focus on the Swedish construction context and the early stages of electrification. Future study aims to move beyond describing the transition toward navigating it. Building on insights from the previous two papers, the proposed framework—Adaptive Construction Business Network toward Electrification—raises new questions: *Can the transition be modeled and simulated? If so, which methodology is appropriate? Which historic data could be useful?* Preliminary desktop research points to agent-based modeling (ABM) as a promising approach. Widely used in economics and social sciences, ABM allows simulation of complex systems beyond the limits of observed data, enabling experimentation with scenarios that may be unfeasible in real life. This method is particularly valuable for exploring how individual decisions shape collective system behavior. Following this thread, the distribution of resource level among actors could be a key indicator for assessing the maturity and fairness of the transition, an issue of growing relevance in global sustainability research.

By simulating the transition, different actors can gain a clearer understanding of the necessary resource ties, actor bonds, activity links and tipping points within alternative future scenarios. The expected findings can effectively inform policymakers, construction companies, OEMs, and other stakeholders in their decision-making and investment planning for electrification. For instance, the number of electric construction equipment required, the level of incentives needed, and the electricity capacity to be allocated to achieve a targeted level of resource distribution among a certain proportion of actors within a specific area and time frame. Although the study focuses on the electrification of the Swedish construction sector, the findings are expected to contribute more broadly to understanding how business networks adapt to sustainability transitions, including other sectors undergoing electrification without a dominant actor, such as logistics and last-mile delivery.

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