Shared Charging Infrastructure in Collaborative Electrification Hubs (CEHs)

Governance, Cost Allocation, and Operational Viability

Master’s thesis in Supply Chain Management

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Abstract

The European road freight sector is transitioning to battery electric vehicles due to stringent decarbonization mandates. However, this transition is hindered by severe physical constraints in the energy grid, rendering individual high-capacity charging connections unfeasible for many logistics service providers (LSPs). Consequently, the industry is gravitating towards Collaborative Electrification Hubs (CEHs). While CEHs resolve grid bottlenecks by aggregating demand, they introduce complex micro-level tensions regarding operational coordination, trust, and equitable cost allocation, particularly under volatile peak-based power tariffs. The central problem is the lack of established organizational models to govern these interdependent actors sharing a finite resource.

This study employs a qualitative, multi-method approach to explore the organizational dynamics of shared charging infrastructure. The methodology integrates a Semi-systematic Literature Review (SSLR) focusing on logistics governance and electric vehicle infrastructure, complemented by semi-structured expert interviews with key stakeholders across academic, independent operational, and procurement domains. The analysis is grounded in a dual-theoretical framework: Resource Dependence Theory (RDT) explains the formation of hubs as bridging strategies to manage resource scarcity, while Game Theory assesses the strategic stability and fairness of cost-allocation mechanisms.

The research proposes a "Three-Level Model of Systemic Interdependence" to illustrate how macro-level grid constraints force meso-level organizational clustering, which in turn generates micro-level operational friction. Preliminary findings suggest that without robust governance mechanisms and neutral orchestrators to enforce fair cost allocation and operational rules, CEHs are susceptible to free-riding and systemic instability. Ultimately, this thesis provides a theoretical and practical framework for designing governance structures that ensure fair access, mitigate operational uncertainty, and lower the Total Cost of Ownership (TCO) for logistics operators navigating the electrification transition.

Keywords: Shared Charging Infrastructure, Electric Freight Vehicles, Logistics Governance, Cost Allocation

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Thank you all.

Nahom Gebregiorgis Gebregziabher & Giuseppe Pellicanò, Gothenburg, June 2025

List of abbreviations

Abbreviation	Meaning
AFIR	Alternative Fuels Infrastructure Regulation
B2B	Business-to-Business
CaaS	Charging-as-a-Service
CAPEX	Capital Expenditure
CEHs	Collaborative Electrification Hubs
CPO	Charge Point Operator
CPP	Critical Peak Pricing
CSC	Charging Station Coverage
DC	Direct Current
DSOs	Distribution System Operators
Ei	Swedish Energy Markets Inspectorate (Energimarknadsinspektionen)
ENTSO-E	European Network of Transmission System Operators for Electricity
ERS	Electric Road Systems
EVs	Electric Vehicles
GDPR	General Data Protection Regulation
HDV	Heavy-Duty Vehicle
HOS	Hours-of-Service
IaaS	Infrastructure-as-a-Service
ICEVs	Internal Combustion Engine Vehicles
IEA	International Energy Agency

kW	Kilowatt
kWh	Kilowatt-hour
LSPs	Logistics Service Providers
MCS	Megawatt Charging System
MW	Megawatt
MWh	Megawatt-hour
PoA	Price of Anarchy
RDT	Resource Dependence Theory
SIM	Systemic Interdependence Model
SLA	Service Level Agreement
SMEs	Small and Medium-sized Enterprises
SoC	State-of-Charge
SSLR	Semi-systematic Literature Review
TCO	Total Cost of Ownership
TEN-T	Trans-European Transport Network
ToU	Time-of-Use
TSOs	Transmission System Operators
TU	Transferable-Utility
V2I	Vehicle-to-Infrastructure

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1. Introduction

This chapter establishes the foundational context for investigating the systemic electrification of the European road freight sector. It begins by outlining the tension between rapid, policy-driven vehicle adoption and existing grid constraints. Subsequently, it formulates the core problem: the emerging "synchronization risk" and the resulting imperative for Collaborative Electrification Hubs (CEHs). The chapter then defines the research purpose, objectives, and questions guiding the analysis of shared infrastructure governance, concluding with the study's scope and delimitations regarding high-power stationary charging.

1.1 Background to the Study

The electrification of the European road freight sector represents a systemic reconfiguration of logistics operations, driven by a rigid interplay between macro-level policy mandates, meso-level infrastructure scarcity, and micro-level operational interdependence. This transition is primarily anchored by the European Union's "Fit for 55" framework and the Alternative Fuels Infrastructure Regulation (AFIR), which impose a stringent timeline for the transition from internal combustion engine vehicles (ICEVs) to battery electric vehicles (EVs) (European Union, 2023). Under Regulation (EU) 2023/1804, the mandates for heavy-duty vehicle (HDV) infrastructure follow a progressive deployment timeline: by the end of 2025, at least 15% of the TEN-T (Trans-European Transport Network) road network length must be equipped with charging pools of at least 1400 kW, including at least one 350 kW charger in each direction of travel. This coverage is mandated to expand to the entire network by 2030, ensuring that charging pools with a total power output of at least 3600 kW (Core) and 1500 kW (Comprehensive) are situated at maximum distances of 60 km and 100 km respectively, with individual charging points providing at least 350 kW (European Union, 2023). The specific progression and technical requirements of this deployment timeline are summarized in Table 1.

Timeline	Network Scope	Max Distance Between Pools	Min. Pool Power Output	Min. Individual Point Power
End of 2025	TEN-T Network (At least 15% length)	N/A	1400 kW	350 kW

End of 2030	TEN-T Core Network (100% length)	60 km	3600 kW	350 kW
End of 2030	TEN-T Comprehensive Network (100% length)	100 km	1500 kW	350 kW

Table 1: Mandatory deployment timeline and power requirements for HDV charging infrastructure under Regulation (EU) 2023/1804.

However, this regulatory momentum faces a significant clash between the rapid pace of electric vehicle deployment and the physical constraints of the energy grid. On the demand side, the value proposition for electric trucks is improving, even for long-haul operations (International Energy Agency [IEA], 2025). Global electric truck sales grew by nearly 80% in 2024, and in Europe, sales exceeded 10,000 units for the second consecutive year despite a lack of substantial subsidies in several major markets (IEA, 2025). Furthermore, it is projected that under current stated policies, the share of electric medium- and heavy-duty trucks in the European Union will reach approximately 25% by 2030 (IEA, 2025).

Conversely, the infrastructure required to support these growing fleets faces severe temporal and physical bottlenecks. The lead times for energizing megawatt-scale charging sites, which are essential to minimize disruptions to regular operations and accommodate mandated driver rest periods, often far exceed the pace of vehicle deployment (IEA, 2024). This creates a "synchronization risk" where the pace of vehicle adoption outstrips the rate at which sites can be energized, transforming grid capacity from a ubiquitous utility into a scarce, strategic resource (IEA, 2024).

Grid reinforcements are often required to enable ultra-fast and megawatt charging, which imposes massive loads on the existing infrastructure (IEA, 2025). As noted by the European Network of Transmission System Operators for Electricity (ENTSO-E), physical capacity cannot be increased beyond security limits without extensive investments in grid expansion and cross-border connections, which operate on significantly longer time frames than market-driven vehicle procurement (ENTSO-E, 2025). Furthermore, grid upgrades at depots can take from one to several years depending on the required voltage, necessitating anticipatory planning that the current market structure lacks (IEA, 2025). This physical scarcity necessitates a meso-level reorganization of the logistics sector, driving the system toward collaborative and shared infrastructure models to manage the collective load on a constrained grid (IEA, 2024, 2025).

1.2 Problem Formulation

The transition toward HDV electrification has introduced a critical "synchronization risk" for LSPs and hauliers, creating a systemic bottleneck that threatens the viability of the freight sector's decarbonization. This risk manifests as a circular dependency where operators cannot deploy electric fleets without a robust charging infrastructure, yet they cannot justify the substantial capital expenditure (CAPEX) required for private infrastructure without guaranteed high utilization rates (McKinsey, 2024). This dilemma is intensified by a severe temporal misalignment, as the lead times for energizing megawatt-scale charging sites, which often span several years, far exceed the rapid pace of vehicle deployment (IEA, 2024).

Individual Logistics Service Providers (LSPs), particularly small and medium-sized enterprises (SMEs), frequently lack the necessary capital and grid access to secure private, high-capacity connections. The financial barrier is significant, with Megawatt Charging System (MCS) infrastructure costs estimated between $0.8 and $1.2 million per megawatt (Bommenahalli & Chandran, 2025). Consequently, the system naturally gravitates toward CEHs, where demand aggregation allows actors to justify the capitalization of high-power connections that are unattainable individually. This systemic shift from individual investment to collective aggregation, necessitated by the temporal misalignment between vehicle procurement and grid capacity, is illustrated in Figure 1.

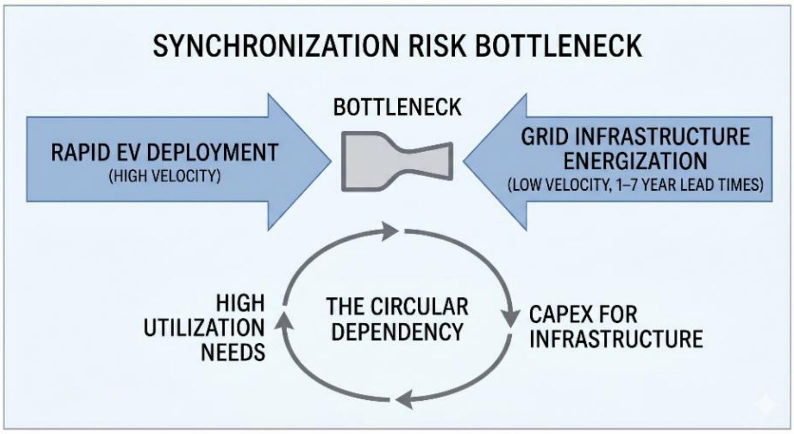


Figure 1: Conceptual model of the 'synchronization risk' and the resulting transition toward CEHs.

The central problem addressed in this study is the misalignment between the economic necessity of shared infrastructure and the lack of established governance models to support it. While technical and empirical research confirms that shared hubs are cost-efficient (Otero-Palencia et al., 2026), with some models estimating a reduction in the Total Cost of

Ownership (TCO) by 20% to 30% (Bommenahalli & Chandran, 2025), there is a limited understanding of the organizational frameworks required to manage co-located, interdependent operators.

Unlike the traditional "diesel paradigm" characterized by autonomous access and operational independence, the electric model requires coordinated replenishment within a finite energy ecosystem. In a CEH configuration, one actor's charging behaviour directly impacts the cost exposure and operational uptime of another. This interdependence creates significant “operational uncertainty”, risking severe system inefficiencies if independent actors optimize their routing and charging without broader coordination. Furthermore, without robust governance to manage multidimensional electricity pricing and peak power tariffs, these shared systems are highly susceptible to non-cooperative behaviours (Xu et al., 2024).

1.3 Purpose and Objectives

The primary objective of this thesis is to investigate and analyse collaborative configurations for shared charging infrastructure within CEHs. This research specifically aims to identify the governance models, cost-allocation mechanisms, and operational strategies required to enable distinct, interdependent logistics actors to share critical energy assets effectively. By addressing the governance of interdependence, this study seeks to demonstrate how shared hubs can serve as a viable organizational response to reduce the TCO for individual firms while simultaneously mitigating macro-level grid bottlenecks through demand aggregation and optimized capacity utilization.

To fulfil this purpose, the following specific research objectives have been defined:

- Typology of Sharing: To categorize the diverse types of shared infrastructure configurations currently emerging in the freight sector, such as semi-public hubs, joint venture depots, and third-party "Infrastructure-as-a-Service" (IaaS) models.
- Mechanism Analysis: To investigate practical mechanisms for cost allocation, including subscription-based versus pay-per-use models and the application of equitable, contribution-based frameworks, and operational coordination tools, such as dynamic booking systems and priority scheduling, used to manage shared assets.
- Barriers and Enablers: To identify the primary economic, organizational, and physical barriers hindering collaborative charging efforts and evaluate the specific enablers,

such as neutral third-party orchestrators or digital platforms, that facilitate collective action and overcome trust deficits among competitors.

1.4 Research Questions

To address the identified misalignment between the economic necessity of shared infrastructure and the current lack of established organizational frameworks to support co-located operators, this thesis investigates the governance and stability of CEHs. The following research questions are formulated to guide the inquiry into how these meso-level configurations can be sustained against competitive self-interest and operational uncertainty:

RQ1: *What governance models and sharing configurations are emerging for heavy-duty charging infrastructure in CEHs?*

RQ2: *How can cost and capacity allocation mechanisms be designed to ensure fairness and high utilization among users of shared infrastructure?*

RQ3: *What are the critical organizational and operational challenges hindering the scalability of these collaborative models?*

1.5 Scope and Delimitations

This research is delimited by specific geographical, technological, and methodological parameters to ensure a focused and rigorous analysis of the governance of interdependence within CEHs.

Geographically, the study is centred on the European context, with a primary analytical focus on Sweden. The Swedish landscape provides a critical case for study due to its acute grid connection challenges and the mandatory implementation of power tariffs, which serve as immediate drivers for collaborative organizational responses. While reference is made to centralized models in other markets, such as China, to provide a comparative perspective, the findings and managerial frameworks developed are intended to be applicable within the European regulatory and competitive environment. Technologically, the scope is restricted to high-power direct current (DC) charging infrastructure intended for shared depot and hub charging. This specific focus addresses the "synchronization risk" associated with megawatt-scale stationary charging, which currently represents the most significant infrastructure bottleneck for LSPs. By narrowing the focus to stationary charging, the research can deeply investigate the specific temporal and physical constraints of the local energy grid.

Consequently, this study explicitly excludes electric road systems (ERS) and hydrogen infrastructure. These alternatives are delimited because they involve fundamentally different regulatory regimes, investment models, and technical requirements that do not align with the study's core objective of analysing co-located operational coordination and shared grid capacity. ERS and hydrogen solutions operate on different development timelines and lack the specific meso-level operational interdependence found in co-located charging hubs.

Methodologically, the research is delimited to the exploration of organizational models and qualitative descriptions of governance and cost-allocation mechanisms. Due to the proprietary and restricted nature of commercial contracts in the private freight sector, this study does not include quantitative financial modelling or the analysis of precise commercial cost data. Instead, the research addresses the organizational stability of these collaborative configurations through a dual-layered qualitative approach, relying specifically on a Semi-systematic Literature Review (SSLR) and targeted semi-structured expert interviews. For clarity, the specific boundaries of this research across geographical, technological, and methodological dimensions are synthesized in Table 2.

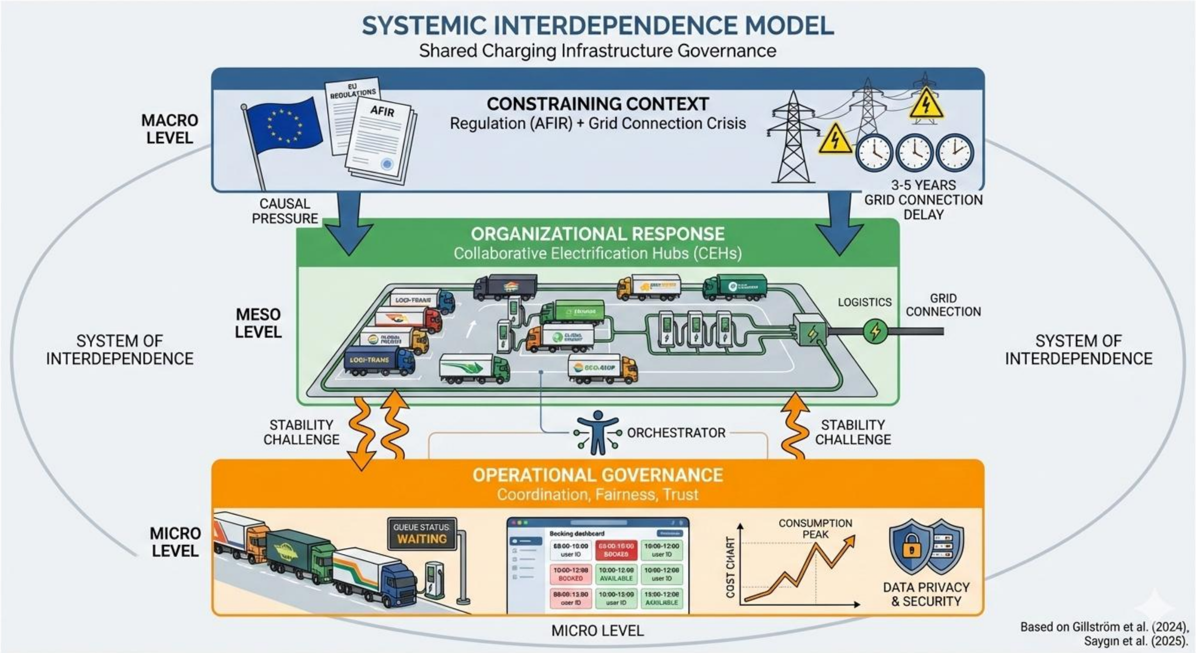
Parameter	In Scope	Out of Scope (Delimitations)
Geography	Europe (Primary analytical focus on Sweden)	Non-European markets (China used only for comparative reference)
Technology	High-power DC stationary charging for shared depots/hubs	ERS and Hydrogen infrastructure
Methodology	Qualitative exploration of governance frameworks utilizing a SSLR and semi-structured expert interviews.	Quantitative financial modelling and precise commercial cost data analysis

Table 2: Summary of research scope and explicit delimitations.

To comprehensively understand and resolve these challenges of governance and operational interdependence, this study will utilize Resource Dependence Theory (RDT) and Game Theory, which serve as the primary analytical frameworks explored in the following chapter.

2. Literature Review

This chapter analyses the existing academic and technical literature surrounding the charging aspects of electrification of heavy-duty road freight. It navigates from the macro-level grid constraints imposing structural changes on the logistics sector, through the meso-level emergence of shared charging hubs, to the micro-level operational and game-theoretic challenges of multi-actor coordination. The hierarchical nature of these challenges, ranging from grid constraints to operational coordination, is synthesized in the Systemic Interdependence Model (SIM) presented in Figure 2.



Based on Gillström et al. (2024), Saygın et al. (2025).

Figure 2: SIM: Mapping the relationship between Macro-level grid constraints, Meso-level infrastructure, and Micro-level actor coordination.

2.1 Macro Context: Grid Scarcity and Electrification Mandates

Building upon the foundational clash between decarbonization mandates and infrastructure lead times, this section evaluates the regulatory depth and economic mechanisms that transform grid capacity from a utility into a strategic constraint. While Regulation (EU) 2023/1804 (AFIR) sets the pace for deployment, the actual operational viability of HDV electrification is governed by the physical security limits of the transmission system and the evolving design of network tariffs (European Union, 2023; ENTSO-E, 2025). This section establishes the macro-environmental constraints that mandate a paradigm shift in heavy-duty logistics. By examining the physical limits of transmission networks alongside international decarbonization mandates, it explores how energy grid scarcity transitions from a utility concern to a strategic barrier for the logistics sector. The subsequent analysis unpacks the institutional and regulatory pressures that force the industry away from operational autonomy.

2.1.1 Physical Limits and Transmission Constraints

Academic and technical consensus highlights that physical grid capacity cannot be increased beyond established security limits without substantial, long-term capital investments (ENTSO-E, 2025). As the European economy electrifies, transmission system operators (TSOs) face a persistent operational challenge where available capacity cross-zonal and local capacity is increasingly limited by operational security margins (ENTSO-E, 2025). Because grid expansion operates on significantly longer time frames than the market-driven procurement of electric trucks, the logistics sector is entering a period of prolonged infrastructure scarcity (IEA, 2024; ENTSO-E, 2025). This physical scarcity is not merely a technical limitation but is profoundly exacerbated by macro-institutional inertia. Scherrer et al. (2026) emphasize that the deployment of large-scale, cross-border charging networks is frequently stalled by a systemic lack of transnational governmental coordination. The prevailing European policy preference for 'technology-open', market-driven solutions fundamentally conflict with the need for centralized, long-term planning security, thereby reinforcing the structural barriers to seamless fleet electrification (Scherrer et al., 2026). This scarcity dictates a shift in perspective: grid efficiency is no longer merely a technical objective for utilities, but a prerequisite for a cost-efficient energy transition (Robles et al., 2025).

2.1.2 The Swedish Regulatory Shift: EIFS 2022:1 and Power Tariffs

The economic landscape for HDV electrification in Sweden is currently being reshaped by the Swedish Energy Markets Inspectorate (Ei) through regulation EIFS 2022:1 (Ei, 2022; Robles et al., 2025). This domestic regulation is not an isolated initiative, but rather a direct implementation of a broader, EU-wide regulatory shift concerning electricity market design. Driven by the mandates of the EU Electricity Directive (Directive (EU) 2019/944) and guided by the European Union Agency for the Cooperation of Energy Regulators (ACER), European regulatory frameworks increasingly require that network tariffs be cost-reflective, capacity-based, and temporally dynamic to incentivize grid flexibility and manage emerging congestion (European Parliament & Council of the European Union, 2019; ACER, 2021). In strict alignment with these supranational objectives, EIFS 2022:1 mandates that all Swedish system operators implement a new network tariff design no later than January 1, 2027, with the specific intent of promoting efficient grid utilization (Robles et al., 2025).

A central pillar of this mandate is the transition toward power tariffs (*effekttariffer*). Unlike the traditional model, wherein variable costs were primarily energy-based (SEK/kWh), this regulatory shift introduces a multidimensional four-component pricing model. Under this new structure, costs are allocated to: (i) variable energy fees, (ii) forward-looking power fees, (iii) customer-specific fees, and (iv) cost-recovery fees (Robles et al., 2025). The technical breakdown of these four components and their respective strategic implications for logistics operators are summarized in Table 3.

Component	Description	Strategic Implication
Variable Energy Fee	A cost based on the total volume of energy consumed (SEK/kWh).	Represents the traditional operational cost metric, which is no longer the sole economic driver.
Forward-Looking Power Fee	A capacity charge (SEK/kW) based on the highest peak power drawn during dimensioning hours.	Penalizes uncoordinated consumption and incentivizes users to flatten load profiles to prevent future grid investments.
Customer-Specific Fee	A fixed or tailored fee allocated directly to the individual customer profile.	Ensures base administrative or connection costs are covered regardless of variable usage.
Cost-Recovery Fee	A fee designed to cover broader systemic or maintenance costs.	Contributes to the overall upkeep of the transitionary infrastructure.

Table 3: Components of the EIFS 2022:1 Power Tariff Model and their strategic implications for energy consumption.

The cornerstone of this framework is the mandatory forward-looking power fee (SEK/kW), which is designed to signal the long-term marginal costs that a customer's current consumption behaviour imposes on the grid's future capacity needs (Robles et al., 2025). By pricing the highest peak power drawn during dimensioning hours, administered through either Critical Peak Pricing (CPP) or Time-of-Use (ToU) methodologies, the tariff structure effectively penalizes uncoordinated electricity consumption. Consequently, the regulation incentivizes users to flatten their load profiles and adapt their behaviour, thereby mitigating the need for extensive future grid investments (Robles et al., 2025; Svenska Kraftnät, 2025).

2.1.3 Economic Drivers of Organizational Change

The introduction of multidimensional power tariffs, particularly under the Swedish EIFS 2022:1 regulation, serves as the primary transmission mechanism between macro-level grid constraints and meso-level organizational change. Under the power tariff regime, uncoordinated charging behaviour carries a severe financial penalty, as power use during a dimensioning peak load hour can disproportionately inflate the capacity charge (Robles et al., 2025). Consequently, the traditional "diesel model" of autonomous, uncoordinated fuelling becomes economically unsustainable for individual LSPs.

The literature suggests that these forward-looking price signals effectively force a reorganization of the sector (IEA, 2024; Robles et al., 2025). To avoid the high costs of individual peak loads, firms must transition toward collaborative configurations that aggregate demand and coordinate replenishment. In this context, the formation of shared charging configurations, such as CEHs, is not merely a response to physical grid connection delays, but a strategic necessity to manage collective cost exposure within a network environment that increasingly penalizes operational independence (Robles et al., 2025).

2.2 Meso Responses: Typologies of Shared Hubs

Transitioning to the meso-level, this section investigates the organizational responses to grid scarcity, specifically focusing on the categorization of shared infrastructure hubs. It outlines the strategic evolution from carrier-driven ownership to provider-driven Charging-as-a-Service (CaaS) models. Through this lens, the discussion introduces the indispensable role of network orchestrators in balancing collective grid efficiency with persistent market competition.

2.2.1 Categorization of Shared Infrastructure Configurations

Shared charging infrastructure can be categorized based on its accessibility and operational intent. Literature identifies three primary archetypes:

- Private Charging: Restricted to a single operator, typically located at a terminal or depot to ensure maximum control over availability (Link & Plötz, 2022; Gillström et al., 2024).
- Semi-Public Hubs: Function as shared infrastructure designed for depot-style charging but restricted to a specific consortium or group of participating stakeholders (Gillström et al., 2024). This model often emerges at destination sites where shippers install chargers to enable their contracted LSPs to transition to EVs while maintaining priority access (Dahlgren & Ammenberg, 2022; Gillström et al., 2024). These collaborative configurations can be formalized into 'green horizontal networks,' which serve as strategic mechanisms to mitigate prohibitive CAPEX. Melander and Wallström (2023) identify that such models enable early-adopter carriers to monetize their proprietary, underutilized infrastructure during daytime idle hours, or to mitigate risk by co-investing in shared facilities anchored to specific spatial opportunities, thereby accelerating the broader transition to electric freight (Melander & Wallström, 2023).
- Public Charging: Open-access sites, typically situated along the road network or at multi-user truck stops, designed to support en-route replenishment (Karlsson et al., 2025; Gillström et al., 2024).

Archetype	Accessibility & Control	Typical Location & Purpose	Strategic Dynamics
Private Charging	Restricted to a single operator.	Terminals or depots for maximum control over availability.	High CAPEX; enables autonomy but lacks scale benefits.
Semi-Public Hubs	Restricted to a specific consortium, participating stakeholders, or contracted LSPs.	Destination sites or strategic spatial locations; often formalized as 'green horizontal networks'.	Mitigates CAPEX; allows early adopters to monetize underutilized idle hours.
Public Charging	Open-access sites for any market participant.	Along road networks or multi-user truck stops for en-route replenishment.	Subject to high competition, variable queuing times, and dynamic pricing models.

Table 4: Comparative analysis of Private, Semi-Public, and Public Charging infrastructure archetypes.

2.2.2 Strategic Roles: IaaS and Neutral Orchestrators

The complexity of managing shared energy assets has given rise to the IaaS model, where third-party providers or landlords assume the capital risk and operational burden of the charging site (MOVE21 Consortium, 2024). Within these configurations, the role of the Charge Point Operator (CPO) has evolved into five distinct strategic archetypes: gatekeeper, accessory provider, contributor, facilitator, and orchestrator (Gillström et al., 2024).

The orchestrator is particularly critical for managing shared infrastructure. Unlike a simple service provider, a neutral orchestrator manages the tension between the algorithmic ideal of grid efficiency and the human reality of market competition (MOVE21 Consortium, 2024; Gillström et al., 2024). To effectively bridge this gap, the orchestrator's function must evolve beyond operational coordination into a role of 'stewardship.' Dessaigne and Pardo (2020) argue that the true value of a network orchestrator lies in actively strengthening shared behavioural norms and institutionalizing trust among competitors. This relational governance ensures that users do not simply react defensively to variable pricing, but proactively engage in value co-creation, thereby stabilizing the hub's long-term collaborative dynamics (Dessaigne & Pardo, 2020). By acting as a third-party intermediary, the orchestrator can manage sensitive operational data, such as real-time vehicle state-of-charge (SoC) and route schedules, needed for coordinated charging without forcing competitors to expose strategic data directly to one another (MOVE21 Consortium, 2024).

2.2.3 Market Dynamics and CPO Competition

Recent findings from agent-based modelling highlight how the geographical spread of CPOs and the behavioural sensitivity of hauliers dictate the stability of these hubs. In a competitive market where CPOs are geographically distributed across a network as per regulatory mandates, the price structure for fast charging tends to become more even throughout the day compared to single-site competition (Karlsson et al., 2025). CPOs adjust both charging prices and the number of physical chargers iteratively to maximize profit, reaching a quasi-equilibrium where high utilization and low queuing are simultaneously achievable (Karlsson & Grauers, 2024; Karlsson et al., 2025).

The behavioural response of haulage companies to these pricing signals significantly influences this equilibrium, demonstrating a fundamental trade-off between price and queuing time. If hauliers are primarily price-sensitive, the competitive market gravitates toward a lower baseline charging price. However, this results in a system with fewer chargers, increased synchronization risk, and frequent, severe queuing problems (Karlsson et al., 2025). In contrast, if hauliers are queue-sensitive, they demonstrate a willingness to pay higher prices to guarantee availability. This enables CPOs to profitably build more chargers to meet peak demand, resulting in a stable system with near-zero queuing and a correspondingly higher mean charging price (Karlsson et al., 2025). This inverse relationship between infrastructure investment, charging price, and queuing probability is visualized in the trade-off curve shown in Figure 3.

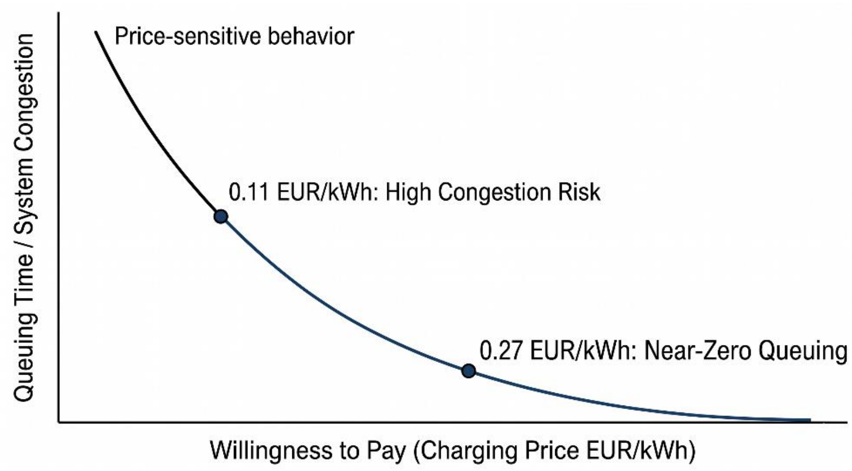


Figure 3: Theoretical equilibrium between charging prices and queuing times in CPO business models.

This suggests that for shared configurations to remain stable and operationally viable, governance must facilitate energy utilization, transitioning from moderate utilization thresholds for geographically spread networks to significantly higher thresholds for isolated sites, while ensuring users accept premium prices that reflect the cost of providing necessary redundancy.

2.3 Micro Challenges: Operational Uncertainty and Coordination

This section drills down into the micro-level operational challenges of shared charging configurations, emphasizing the friction between individual logistics schedules and finite energy capacities. It analyses the 'Price of Anarchy' (PoA) and the systemic risks of uncoordinated behaviour, highlighting the limitations of relying purely on dynamic pricing mechanisms. Consequently, the discussion underscores the necessity of algorithmic integration and deep behavioural coordination to prevent systemic failure.

2.3.1 Temporal Dependencies and the PoA

The central challenge in these shared systems is the management of "operational uncertainty," specifically regarding temporal dependencies. Because charging is inextricably linked to parking, an idle truck blocking a charger creates a physical bottleneck that pricing mechanisms alone may struggle to resolve (Tan & Kang, 2026). Addressing this physical bottleneck necessitates advanced mathematical integration across multiple planning horizons. Zhou et al. (2026) mathematically validate that implementing an integrated hierarchical framework, one that simultaneously optimizes spatial layout design, medium-term resource allocation, and real-time scheduling, is critical for overcoming these rigid constraints. Their findings demonstrate that such vertical integration can drastically reduce systemic queuing and overall energy costs, providing a necessary technical foundation for efficient hub operations (Zhou et al., 2026). This operational friction is quantified through the PoA, which measures the efficiency loss occurring when independent logistics operators optimize their own charging and routing schedules without coordinating for the collective system optimum (Sasahara et al., 2025).

In a "green routing game," operators face a constant trade-off between the delayed delivery costs caused by congestion at shared charging stations and the environmental costs of alternative fuelling (Sasahara et al., 2025). Research indicates that uncertain waiting times at congestible public or shared stations are a primary factor in the final operational cost of long-haul freight (Sasahara et al., 2025). Without robust governance, these systems are susceptible to high PoA, where selfish optimization leads to systemic queuing and underutilization of expensive megawatt-scale assets.

2.3.2 The Helsingborg-Stockholm Case: Queues and Utilization

The micro-level coordination challenge is illustrated by agent-based modelling of a primary national highway corridor (Karlsson & Grauers, 2023). The study reveals that the behaviour of individual drivers significantly dictates system-level efficiency. When trucks are programmed to be 'unconcerned' with queues, both maximum and average queuing times increase substantially (Karlsson & Grauers, 2023). Conversely, a driver’s reluctance to queue acts as a self-regulating mechanism that improves the overall system solution, potentially reducing the need for rigid booking systems (Karlsson & Grauers, 2023).

2.3.3 Limits of Pricing and Local Optimization

Furthermore, micro-level coordination cannot always be resolved through simple variable pricing. Simulations of extensive line-haul routes show that while increasing prices during a 'rush hour' spike can reduce the queue at one specific station, it often merely shifts the bottleneck to a subsequent station, sometimes worsening the maximum queuing time for the system as a whole (Karlsson & Grauers, 2023).

This suggests that resolving operational uncertainty requires moving beyond independent local optimization toward meso-level governance. While algorithmic coordination can theoretically reduce wait times by over 46% (Bai et al., 2025), such efficiency relies on high levels of data transparency, data that private entities are often hesitant to share. This data-sharing hesitancy exposes the severe organizational friction inherent in joint operations, often leading to a 'tragedy of the facilitated commons.' Sternberg et al. (2022) empirically demonstrate that horizontal logistics collaborations systematically fail because transport actors perceive the disclosure of strategic routing and cost data as a critical moral hazard. Consequently, a fundamental lack of goal congruence and the pervasive fear of violating anti-competition laws cause firms to decouple from shared projects, neutralizing the mathematical benefits of collaborative infrastructure (Sternberg et al., 2022). For this reason, the stability of these shared hubs depends on the ability of a neutral orchestrator to enforce 'rules of the game' that manage these micro-level frictions without compromising the strategic autonomy of the participants (Gillström et al., 2024). The theoretical viability of such rules relies heavily on the 'shadow of the future' within repeated interactions. Drawing upon the seminal game-theoretic insights of Axelrod and Hamilton (1981), the stability of these cooperative configurations can spontaneously emerge if transport actors recognize that short-term defection will be penalized in future encounters. Within the CEH, this iteration transforms sporadic charging events into a continuous relationship, structurally incentivizing competing LSPs to abandon selfish optimization in favour of sustained collaborative efficiency (Axelrod & Hamilton, 1981).

2.4 Cost Allocation and Power Tariffs

Building upon the operational constraints, this section evaluates the financial mechanisms required to sustain shared charging hubs. It details the transition toward multi-dimensional cost allocation models, which penalize uncoordinated peaks and reward collective load flattening. Ultimately, it illustrates how equitable power tariff management is fundamental to ensuring long-term individual rationality and group stability within the coalition.

2.4.1 Utilization Factors and Cost-Effectiveness

The cost-effectiveness of shared infrastructure is highly sensitive to the charger utilization factor. Because the costs of grid connection and hardware are fixed and significant, the normalized cost per delivered kWh drops precipitously as utilization increases (Karlsson & Grauers, 2023). To contextualize the scale of this infrastructure, agent-based modelling estimates that achieving full electrification of a long-haul fleet requires a dense network of high-capacity chargers to maintain a robust system with minimal queuing (Karlsson & Grauers, 2023). Under this configuration, the realistic system charger utilization factor must reach a critical operational threshold. However, as Karlsson and Grauers (2023) emphasize, achieving these utilization levels without causing prohibitive queuing times at the stations relies on specific operational assumptions. It requires adjustments to smooth out the charging demand profile, such as logistics operators staggering their fleet departure times, and CPOs implementing dynamic, ToU pricing models to incentivize charging during off-peak hours.

Research indicates that reaching a minimum utilization threshold is critical for shared or public chargers to be profitable while remaining cost-competitive with diesel (Karlsson & Grauers, 2023). When utilization exceeds this threshold, the cost of the charger and grid connection becomes manageable, allowing for a lower baseline charging price (Karlsson & Grauers, 2023), scaling up to a premium tariff when factoring in the redundancy required to eliminate queuing (Karlsson et al., 2025). Below this level of demand aggregation, the fixed costs dominate the total cost of propulsion, rendering the “small-battery electric strategy” more expensive than the diesel benchmark. As defined by Karlsson and Grauers (2023), this operational approach involves equipping line-haul trucks with reduced-capacity battery packs to minimize upfront capital costs and prevent the loss of payload capacity caused by excessive battery weight. To successfully cover long-haul distances, this strategy structurally relies on combining overnight depot charging with public fast charging, specifically synchronizing the charging sessions with mandatory statutory driver rest breaks dictated by transport regulations.

2.5 Identified Theoretical and Empirical Gaps

The synthesis of current literature reveals a fundamental misalignment between the proven technical potential of shared electrification and the organizational frameworks required to sustain it. While academic models and agent-based simulations have successfully quantified the economic benefits of demand aggregation, a critical gap remains in the identification of practical, real-world governance frameworks, such as standardized cost-sharing contracts, dynamic priority-access rules, and neutral oversight structures, capable of managing the collective load and enforcing fair usage among competing logistics actors.

2.5.1 The Paradox of Technical Profitability and Operational Friction

Technical and economic modelling provides a clear mandate for the formation of shared hubs. Research demonstrates that achieving sufficient charger utilization is a critical threshold that allows shared charging to be profitable for operators while providing LSPs with cost-competitive fast-charging pricing (Karlsson & Grauers, 2023; Karlsson et al., 2025). Empirical studies confirm that collaborative configurations can substantially reduce propulsion energy costs compared to baseline diesel scenarios, with broader organizational collaboration yielding additional private savings (Karlsson & Grauers, 2023; Otero-Palencia et al., 2026).

However, these models often rely on the assumption of self-regulating behaviour or centralized algorithmic optimization. While algorithmic coordination has the theoretical capacity to reduce queuing wait times by over 46% (Bai et al., 2025), such efficiency is contingent upon high levels of data transparency, data that private entities are traditionally hesitant to share. This creates a tension between the individual drive for operational autonomy and the meso-level necessity of grid-load management.

2.5.2 The Stability Gap: Governance against Self-Interest

While one might intuitively assume that diverse demand profiles inherently create operational complementarity, such as temporally staggered charging that naturally shaves peak loads, this diversity actually poses a severe threat to the financial stability of the coalition. As demonstrated by Saygın et al. (2025) in collaborative hub networks driven by economies of scale, high asymmetry in demand volumes complicates fair cost allocation. Because the benefits of scaling are non-linear, users with massively different demand profiles experience asymmetric marginal savings. If a sophisticated allocation mechanism is not employed, large-volume logistics actors end up inadvertently cross-subsidizing the smaller ones. Consequently, this financial imbalance can lead to an "empty core" in the cooperative game, meaning no stable cost allocation exists to prevent the high-demand users from defecting from the shared hub.

Without sophisticated cost-allocation mechanisms to appropriately penalize marginal peak contributions, high-utilization fleets are likely to defect, perceiving that they are subsidizing the reckless peak-creating behaviour of others, causing the ecosystem to devolve into non-cooperative states (Wang et al., 2023, 2026; Xu et al., 2024). While the inefficiency of uncoordinated charging can be quantified (Sasahara et al., 2025), there is a lack of empirical research on how a neutral orchestrator, such as a landlord or specialized CPO, can practically enforce the necessary governance to mitigate the risk of defection (Gillström et al., 2024).

2.6 Problem Discussion

The literature highlights a clear paradox in the transition toward heavy-duty electrification: while CEHs are technically and economically necessary to overcome macro-level grid constraints and high capital costs, they introduce severe micro-level operational uncertainties. A primary challenge within these collaborative ecosystems is the temporal asymmetry of power tariffs. While energy spot prices are known *ex-ante*, power tariffs are often determined *ex-post* based on the highest peak recorded during a billing cycle (Robles et al., 2025). In a shared hub, this creates a significant risk of "free riding." Prudent participants, who adjust their schedules to shave peaks, effectively subsidize the costs of those who do not, meaning that uncoordinated usage inflates capacity charges for the entire collective (Xu et al., 2024). The economic distortion caused by uncoordinated demand, often referred to as the 'free-rider' problem, is illustrated in Figure 3, highlighting how a single peak affects the collective cost threshold.

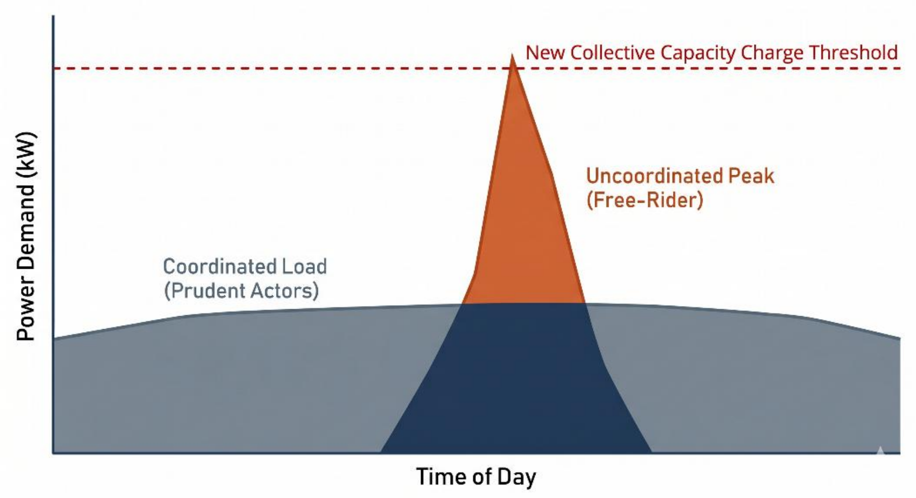


Figure 4: Impact of uncoordinated peak demand on collective capacity charges (The Free-Rider Effect).

Without robust governance to manage these peak penalty costs, the hub faces a high PoA (Sasahara et al., 2025). This erosion of fairness can shrink the "Core" of the cooperative game, leading high-utilization users to defect from the shared model. To mitigate this, shared ecosystems require sophisticated cost-allocation mechanisms, such as those based on Nash bargaining (Paudel et al., 2025) or the Shapley Value improved via matrix semi-tensor products (Wang et al., 2026), that distribute benefits and penalties according to each actor's marginal contribution to the collective load.

Consequently, the transition from the 'diesel paradigm' to shared electrification is currently stalled not by a lack of technological readiness or hardware, but by a substantial governance deficit. While theoretical simulations prove that demand aggregation is highly cost-effective (Karlsson & Grauers, 2023), LSPs are understandably reluctant to expose themselves to the operational risks and unchecked peak-penalty costs generated by co-located competitors.

This precise misalignment forms the foundational problem of this thesis. To operationalize shared hubs, the sector urgently requires actionable managerial frameworks capable of stabilizing cooperative game dynamics against competitive self-interest. Addressing this gap directly motivates the Research Questions presented in Chapter 1: understanding the emerging typologies of shared hubs (RQ1), exploring how actors perceive and negotiate cost and capacity allocation to mitigate phenomena like free-riding (RQ2), and identifying the broader organizational barriers that must be overcome by neutral orchestrators to ensure scalability (RQ3).

3. Theoretical Framework

This chapter outlines the theoretical foundation of the study. It brings together RDT and Game Theory to explain why firms collaborate under infrastructure constraints and how such collaborations are intended to function in practice. Furthermore, the chapter introduces a SIM to connect broader policy and grid limitations with firm-level responses and operational challenges in shared charging environments. Ultimately, these frameworks provide the conceptual baseline that will be empirically explored through the lens of managerial perception in the subsequent methodology.

3.1 Resource Dependence Theory (RDT)

This section establishes the organizational logic behind the shift from independent fleet management to shared infrastructure reliance. It utilizes RDT to analyse how the scarcity of high-power grid access alters the power dynamics between LSPs and network orchestrators. The analysis focuses on how firms manage environmental uncertainty through collaborative exchange and relational governance to ensure organizational survival.

RDT provides a useful analytical framework for understanding how organizations navigate constraints imposed by their external environments. Pfeffer and Salancik (1978) argue that organizational survival depends on the ability to acquire and maintain critical resources controlled by external actors. Aldrich and Pfeffer (1976) similarly emphasize that organizations are not self-sufficient but instead operate through exchange relationships that create interdependence and power asymmetries.

In the context of electrified heavy-duty road freight, charging infrastructure can be interpreted as a scarce and non-substitutable resource that shapes the strategic autonomy of LSPs.

3.1.1 High-Power Charging as a Critical Resource

Cook (1977) and Pfeffer and Salancik (1978) define a resource as any input necessary for organizational survival, such as capital, materials, or legitimacy. Emerson (1962) and Casciaro and Piskorski (2005) further show that a resource becomes critical when it is highly important for continued operations and when control over it is concentrated among a limited number of external providers.

For LSPs operating within the European Union’s decarbonization framework, high-power charging capacity and grid access have emerged as critical resources. The European Union (EU, 2023) sets binding timelines for fleet electrification, while the IEA (IEA, 2024) highlights how physical grid limitations have turned power capacity into a scarce commodity. From an RDT perspective, this creates strong dependence, because without access to high-power infrastructure, firms cannot operate battery-EVs effectively. Since these grid connections are often geographically fixed and difficult to replace, they represent a non-substitutable resource in the short to medium term.

3.1.2 Uncertainty and Power Asymmetries

Pfeffer and Salancik (1978) argue that external control of critical resources exposes organizations to uncertainty and reduces decision-making autonomy. In logistics, this becomes visible in situations where the CAPEX required for private charging infrastructure cannot be justified without assured utilization, which McKinsey (2024) identifies as a major barrier to investment.

Casciaro and Piskorski (2005) and Zou and Wang (2022) show that when dependence is asymmetric, the more powerful actor can influence or constrain the behaviour of the dependent firm. This is particularly relevant for LSPs, especially SMEs, which often negotiate from a weak position when seeking grid capacity or charging hardware. Niehuser (2008) and Pfeffer and Salancik (1978) show that such asymmetry creates two main risks, operational uncertainty and reduced autonomy. In this setting, firms may struggle to secure energy replenishment on acceptable terms, while their schedules and routing decisions may become shaped by the constraints imposed by external resource providers. This dependence is not merely a constraint but a catalyst for the formation of 'green horizontal networks,' where power asymmetry is mitigated through the collaborative pooling of resources. Melander and Wallström (2023) suggest that when firms face prohibitive capital risks, the strategic value of the resource shifts from ownership to access-sharing. In this framework, horizontal collaboration acts as a mechanism to stabilize the firm’s external environment, allowing smaller actors to bypass their individual resource deficiencies by leveraging the idle capacity or joint investments of a broader network (Melander & Wallström, 2023). Table 5 summarizes the core organizational concepts of RDT and maps them to their specific manifestations within electrified logistics.

RDT Concept	General Theoretical Definition	Manifestation in Electrified Logistics
Critical Resource	An input essential for survival controlled by a limited number of external providers.	High-power charging capacity and fixed grid access.
Power Asymmetry	A state where a more powerful actor can constrain a dependent, weaker firm.	SMEs negotiating from a weak position for grid capacity against energy providers.
Operational Uncertainty	Reduced autonomy caused by external control of resources.	Justifying high CAPEX without assured utilization; disrupted routing schedules.
Bridging Strategy	Collaborations or joint ventures formed to stabilize the environment and reduce dependence.	CEHs that pool demand and share access.

Table 5: Alignment between RDT core concepts and the dynamics of electrified logistics.

3.1.3 CEHs as Bridging Strategies

Pfeffer and Salancik (1978), together with Hillman et al. (2009), argue that organizations are not passive in the face of environmental pressure. Instead, they may use strategic responses to reshape dependence relationships and reduce uncertainty. Hillman et al. (2009) and Drees and Heugens (2013) identify collaborations and joint ventures as important bridging strategies for managing environmental complexity.

CEHs can be interpreted as such a response. EY (2024) describes these hubs as collective arrangements through which LSPs pool demand and secure grid connections that would be difficult to obtain individually. This arrangement serves two functions. First, it consolidates demand and reduces individual dependence on volatile grid conditions. Second, it moderates power asymmetries by allowing smaller hauliers to act through a collective structure rather than as isolated buyers. Johnson (1995) notes that such arrangements can be used to reduce organizational power imbalances through collective action.

At the same time, Casciaro and Piskorski (2005) show that strategies that reduce external dependence often create internal mutual dependence. Within a CEH, the charging behaviour of one participant affects the costs and operational uptime of others. The result is a shift from dependence on an external resource provider to dependence within a shared governance structure. However, managing this dependence requires a shift from transactional coordination to a 'stewardship' orientation within the network. Dessaigne and Pardo (2020) argue that the mere presence of a facilitator is insufficient if it does not actively institutionalize shared norms that govern the exchange. From a Resource Dependence perspective, stewardship serves as a meta-governance practice that stabilizes the relationship between competing actors, ensuring that the critical resource, in this case, energy capacity, is managed through value co-creation rather than zero-sum power struggles (Dessaigne & Pardo, 2020).

3.2 Game Theory and Coalition Stability

Building on the structural constraints identified in the previous section, this part applies Game Theory as a conceptual lens to understand strategic interactions within shared charging environments. It contrasts non-cooperative behaviours with coalitional stability, exploring the structural and behavioural incentives for coordination. By establishing this theoretical baseline, the discussion provides a rigorous foundation for qualitatively investigating how actors perceive cost-allocation fairness and the conditions under which long-term cooperation becomes a rational choice for competing actors.

3.2.1 Cooperative and Non-Cooperative Dynamics

Game Theory distinguishes between non-cooperative and cooperative settings. Luo et al. (2022) describe non-cooperative settings as situations in which actors optimize their own schedules without regard for system limits, whereas cooperative settings involve joint action to maximize collective surplus or minimize total costs. The resulting divergence between non-cooperative equilibrium outcomes and the cooperative system optimum, commonly formalised as the Price of Anarchy, can be mitigated through integrated hierarchical frameworks that align decentralized decision-making with system-wide constraints. Zhou et al. (2026) show that the transition from a non-cooperative to a cooperative state requires more than just communication; it demands a multi-layer optimization that reconciles spatial layout with real-time resource allocation. Their research highlights that the physical and temporal interdependencies of high-power charging require a technical coordination layer that acts as a mathematical 'enforcer' of the cooperative game's equilibrium (Zhou et al., 2026). In the case of CEHs, Saygın et al. (2025) argue that the interaction is best modelled as a transferable-utility (TU) cooperative game, since the economic effects of shared infrastructure can be quantified in monetary terms and distributed among participants.

Luo et al. (2022) define a cooperative game as a set of players and a characteristic function that assigns a cost to every possible sub-coalition. In electrified logistics, the stability of the grand coalition depends on three conditions. Efficiency means that the total cost of the hub is fully allocated among the members, leaving no surplus or deficit (Saygın et al., 2025). Individual rationality means that no participant should pay more within the hub than under a private stand-alone charging arrangement (Luo et al., 2022). Group rationality, or stability, means that no subgroup of LSPs should be able to achieve a lower collective cost by leaving the hub and forming a smaller, independent coalition (Saygın et al., 2025). To maintain the grand coalition within a shared charging hub, three distinct conditions of game-theoretic stability must be met, as outlined in Table 6.

Stability Condition	**Game Theory Definition**	**Practical Implication for CEHs**
Efficiency	The total cost of the cooperative game is completely allocated among members, leaving a zero balance.	The hub operates without deficit or unallocated surplus costs.
Individual Rationality	No single player pays more in the coalition than they would operating independently.	No haulier or LSP (as a contracting entity) joins the hub if its cost exceeds a stand-alone or internally coordinated charging solution
Group Rationality (Stability)	No subgroup of players can form a separate coalition to achieve a lower collective cost.	No subgroup of hauliers, LSP-managed fleets, or mixed coalitions can form an alternative hub or internal charging arrangement that yields lower collective cost

Table 6: Conditions for stability, efficiency, and rationality in CEH cost allocation.

In practice, coalition formation in CEHs may occur at multiple organisational levels, where LSPs act as aggregators of multiple hauliers. This introduces a hierarchical coalition structure in which stability conditions must hold both at the individual firm level and at the level of LSP-mediated sub-coalitions. This theoretical equilibrium is deeply influenced by the 'shadow of the future,' which determines the viability of cooperation in repeated games. Axelrod and Hamilton (1981) demonstrate that the emergence of stable cooperation does not require altruism but rather the expectation of continued interaction. In the context of shared charging hubs, the iterated nature of daily logistics schedules transforms the infrastructure into a theater for 'tit-for-tat' dynamics, where the threat of future retaliation by the network orchestrator or peers effectively curbs the short-term incentive for individual defection (Axelrod & Hamilton, 1981).

3.2.2 The Core and Coalition Stability

Gillies (1959) introduced the Core as a central concept for assessing stability in cooperative games. Saygın et al. (2025) describe the Core as the set of cost allocations where no participant, or group of participants, has an incentive to deviate.

If an allocation lies within the Core, the coalition is stable. However, a stable allocation does not always exist. Saygın et al. (2025) show that in some infrastructure-sharing contexts, the Core may be empty, meaning that no allocation satisfies all participants simultaneously. This highlights a key challenge, technical feasibility does not guarantee organizational stability.

Bondareva (1968), Shapley (1967), and Luo et al. (2022) explain that the existence of a non-empty Core depends on the game being balanced.

3.2.3 The Shapley Value and Fair Allocation

Shapley (1953) proposed the Shapley Value as a mechanism for allocating costs or benefits based on each participant’s marginal contribution. Luo et al. (2022) show that, unlike the Core, the Shapley Value produces a unique allocation rule.

In shared charging systems, this approach allows costs to be distributed in proportion to each actor’s impact on total system demand. For example, participants that contribute to peak demand can be assigned higher costs. Saygın et al. (2025) explain that the Shapley Value considers every possible order in which players could join the hub and averages their marginal effect on system cost.

However, fairness does not guarantee stability. Luo et al. (2022) and Saygın et al. (2025) note that an allocation based on the Shapley Value may still fall outside the Core. Consequently, governance mechanisms must balance fairness with the requirement for coalition stability.

3.3 Systemic Interdependence Model

This thesis uses a SIM to connect external constraints, organizational responses, and operational dynamics within a single analytical structure. The model conceptualizes the system across three interconnected levels: macro, meso, and micro. The hierarchical interaction and feedback loops between these external constraints and organizational responses are visually represented in Figure 5.

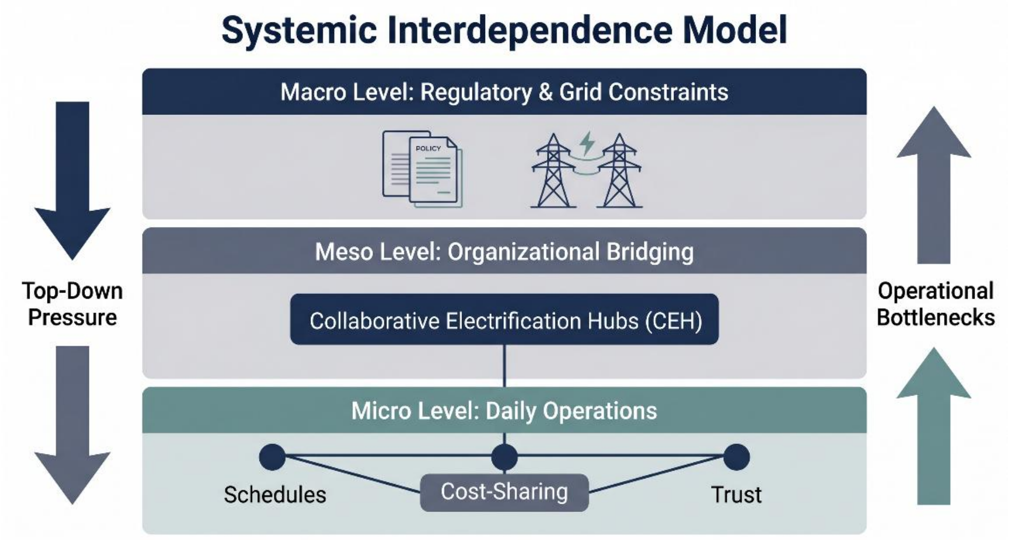


Figure 5: Hierarchical representation of the SIM across macro, meso, and micro levels.

At the macro level, the external environment shapes organizational behaviour. The European Union (EU, 2023) and the IEA (IEA, 2024) show that regulatory pressure and resource scarcity limit the feasibility of independent operations and create incentives for collaboration. These delays are symptomatic of what Scherrer et al. (2026) define as institutional barriers rooted in technology-neutral policy frameworks. The link between macro-level grid scarcity and micro-level operations is often severed by a lack of transnational governmental commitment to specific infrastructure standards. This theoretical gap suggests that for the SIM to be effective, it must incorporate the 'institutional inertia' of regulators who wait for market signals rather than providing the centralized planning necessary for high-capacity, shared infrastructure corridors (Scherrer et al., 2026).

In response to these macro constraints, the meso level represents the organizational structures that emerge. As described through RDT, CEHs function as bridging strategies that allow firms to access shared resources and reduce individual dependence. However, this level also introduces interdependence among participants, as resource access becomes jointly managed.

Consequently, at the micro level, daily operations become deeply interdependent. Sasahara et al. (2025) and Tan and Kang (2025) show that charging is closely tied to parking, which can create physical bottlenecks and lead to inefficiency when actors optimize independently. This makes operational uncertainty a central issue. Cost sharing is another challenge, as the retrospective nature of power tariffs complicates cost allocation (Svenska kraftnät, 2025). Saygın et al. (2025) show that without a mechanism for fair distribution, the Core of the cooperative game may be empty. Trust is also important, because shared charging requires the exchange of sensitive operational data, which Gillström et al. (2024) identify as a source of hesitation among participants. This behavioral layer is the most fragile component of the model, as it is susceptible to the 'tragedy of the facilitated commons.' Sternberg et al. (2022) point out that even when a system is theoretically optimized for efficiency, it may fail due to a fundamental lack of goal congruence and 'informational boundaries.' The systematic failure of horizontal collaborations often stems from the fact that actors decouple from the ecosystem to protect strategic data, creating a friction that the SIM must account for as a primary risk factor for hub collapse (Sternberg et al., 2022).

For these reasons, the role of the orchestrator becomes central. Gillström et al. (2024) and Saygın et al. (2025) argue that the orchestrator is needed to manage coordination, fairness, and trust, and to bridge the gap between operational reality and grid constraints in long-term shared charging arrangements.

4. Methodology

This chapter outlines the methodological framework used to investigate the governance of CEHs. It details the research design, the dual-layered data collection strategy comprising a SSLR and semi-structured interviews, and the thematic synthesis used for analysis to ensure a robust bridge between theoretical constructs and empirical industry realities.

4.1 Research Design and Approach

This research adopts a qualitative, multi-method approach specifically designed to explore the complex and emerging phenomenon of shared infrastructure governance within CEHs. Given the emergent nature of CEHs, an interpretivist, exploratory case study approach presents a valuable opportunity to capture the nuanced, real-world complexities of these early-stage configurations and uncover novel governance dynamics as they unfold in practice. Due to the scarcity of historical data on systemic interdependence, this methodology is designed to understand how organizational actors interpret, negotiate, and make sense of their strategic environments. While RDT (Pfeffer & Salancik, 1978) and Game Theory often rely on positivist, rationalist assumptions, this study utilizes a qualitative design to operationalize these constructs through the lens of managerial perception. Rather than attempting to mathematically prove coalition stability or re-establish well-documented macro-environmental constraints, this approach strictly investigates how actors perceive power asymmetries, evaluate the fairness of cost allocation, and negotiate strategic autonomy. By doing so, it addresses the need for empirical investigations into the operational challenges of electrified freight transport highlighted by Björklund et al. (2025), thereby providing a crucial empirical basis for understanding coalition stability within shared hubs.

Furthermore, the selection of an exploratory design is not merely a response to the proprietary and restricted nature of commercial contracts or quantitative grid data; rather, it is the most robust methodological choice for investigating the organizational and game-theoretic stability of shared infrastructure. By leveraging reported models and qualitative descriptions from industry experts, this inquiry intentionally bypasses the limitations of traditional financial modelling to capture the complex, human-driven operational dynamics of the electrification transition.

Furthermore, this design is best suited to investigate the governance of interdependence because these collaborative models are currently being formulated and tested primarily in pilot environments. To translate macro-structural constraints, such as power tariffs and peak-load penalties, into analysable variables, the qualitative inquiry focuses on identifying operational governance mechanisms. By employing semi-structured interviews, the research maps the organizational logic adopted by distinct market actors to mitigate resource dependence. This approach directly addresses the empirical governance deficit identified in the literature, transitioning from technical infrastructure requirements to actionable managerial frameworks (MOVE21 Consortium, 2024; Sasahara et al., 2025).

4.2 SSLR and Secondary Data Strategy

To address the accelerating and highly fragmented nature of research in HDV electrification, this study employs a SSLR. Following the methodological protocol established by Snyder (2019, 2024), this approach is explicitly designed to synthesize collective evidence at a meta-level, crossing disciplinary boundaries between engineering, energy economics, and logistics management.

Rather than merely mapping existing literature, the review serves as the primary foundational data source for this study. The inclusion criteria were calibrated to isolate studies offering distinct managerial implications for shared resource governance, excluding purely technical engineering models. By extracting critical variables, such as cost-allocation mechanisms and the role of neutral orchestrators, the semi-systematic review constructs the theoretical framework that is subsequently explored and contextualized through primary empirical data. This transparent, reproducible protocol ensures the trustworthiness of the synthesized evidence, providing a robust baseline to investigate the governance of shared charging infrastructure.

4.2.1 Database Selection and Keyword Strategy

The primary search for academic literature was conducted using the Google Scholar databases, selected for their comprehensive coverage of high-quality, peer-reviewed journals in transportation research, energy economics, and business management. Because academic publishing often lags behind the rapid market developments in the electrification sector, a field currently in its infancy, this search was supplemented by a targeted collection of "grey literature," including technical reports from the IEA, European Union policy mandates such as AFIR, and industry white papers (Björklund et al., 2025).

The keyword strategy utilized Boolean operators to link technical infrastructure terms with organizational governance concepts. Key search strings included combinations of:

- ("Heavy-duty vehicle" OR "HDV" OR "freight") AND ("Electrification" OR "Charging infrastructure")
- ("Shared infrastructure" OR "Collaborative Electrification Hub" OR "CEH")
- ("Governance" OR "Cost allocation" OR "Power tariffs" OR "Shapley value")

These terms were refined through a pilot test to ensure they captured the necessary intersection of grid constraints and organizational response.

4.2.2 Inclusion and Exclusion Criteria

To maintain a rigorous focus on the governance of interdependence within CEHs, specific eligibility criteria were applied during the screening process. Decisions regarding these criteria were documented carefully to ensure the protocol remained transparent and the final sample was appropriate for the research objectives. Table 7 summarizes the specific parameters used to filter academic and grey literature to maintain focus on shared infrastructure governance.

Parameter Category	Inclusion Criteria	Exclusion Criteria
Thematic Focus	Literature linking technical constraints (grid capacity, battery storage) to organizational governance and cost-sharing.	Purely engineering-focused papers lacking managerial or organizational implications.
Infrastructure Type	Configurations based on "semi-public" or "consortium-based" charging.	Literature focused on ERS or hydrogen infrastructure.
Vehicle Scope	HDVs facing megawatt-scale infrastructure challenges.	Studies focusing exclusively on passenger vehicles.
Timeframe	Recent publications, primarily ranging from 2020 to 2025.	Older literature less relevant to current disruption risks in freight transport.

Table 7: Inclusion and exclusion criteria applied to the SSLR.

Inclusion Criteria:

- Literature that explicitly links technical constraints, such as grid capacity and battery storage, to broader organizational questions of governance, cost-sharing, and multi-actor coordination, following the semi-systematic review protocol.
- Studies focusing on "semi-public" or "consortium-based" charging configurations as opposed to general public on-street charging.
- Recent publications (primarily from 2020–2025) to ensure relevance to current megawatt-scale infrastructure challenges, which represent a significant disruption risk to freight transport (Björklund et al., 2025).

Exclusion Criteria:

- Purely engineering-focused papers devoid of managerial or organizational implications.
- Studies focused exclusively on passenger vehicles, as the operational requirements and grid loads for HDVs represent a distinct strategic bottleneck (Björklund et al., 2025).
- Literature regarding ERS or hydrogen infrastructure, as these involve fundamentally different regulatory and investment models outside the scope of co-located charging hubs.

By applying these boundaries, the review ensures that the synthesized data captures the vital nuances of trust, data transparency, and strategic autonomy required to stabilize collaborative configurations. Specifically, this targeted focus addresses the 'resilience gaps', such as operational vulnerabilities and coordination failures, identified by Björklund et al. (2025). Furthermore, by adopting the contribution-focused review design outlined by Snyder (2024), this literature synthesis moves beyond mere description to construct a foundational framework that actively advances managerial practice in shared infrastructure.

4.2.3 Search Results and Sample Analysis

Following the strict application of the predefined inclusion and exclusion criteria, the literature retrieval process resulted in a final analytical sample of exactly 56 sources. This finalized sample is composed of 42 peer-reviewed academic papers and 14 pieces of grey literature, encompassing European Union regulatory directives, institutional reports from the International Energy Agency (IEA), and applied industry publications.

A qualitative assessment of the synthesized sample reveals a deliberately interdisciplinary scope, successfully bridging foundational constructs from logistics and supply chain management, energy economics, and cooperative game theory. Furthermore, the selected literature exhibits strong temporal relevance. Most of the incorporated sources were published between 2022 and 2026, accurately reflecting the nascent, rapidly evolving stage of heavy-duty vehicle (HDV) electrification and the contemporary urgency of megawatt-scale infrastructure challenges. Within this comprehensive corpus, the 14 grey literature sources serve a critical methodological function. By integrating current institutional mandates, such as the AFIR directive and national grid regulations, alongside applied insights from market consortia, these non-academic texts complement the 42 peer-reviewed articles by effectively grounding abstract theoretical models and game-theoretic algorithms in current policy and market realities. Consequently, this curated sample provides a robust, contextualized foundation for analysing the practical governance and strategic interdependence inherent in shared electrification hubs.

4.2.4 Pilot Projects, Secondary Case Studies, and Simulations

To effectively bridge the gap between abstract theoretical literature and real-world application, this methodology incorporates a targeted selection of secondary empirical data. Because fully mature, megawatt-scale CEHs are not yet widely operational, relying solely on primary qualitative interviews or conceptual frameworks is insufficient to capture the full spectrum of systemic and operational dynamics. Therefore, the research design integrates secondary empirical sources to establish a robust, triangulated baseline for analysis.

This secondary data strategy comprises two distinct streams:

- **Operational Pilot Projects and Case Studies:** The study incorporates observational and reported data from recent market pilot projects and secondary case studies (e.g., Prologis, 2024; Melander & Wallström, 2022). These real-world observations supply critical insights into the practical friction, spatial requirements, and early-stage governance structures of shared infrastructure currently being tested by early adopters and independent logistics operators.
- **Advanced Numerical and Agent-Based Simulations:** To contextualize the physical and financial limits of these hubs, the methodology leverages advanced numerical and agent-based simulations extracted from recent technical literature (e.g., Karlsson et al., 2025; Sasahara et al., 2025). These simulations are essential for understanding technical utilization rates, grid constraints, and the algorithmic coordination required to model peak-load penalties and capacity sharing.

By systematically synthesizing these secondary case studies and quantitative simulations with the primary data gathered through expert interviews, the study constructs a comprehensive methodological foundation that accurately aligns macro-level technical constraints with micro-level managerial decision-making.

4.3 Primary Data Collection: Semi-Structured Interviews

Because fully operational, collaborative megawatt-scale hubs do not yet exist in the mature form conceptualized by recent literature, traditional large-sample empirical data collection is fundamentally impossible. Consequently, this study adopts a literature-grounded framework contextualized through exploratory expert interviews.

Rather than seeking statistical saturation, the primary data collection leverages highly targeted, semi-structured interviews with three leading industry and academic experts (N=3). These elite interviews are not intended to generate raw, standalone quantitative data; instead, they serve to ground the research in critical real-market perspectives. By utilizing a purposive sampling strategy, these interviews explore the theoretical constructs and governance mechanisms derived from the semi-systematic review in light of the empirical realities, systemic bottlenecks, and operational friction faced by market pioneers.

4.3.1 Sampling Strategy and Interview Design

The sampling strategy employed a purposive approach, targeting industry professionals and academic experts directly involved in the systemic analysis, investment, or daily operations of electrified heavy transport and charging configurations. The interview protocol was explicitly designed to map macro-structural constraints onto firm-level responses. For instance, rather than asking generalized questions about electrification, the interview guide probes specific mechanisms derived from RDT (Pfeffer & Salancik, 2003): how actors mitigate power asymmetries, how they negotiate cost-allocation under peak-load penalties, and their propensity to adopt neutral orchestration to solve non-cooperative games.

The selection of these three specific profiles was strategically designed to capture the operational, commercial, and systemic dimensions of the CEH governance challenge. By engaging an academic specialist (systemic feasibility), a pioneering infrastructure owner (operational friction), and large-scale procurement experts (commercial interdependence), the study ensures that this empirical contextualization encompasses the entire spectrum of the 'collaborative game' being investigated. Each interview was conducted via Microsoft Teams and lasted approximately one hour.

A summary of the expert panel, their respective domains of expertise, and the core themes explored during data collection is provided in Table 8.

Interviewee	Role & Organization	Primary Perspective	Core Themes Explored
Anders Grauers	Associate Professor, Chalmers University; Specialist, Swedish Electromobility Centre.	Academic / Systemic Analysis.	Physical/systemic feasibility of hubs, grid constraints, V2I data constraints, and cost-allocation models.
Victor Falkenklev	CEO, Falkenklev Logistik AB.	Independent Logistics / Operational Friction.	Real-world scaling barriers, drop-in charging practicalities, and financial pressures of grid constraints.
Björn Christensson & Patrik Lindholm	Category Manager & Purchasing Manager, PEAB (Swerock).	Procurement / Commercial Interdependence.	Operational interdependence, willingness to share data, procurement demands, and SLAs.

Table 8: Overview of the expert panel and corresponding research themes.

The profiles are as follows:

Anders Grauers is an Associate Professor in Electric and Hybrid Vehicle Systems at Chalmers University of Technology and serves as a specialist within the Swedish Electromobility Centre. Holding a PhD in electric machines and having previously served as a technical specialist in Autonomous Driving Support Systems at Volvo Cars, Grauers provides a robust bridge between technical engineering and systemic analysis. His system-oriented research focuses on EVs, powertrains, and charging infrastructure, spanning technical, economic, and user perspectives. Interviewed on May 13th, the themes explored included the physical and systemic feasibility of collaborative hubs, grid scarcity constraints, vehicle-to-infrastructure (V2I) data constraints, and the viability of various cost-allocation models.

Victor Falkenklev is the CEO of Falkenklev Logistik AB and is recognized as a pioneering early adopter in the electrification of heavy-duty fleets. His experience includes the development of independent charging infrastructure in Skåne to support his company's transition. Within this triangulated sample, Victor Falkenklev serves as a vital empirical baseline, representing the perspective of an independent logistics operator. His real-world experiences provide a practical contrast to theoretical consortium models, highlighting the immediate operational and financial hurdles faced by fleet owners transitioning today. Interviewed on April 28th, the session focused on real-world scaling barriers, the practicalities of drop-in charging, and the financial pressures of grid constraints.

Björn Christensson serves as the Category Manager for Transport & Mobile Machinery Services and Water & Sewage Materials at PEAB. He was interviewed alongside Patrik Lindholm, Purchasing Manager for Swerock and PEAB. Together, Christensson and Lindholm possess deep expertise in sustainability, construction operations, and efficient procurement strategies. Interviewed jointly on May 18th, the themes explored included the operational interdependence of time-sensitive civil engineering logistics, the willingness of commercial actors to share data with a neutral orchestrator, procurement demands, and the non-negotiable Service Level Agreements (SLAs) required to ensure the stability of shared infrastructure.

By anchoring the interview questions in the variables extracted from the semi-systematic review, the data collection is directly aligned with the overarching research questions. This alignment ensures that the empirical findings capture the vital nuances of trust, data transparency, and strategic autonomy that purely quantitative metrics would overlook (MOVE21 Consortium, 2024).

4.4 Data Analysis

The analysis of the collected data follows a structured qualitative approach designed to bridge the findings from the SSLR with the primary empirical insights gathered from stakeholders. To ensure a rigorous and transparent synthesis, the study adopts the ladder of analytical abstraction, a process that involves moving systematically from empirical raw data to the identification of common themes. The application of this methodology aligns with the guidelines proposed by Snyder (2019), who emphasizes that transitioning from descriptive summaries to conceptual synthesis must be rigorous, reproducible, and grounded in a theoretical framework. Furthermore, this analytical approach enables the extraction of practical disruptions and mitigation strategies directly from industry actors, similar to the qualitative empirical design utilized by Björklund et al. (2025).

The analytical process is conducted in three distinct stages. This hierarchical progression, moving from raw empirical data to conceptual theory, is visually represented in Figure 6.

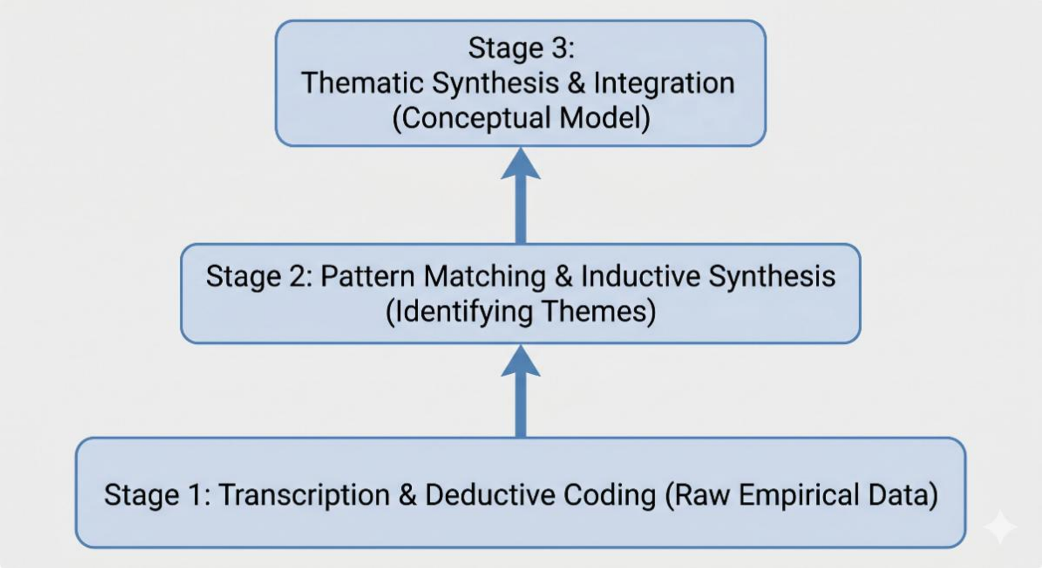


Figure 6: The three-stage ladder of analytical abstraction utilized for qualitative data synthesis.

Stage 1: Transcription and Deductive Coding

Following the documentation of the secondary literature and the completion of the semi-structured interviews, all primary data is transcribed to ensure a complete and accurate record for analysis. In the first step of the abstraction ladder, the raw data is coded using a deductive approach. These initial codes are derived from the existing literature and the study's theoretical lenses, focusing on categories such as the origins of disruptions, types of governance configurations, and specific cost-allocation mechanisms like power tariffs.

Stage 2: Pattern Matching and Inductive Synthesis

In the second stage, the research employs pattern matching to identify recurring themes and connections within the coded data. This stage is characterized by an inductive search for patterns across the differing perspectives of the infrastructure owner, the B2B customer, and the system evaluator. By comparing these viewpoints, the analysis identifies commonalities and contradictions regarding the PoA, data transparency fears, and the perceived fairness of marginal cost attribution (Sasahara et al., 2025; Saygın et al., 2025). This process effectively highlights operational governance gaps that remain undetailed in purely academic simulations.

Stage 3: Thematic Synthesis and Integration

The final stage involves a thematic synthesis where the identified patterns are abstracted into a coherent conceptual model. This step moves beyond merely describing the findings to understanding the underlying relationships between macro-level grid constraints, meso-level hub formations, and micro-level operational friction. The output of this synthesis directly answers the research questions by evaluating how different governance models can stabilize the 'Core' of the collaborative game against competitive self-interest, ultimately helping to mitigate the operational disruptions and vulnerabilities within electrified logistics networks identified by Björklund et al. (2025).

4.5 Trustworthiness, Ethical Considerations, and Limitations

To ensure academic rigor within a qualitative, interpretivist paradigm, this study shifts away from positivist metrics of validity and reliability, adopting Lincoln and Guba’s (1985) criteria for qualitative trustworthiness: credibility, transferability, dependability, and confirmability. Credibility is established through methodological triangulation, merging the macro-level findings of the SSLR with the micro-level realities extracted from expert interviews. Dependability is maintained through a transparent, highly documented analytical process utilizing the ladder of analytical abstraction, ensuring the thematic synthesis can be audited and traced back to the raw data.

4.5.1 Ethical Considerations

The primary data collection was conducted with strict adherence to academic research ethics and the General Data Protection Regulation (GDPR). Prior to the interview’s explicit, informed consent was obtained from all participants. Participants were thoroughly briefed on the study’s objectives, data handling protocols, and their right to withdraw from the research at any time without consequence. Given the elite nature of the sample, anonymity was not sought; rather, explicit written consent was granted by Anders Grauers, Victor Falkenklev, and Björn Christensson to be named, securely recorded, and directly quoted within the context of this thesis, thereby maximizing the transparency and contextual weight of their expert insights. Furthermore, in the interest of full academic transparency regarding the preparation of this manuscript, Artificial Intelligence (AI) was utilized strictly for linguistic refinement and figure generation; a comprehensive disclosure of its application is provided in the Appendix A: AI Use Declaration.

Despite these measures, the research faces distinct methodological limitations inherent in the exploratory nature of electrified logistics. First, because the transition to HDVs is in its infancy, there is a scarcity of longitudinal, empirical data, an empirical gap explicitly acknowledged by Björklund et al. (2025) regarding the early phase of electrified freight implementation. Consequently, the study relies significantly on agent-based simulations and mathematical models (e.g., Karlsson et al., 2025; Sasahara et al., 2025). While these models provide critical insights into the PoA and technical utilization factors, they often rely on assumptions of centralized algorithmic coordination or perfect data transparency. However, as Björklund et al. (2025) observe in their investigation of LSPs, private and competing actors are traditionally hesitant to accept such conditions due to perceived operational risks. Additionally, moving beyond superficial assumptions to critically engage with these complex empirical realities is essential for generating a strong, conceptual research contribution, as argued methodologically by Snyder (2024).

Furthermore, the study is limited by the proprietary nature of commercial freight data. Precise cost-allocation structures and contract terms between logistics actors and infrastructure owners are often restricted, necessitating a reliance on qualitative descriptions and reported models rather than quantitative financial modelling. This methodology mirrors the qualitative approach employed by Björklund et al. (2025) to capture the operational perspectives of LSPs, while also corroborating current industry insights reported by McKinsey (2024). Additionally, the use of grey literature from agencies such as the IEA (2024) is essential to capture rapid market developments. However, this material lacks the traditional, multi-year peer-review process characteristic of academic journals, which Snyder (2019) identifies as a core component of maintaining robust quality and trustworthiness in research reviews.

By acknowledging these boundaries, the research moves beyond purely technical abstractions to address the governance deficit hindering the scalability of CEHs. The following chapter transitions from these methodological foundations to the Empirical Findings, presenting the raw data gathered from stakeholders regarding emerging governance configurations and the practical barriers to collaborative charging.

5. Empirical Findings

This chapter presents a comprehensive cross-analysis of the empirical data, building upon the qualitative, multi-method methodology detailed in Chapter 4. To effectively unpack the practical realities of CEHs, the analysis explicitly bridges primary qualitative data, gathered through targeted expert interviews, with secondary empirical data, encompassing recent pilot projects, secondary case studies, and advanced numerical simulations (as outlined in Section 4.2.4). The objective is to examine three core dimensions: emerging governance structures, operationalized cost-allocation mechanisms, and the practical barriers that currently stall collaborative scalability. By synthesizing these triangulated real-world data points with theoretical models, the following sections provide a robust empirical foundation to address the primary research questions. Table 9 below provides a structured overview of the key empirical cases and examples analysed throughout this chapter.

Case / Example	Location	Main Characteristics	Reference
Prologis Mobility Denker Hub	California, USA	Microgrid-powered hub (9 MW) serving up to 96 heavy-duty electric trucks simultaneously to bypass utility grid constraints.	Prologis, 2024
MIT Consortium US Fleet Example	Generalized (US Focus)	Highlights the shift from carrier-driven to provider-driven models and semi-private structures for fleet charging.	MIT Consortium, 2024
Stockholm & Helsingborg Pilot	Sweden	1:1 replacement of diesel line-haul fleets utilizing midway fast chargers; focuses on utilization thresholds.	Karlsson & Grauers, 2023
Stockholm Early Adopters Hubs	Stockholm, Sweden	Monetization of private proprietary chargers during daytime idle hours by early adopter carriers.	Melander & Wallström, 2022
Beijing Shared Piles Case	Beijing, China	Point-to-point tripartite model using the Modified Shapley Value to allocate surplus to infrastructure owners.	Wang et al., 2023
Turkish Postal Network & Australia Post	Turkey & Australia	Horizontal collaboration using the Nucleolus method to ensure rational coalition pricing and group stability.	Saygın et al., 2025

Table 9: Summary of Empirical Cases and Pilot Projects.

5.1 Emerging Governance and Sharing Configurations

By triangulating recent pilot data (MIT Climate & Sustainability Consortium, 2024; Melander & Wallström, 2022), this analysis identifies that the governance of CEHs is currently coalescing around four primary archetypes of sharing configurations, defined by their degree of exclusivity and the level of commitment required from participants. These emerging models range from fully public networks, where infrastructure providers build and operate stations with uniform rates and no demand-side commitments, to private configurations with extra capacity, where a single user manages a facility but offers unused charging windows to external partners under predefined terms (MIT Climate & Sustainability Consortium, 2024).

Between these extremes, the semi-private model is identified as a versatile configuration for balancing exclusivity and asset utilization. These hubs are often structured as member-exclusive to minimize the high costs of operating a commercial fleet, calculated at 90.78 USD per vehicle per hour, and the potential loss of revenue from idle vehicles, which ranges from 3 to 7 USD per mile (MIT Climate & Sustainability Consortium, 2024). Alternatively, public-facing semi-private models provide priority access to a core pool of members while allowing non-committed users to access the chargers under specific conditions, such as higher usage rates during off-peak hours (MIT Climate & Sustainability Consortium, 2024). The spectrum of these emerging configurations, varying by their degree of exclusivity and participant commitment, is summarized in Table 10.

Archetype	Degree of Exclusivity	Commitment Required	Key Characteristics
Fully Public	Low	None	Stations built and operated by providers with uniform rates and no demand-side commitments.
Semi-Private (Public-Facing)	Medium	Low to Medium	Provides priority access to a core pool of members while allowing conditional access to non-committed users (e.g., higher rates off-peak).
Semi-Private (Member-Exclusive)	High	High	Restricted access to minimize operating costs and loss of revenue from idle vehicles.

Private (Extra Capacity)	Very High	High (Predefined terms)	A single user manages the facility but offers unused charging windows to external partners under strict predefined terms.

Table 10: Comparison of emerging CEH sharing configurations.

Cross-referencing the operational frameworks of current hubs reveals a critical distinction: a definitive shift from shipper- or carrier-driven models toward provider-driven structures. In carrier-driven models, users must coordinate ownership and management among themselves, which often complicates collaboration between market competitors (MIT Climate & Sustainability Consortium, 2024). When carriers do attempt to coordinate ownership, empirical evidence indicates they bypass competitive tensions by anchoring joint investments to specific spatial opportunities, either by co-investing at neutral urban loading zones or by leveraging long-term contracts to build member-exclusive hubs at a shared customer's site (Melander & Wallström, 2022). Conversely, provider-driven models utilize a centralized approach where a specialized infrastructure provider assumes the capital risk and manages the CaaS solution. A prime empirical example is the Prologis Mobility Denker Hub in California, which caters specifically to high-powered heavy-duty electric trucks. To bypass local utility grid constraints, this hub operates as an advanced microgrid with 9 MW of charging capacity capable of serving up to 96 trucks simultaneously, backed by 18 MWh of battery energy storage and 3 MW of linear generators (Prologis, 2024). This centralized governance allows for the aggregation of demand across a diverse user base, generating the long-term demand signals necessary to justify megawatt-scale investments (MIT Climate & Sustainability Consortium, 2024).

Despite the theoretical advantages of these centralized, provider-driven models, primary empirical evidence from independent logistics operators highlights a strong initial preference for autonomous control. For instance, Victor Falkenklev, CEO of Falkenklev Logistik AB, notes that his firm currently bears the infrastructure investment costs independently, offering excess capacity to the public rather than entering collaborative governance models, primarily to preserve operational autonomy (V. Falkenklev, personal communication, April 28, 2026). Furthermore, while current literature often frames the "neutral orchestrator" as a novel, independent entity, A. Grauers (Associate Professor, Chalmers University) argues that such administrative layers already exist within the freight sector in the form of cooperative truck-central organizations. Grauers suggests that orchestrators can be cooperatively owned by the users themselves, which redistributes administrative costs and significantly reduces fears of opportunistic extraction by third-party intermediaries (A. Grauers, personal communication, May 13, 2026).

However, cross analysing these empirical cases reveals a strict geographic dependency, indicating that these configurations are not universally replicable. For instance, the microgrid approach utilized by Prologis in California is heavily influenced by the specific regulatory structure of US utility markets and federal grid constraints (Prologis, 2024). Conversely, pilot implementations along the 553 km E4 highway corridor between Helsingborg and Stockholm are constrained by the distinct regulatory framework of European TSOs and Distribution System Operators (DSOs). These pilots utilize a “small-battery electric strategy”, equipping line-haul trucks with lighter 400 kWh battery packs instead of standard 800 kWh packs to minimize capital costs and maximize payload capacity. Consequently, this operational approach is highly reliant on synchronized public fast charging and bound by stringent European Hours-of-Service (HOS) regulations, specifically the mandatory 45-minute driver rest breaks, which dictate entirely different temporal charging windows and operational limits compared to the Chinese or North American markets (Karlsson & Grauers, 2023; Wang et al., 2023). Furthermore, the replicability of these European configurations is heavily constrained by macro-institutional barriers. Recent structural analyses reveal that the deployment of advanced, cross-border charging networks is frequently stalled by a systemic lack of transnational governmental coordination, exacerbating the conflict between the necessity for centralized infrastructure planning and the prevailing European preference for technology-open, market-driven policies (Scherrer et al., 2026).

A central finding regarding the internal stability of these configurations is the indispensable role of the neutral orchestrator. Unlike traditional gatekeepers who simply control access to a resource, the orchestrator acts as a third-party intermediary that manages the inherent tension between algorithmic grid efficiency and market competition (Gillström et al., 2024). Empirically, this role is rarely assumed by state entities or formal joint ventures; instead, it is filled by private-sector actors. These range from highly specialized B2B software start-ups offering subscription-based flexible access (Melander & Wallström, 2022), to established logistics and energy corporations that expand their business models to abstract the complexity of routing, roaming, and grid capacity away from the end-users (Gillström et al., 2024). Real-world pilot implementations demonstrate that orchestrators are essential for managing data transparency. By handling sensitive operational information, such as real-time vehicle SoC and route schedules, the orchestrator facilitates coordinated charging without forcing competitors to expose strategic data directly to one another (Gillström et al., 2024; MIT Climate & Sustainability Consortium, 2024).

These configurations directly address RQ1 by demonstrating that emerging governance is moving away from autonomous access toward structured, interdependent configurations. The stability of these hubs depends on a combination of flexible membership rules, which allow for high asset utilization, and real-time data-sharing platforms that align truck availability with load/unload schedules to maximize throughput and reduce systemic queuing (Gillström et al., 2024; MIT Climate & Sustainability Consortium, 2024). Empirical studies of early adopters in Stockholm validate this archetype, demonstrating that carriers actively seek to monetize their private proprietary chargers during idle daytime hours to offset high initial CAPEX (Melander & Wallström, 2022).

5.2 Operationalized Cost Allocation Mechanisms

The financial stability of CEHs is highly contingent on how effectively shared costs are distributed among participants. This section explores the operationalized cost-allocation mechanisms identified in recent simulations and pilot projects. It demonstrates the necessity of moving beyond simple volumetric energy pricing towards multi-dimensional approaches that capture fixed infrastructure expenditures and the temporal volatility of grid demand. Ultimately, the following analysis highlights that successful cost-allocation designs must concurrently ensure economic efficiency, individual rationality, and long-term group stability (Saygın et al., 2025; Wang et al., 2023).

5.2.1 Distribution of High Fixed Costs and CAPEX

Given the prohibitive CAPEX and grid bottlenecks established in Chapter 3, operationalized models manage the financial barriers to individual firm electrification through two primary strategies:

- Utilization-Based Amortization: Case studies of heavy-duty line-haul routes, specifically evaluating a 1:1 replacement of diesel fleets along the 553 km E4 highway corridor between Helsingborg and Stockholm, indicate that the normalized cost per delivered kWh is highly sensitive to the charger utilization factor. Agent-based modelling of this route estimates that achieving full electrification requires a network of 140 chargers, each with a capacity of 900 kW (Karlsson & Grauers, 2023). In this specific pilot, while private chargers handle terminal logistics, peak charging demands during mandatory 45-minute driver breaks are met by strategically placed midway rest areas equipped with public fast chargers. A critical threshold of 20% to 25% utilization is required for shared chargers to remain cost-competitive with diesel benchmarks, with empirical estimates projecting utilization around 18% for geographically spread networks and up to 31% for isolated sites (Karlsson & Grauers, 2023; Karlsson et al., 2025). When utilization reaches this level, the fixed costs of grid connection and hardware become manageable. Depending on haulier behaviour, competitive market forces can push fast-charging prices as low as 0.11 EUR/kWh for highly price-sensitive users willing to accept frequent queues; however, a more robust operational baseline is 0.17 EUR/kWh, scaling up to approximately 0.27 EUR/kWh to fund the redundancy required to achieve near-zero queuing times (Karlsson et al., 2025; Karlsson & Grauers, 2023).

- Rational Coalition Pricing: In horizontal collaboration models, such as the Turkish Postal Network and Australia Post benchmarks, agents (origin-destination pairs) are allocated shares of the total hub setup costs based on their specific flow demands (Saygın et al., 2025). These empirical results demonstrate that in scenarios where the "Core" of a shared hub is empty, applying the Nucleolus method successfully mitigates coalition instability by ensuring the least-satisfied participants remain incentivized to cooperate (Saygın et al., 2025).

The practical realization of this utilization-based amortization is, however, severely hampered by what A. Grauers identifies as "step effects" in CAPEX. Expanding hub capacity does not occur in smooth increments; rather, accommodating even a single additional participant can trigger massive, disproportionate infrastructure upgrade costs, such as substation expansions and transformer reinforcements (A. Grauers, personal communication, May 13, 2026). In practice, this capital burden is exacerbated by severe institutional delays. V. Falkenklev highlights that waiting times for grid connections currently range from one to three years, creating a massive temporal bottleneck that prevents scaling and forces early adopters to consider expensive on-site battery storage as a stopgap measure rather than a strategic optimization choice (V. Falkenklev, personal communication, April 28, 2026).

5.2.2 Management of Power Tariff Penalties

A significant operational challenge identified in the sources is the management of ex-post power tariffs, where a single participant’s uncoordinated charging behaviour can create a peak load that inflates the capacity charges for the entire hub (Robles et al., 2025). Empirical implementations utilize "correction factors" to move away from egalitarian distribution, which often leads to the defection of high-utilization fleets (Saygın et al., 2025; Wang et al., 2023).

The Modified Shapley Value, operationalized through methods like the cloud gravity center, allows hub orchestrators to adjust cost shares based on three critical factors: risk, input, and service quality (Wang et al., 2023). For example, shared charging pilots in Beijing utilize this mechanism to manage a tripartite structure involving private charging pile owners, sharing platforms, and residential community managers. Because this point-to-point model monetizes localized private piles that remain idle for approximately 75% of the day, the mechanism attributes higher shares of the surplus to the infrastructure owners who bear the security risks and management costs associated with unfamiliar vehicle entry (Wang et al., 2023). By penalizing participants whose behaviour imposes high marginal costs on the system, such as charging during peak "dimensioning hours", these mechanisms incentivize the "flattening" of the collective load profile (Karlsson & Grauers, 2023; Robles et al., 2025).

Translating these algorithmic penalty models into real-world pricing structures reveals significant friction. V. Falkenklev emphasizes that outsiders often conflate the electricity spot price (e.g., 1 SEK/kWh) with the necessary commercial charging price (e.g., 4.49 SEK/kWh), failing to recognize the hidden costs of peak power tariffs, taxes, and bank fees that make operating charging businesses financially precarious under low utilization (V. Falkenklev, personal communication, April 28, 2026). To ensure coalition stability and prevent opportunistic behaviour, A. Grauers argues that hubs must implement a dual-pricing model, combining a sufficiently high fixed membership fee with a marginal usage fee, to deter "free-riders" who might otherwise exploit the shared infrastructure only during peak operational necessities without contributing to the underlying fixed CAPEX (A. Grauers, personal communication, May 13, 2026).

5.2.3 Fairness and Utilization Trade-offs

Numerical experiments highlight a practical operational trade-off: implementing the Shapley Value effectively minimizes the maximum difference in relative savings (promoting individual fairness), whereas applying the Nucleolus proves empirically more robust for preventing the defection of key actors from the grand coalition (Saygın et al., 2025). A comparison of these two operationalized cost-allocation mechanisms and their strategic trade-offs is provided in Table 11.

Mechanism	Primary Focus	Operational Implementation	Empirical Outcome
Modified Shapley Value	Individual Fairness	Adjusts cost shares using correction factors based on risk, input, and service quality.	Effectively minimizes the maximum difference in relative savings among participants.
Nucleolus	Group Stability	Allocates shares of hub setup costs based on specific origin-destination flow demands.	Empirically more robust for preventing the defection of key actors from the grand coalition.

Table 11: Strategic trade-offs between cost-allocation mechanisms in collaborative hub networks.

To further maximize the utilization of infrastructure and reduce systemic queuing, it is critical that the participant base within the hub exhibits high degrees of both heterogeneity and complementarity. Heterogeneity, involving diverse fleet types, such as a mix of long-haul heavy-duty trucks, regional delivery vans, and municipal utility vehicles, ensures a broader spread of charging needs. Complementarity refers to the natural synchronization of these varying requirements, where the "when and where" of different users seamlessly interlock without overlapping. For instance, while regional delivery fleets might charge overnight, line-haul trucks could utilize the same infrastructure during mandatory midday driver breaks, effectively flattening the load curve and preventing bottleneck congestion at peak times.

The operational necessity of this synchronization is mathematically supported by recent advances in hierarchical optimization frameworks. Empirical validations demonstrate that integrating spatial layout design, medium-term resource allocation, and real-time algorithmic scheduling can reduce vehicle waiting times by up to 48.6% and decrease overall electricity costs by 14.2% within shared charging facilities (Zhou et al., 2026).

Furthermore, empirical evidence suggests that time-variable pricing is a necessary tool for maintaining high utilization without systemic queuing. By setting higher prices during "rush hour" spikes and lower prices during off-peak windows, orchestrators can successfully shift demand to idle periods, increasing the total energy delivered and consequently lowering the normalized cost for all users (Karlsson & Grauers, 2023). However, simulations of the Helsingborg-Stockholm route reveal the limits of pricing alone: increasing prices during a 'rush hour' spike often merely shifts the bottleneck to a subsequent station, sometimes worsening the maximum queuing time for the system as a whole (Karlsson & Grauers, 2023). As networks spread geographically to meet mandates (e.g., placing chargers every 60 km as per AFIR mandates), driver queuing sensitivity becomes paramount. If drivers remain "unconcerned" with queues, both maximum and average queuing times increase by approximately 70%, proving that behavioural self-regulation is equally critical as pricing for system-level efficiency (Karlsson & Grauers, 2023). This combined approach ensures that shared hubs can achieve the high level of asset utilization required to justify megawatt-scale grid connections while preventing the "free-riding" behaviour that threatens collaborative stability (Karlsson & Grauers, 2023; Xu et al., 2024).

However, while these time-variable pricing strategies represent typical "market solutions," their practical implementation requires careful calibration to avoid alienating participants. Primary empirical data indicates that users firmly reject rigid cost structures; B. Christensson and P. Lindholm (PEAB/Swerock) strongly advocate for direct, usage-based pricing tied to kWh consumption, rejecting fixed capacity reservations because construction transport assignments are highly variable and unpredictable (B. Christensson & P. Lindholm, personal communication, May 18, 2026). Furthermore, A. Grauers advises that coordination mechanisms should prioritize decentralized dynamic pricing to shift demand voluntarily, reserving rigid algorithmic booking systems only as a last resort, as logistics operators rarely possess sufficiently early information to commit to strict charging windows (A. Grauers, personal communication, May 13, 2026). If congestion does occur, Grauers suggests maintaining fairness through compensatory mechanisms, such as pricing discounts or refunds for fleets experiencing queues, rather than attempting to build economically inefficient overcapacity. Ultimately, achieving sustainable utilization requires a hybrid approach, balancing the immediate regulatory power of market tariffs with the enduring stability of relational cooperation. In this hybrid context, the neutral orchestrator transcends its technical routing function to act as a network 'steward', an entity whose primary value lies in actively strengthening shared behavioural norms and facilitating value co-creation among historically competing actors (Dessaigne & Pardo, 2020).

5.3 Identified Barriers to Collaborative Scalability

Despite the mathematically demonstrable economic benefits of shared charging infrastructure, the widespread implementation of CEHs faces significant friction. This section delves into the primary practical and organizational barriers that hinder collaborative scalability. By examining trust deficits, scheduling rigidities, and financial uncertainties, the discussion reveals the profound challenges of transitioning toward a model of systemic interdependence, where the operational viability of one actor is directly affected by the actions of another. The convergence of these operational, technical, and financial hurdles culminates in a systemic bottleneck, visually represented in Figure 7.

Figure 7: Conceptual framework illustrating the compounding barriers driving synchronization risk and organizational instability in CEHs.

5.3.1 Trust Deficits and Data Sharing Hesitancy

A fundamental barrier to scaling collaborative models is the pervasive trust deficit among competing LSPs. Empirical findings suggest that LSPs exhibit a high degree of insecurity and an explicit unwillingness to share strategic information with competitors, specifically regarding route schedules, operational costs, and revenue data (Björklund et al., 2025). This hesitancy is a critical bottleneck because the algorithmic efficiency of shared hubs, which can theoretically reduce wait times by over 46% (Bai et al., 2025), is entirely contingent upon high levels of data transparency (Björklund et al., 2025).

Primary interview data explicitly validates this theoretical hesitancy while outlining strict commercial boundaries. Representatives from PEAB/Swerock confirm that while basic billing data and vehicle charging statuses can be shared, providing real-time location tracking or detailed operational schedules to an external orchestrator is vehemently opposed due to GDPR constraints and the threat of exposing competitive advantages (B. Christensson & P. Lindholm, personal communication, May 18, 2026). Conversely, academic experts suggest that the literature's emphasis on deep data integration may be overstated. A. Grauers argues that as hubs scale, aggregate charging demand statistically smooths out, allowing operators to reliably forecast congestion through operational learning and repetitive usage patterns without ever requiring access to commercially sensitive telemetry from individual carriers (A. Grauers, personal communication, May 13, 2026).

This hesitancy is not merely a technological barrier, but a deeply rooted strategic defence mechanism stemming from severe agency problems in common-pool resource governance. Empirical analyses of systematic horizontal logistics collaborations reveal that transport actors frequently decouple from shared projects due to a fundamental lack of goal congruence and the explicit fear of violating anti-competition laws (Sternberg et al., 2021). Furthermore, data sharing is often actively stalled by third-party LSPs who hold the operational routing data and perceive horizontal collaboration as a moral hazard and a direct threat to their own competitive advantage (Sternberg et al., 2021).

Furthermore, the shift to electric fleets introduces new communication challenges. LSPs have reported a "loss of informal information" from drivers, as the necessity to focus on complex charging requirements during rest periods replaces the traditional informal interaction between drivers and fleet managers (Björklund et al., 2025). This reduction in operational visibility can lead to undetected disturbances in the transport system design, further eroding the organizational trust required for horizontal collaboration. Although the current landscape is characterized by this pervasive mistrust and defensive data hoarding, insights from game theory suggest a potential pathway for overcoming these barriers. In their seminal work "The Evolution of Cooperation", Axelrod and Hamilton (1981) demonstrated that even in environments initially dominated by self-serving behaviours, cooperation can spontaneously emerge and thrive if interactions between participants are repeated over time. Within the context of CEHs, these "iterated interactions" imply that as LSPs consistently share infrastructure day after day, the shadow of the future, the expectation of continued encounters, can incentivize actors to abandon short-term defection (such as hoarding data or monopolizing chargers) in favour of mutually beneficial cooperation. Over time, repeated successful charging cycles mediated by a neutral orchestrator could cultivate the necessary trust to mitigate the fear of sharing sensitive routing data (Axelrod & Hamilton, 1981).

5.3.2 Scheduling Conflicts and Regulatory Rigidity

Scaling collaborative configurations is further complicated by severe scheduling conflicts arising from the interplay between technical constraints and labour regulations. Heavy-duty battery electric trucks require long recharging cycles, often spanning several hours, which significantly reduces productive driving time (Otero-Palencia et al., 2026). When integrated with federal HOS regulations, which mandate strict driving and rest periods, these charging delays create rigid operational bottlenecks (Otero-Palencia et al., 2026).

Empirical analysis shows that when charging station coverage (CSC) exceeds 100 miles, the limited autonomy of current BETs (typically 150–250 miles) forces LSPs to include frequent opportunistic charging stops (Otero-Palencia et al., 2026). These stops often lead to delayed deliveries and severe service-level agreement (SLA) breaches when vehicles cannot meet strict customer time windows, necessitating higher rates of outsourcing to third-party carriers (Otero-Palencia et al., 2026). Additionally, LSPs face "lock-in" effects, where the limited range and weight penalties of heavy batteries make the fleet less flexible, as certain trucks can only be assigned to specific, "easy" routes near the hub (Björklund et al., 2025).

For highly time-sensitive sectors, such as civil engineering and construction logistics, this scheduling rigidity represents an absolute dealbreaker. B. Christensson emphasizes that construction drivers rely on legally mandated lunch breaks to perform charging activities; if a shared charger is occupied during this narrow window, the entire project timeline is disrupted (B. Christensson & P. Lindholm, personal communication, May 18, 2026). Consequently, PEAB/Swerock views guaranteed charging access and non-negotiable SLAs as foundational prerequisites for utilizing shared hubs. This operational friction is corroborated by V. Falkenklev, who notes that while informal "drop-in" charging is currently viable due to low overall fleet electrification, the impending saturation of early infrastructure will inevitably trigger severe queueing, threatening the very operational flexibility that independent carriers rely upon (V. Falkenklev, personal communication, April 28, 2026).

5.3.3 Financial Uncertainty and Resource Scarcity

Building upon the macro-level financial and infrastructural constraints detailed previously, empirical data demonstrates that the scalability of CEHs is profoundly threatened by institutional and policy-level unpredictability. While the literature points to credit access barriers for SMEs (Otero-Palencia et al., 2026), primary insights reveal that shifting political frameworks actively undermine the transition. V. Falkenklev argues that government interventions to artificially lower diesel prices actively destroy the business case for electrification, maintaining a hostile financial environment for early adopters (V. Falkenklev, personal communication, April 28, 2026). Furthermore, while government subsidies are deemed absolutely essential for covering the massive initial capital costs, financing up to 70% of charging stations in some Swedish pilots, the administrative burden required to secure them is incredibly resource-intensive, creating an additional hidden barrier for smaller logistics firms lacking dedicated administrative staff. Without consistent, supportive macro-policy and a neutral orchestrator to manage temporal dependencies, the financial risk of transitioning to shared electrification models remains a primary deterrent for LSPs.

5.4 Synthesis of Empirical Evidence

The synthesis of empirical findings confirms that the transition from the "diesel paradigm" to CEHs is characterized by a fundamental tension between technical economic efficiency and organizational instability. The evidence demonstrates that while shared infrastructure can theoretically reduce the TCO by 20% to 30% through demand aggregation, the realization of these savings is contingent upon resolving the "synchronization risk" that arises at the intersection of governance, cost allocation, and operational barriers (Bommenahalli & Chandran, 2025; MIT Climate & Sustainability Consortium, 2024).

The primary interaction identified is between data transparency barriers and governance configurations. The empirical investigation into RQ1, supported by both recent pilot data and primary expert validation, suggests that provider-driven models, particularly those where the orchestrator is cooperatively owned by the logistics actors themselves, are the most viable configurations for overcoming the trust deficits reported in RQ3.

This is because the efficiency of a shared hub depends on algorithmic coordination to manage the PoA (Sasahara et al., 2025), yet LSPs exhibit a high degree of hesitancy to share the real-time route and cost data required for such optimization (Björklund et al., 2025). The orchestrator acts as a neutral intermediary, aggregating sensitive data to flatten the collective load profile without forcing competitors to expose strategic information directly to one another (Gillström et al., 2024).

Furthermore, a critical dependency exists between scheduling conflicts and the stability of cost-allocation mechanisms. Empirical simulations for RQ2 indicate that shared chargers must reach a 20% to 25% utilization threshold to remain cost-competitive with diesel (Karlsson & Grauers, 2023). However, achieving this high utilization creates temporal conflicts where the charging needs of one truck interfere with the strict HOS windows of another (Björklund et al., 2025; Otero-Palencia et al., 2026). When these conflicts lead to peak-load power tariffs, the coalition faces a stability risk; unless cost mechanisms like the Nucleolus or Modified Shapley Value are employed to attribute peak penalties to specific reckless users, high-utilization fleets are likely to perceive the arrangement as unfair and defect from the grand coalition (Saygın et al., 2025; Wang et al., 2023).

While provider-driven models currently appear as the most viable solution to mitigate trust deficits and manage the PoA, they introduce a secondary systemic risk: the creation of new monopolistic dependencies on the centralized CaaS provider. Empirically, shifting reliance from decentralized fossil fuels to a single centralized data and energy orchestrator introduces a critical structural vulnerability that future governance frameworks must monitor.

In conclusion, the empirical cross-analysis confirms that while the technical and economic barriers of CEHs are mathematically solvable, scalability is fundamentally stalled by a governance deficit. The persistent trust barriers, data-sharing hesitancy, and synchronization risks identified in this chapter highlight the inadequacy of purely operational solutions. Consequently, Chapter 6 will interpret these structural frictions through the theoretical lenses of RDT and Game Theory, proposing frameworks to stabilize coalition dynamics.

6. Discussion

This chapter interprets the empirical findings in relation to the theoretical framework and the three research questions. The analysis highlighted how CEHs are organised in practice, which governance arrangements are emerging, how costs are allocated, and which barriers continue to constrain scalability. The purpose of this chapter is to explain what these findings mean and what they reveal about CEHs as shared systems shaped by dependence, coordination, and incentives.

The chapter is organised in four parts. Section 6.1 addresses Research Question 1 (RQ1) by using Resource Dependence Theory to explain how the four hub archetypes emerge in response to resource constraints. Section 6.2 addresses Research Question 2 (RQ2) through cooperative game theory, focusing on how cost allocation shapes the stability of collaboration. Section 6.3 addresses Research Question 3 (RQ3) by applying the Systemic Interdependence Model to examine the role of orchestration in managing coordination under competitive and informational constraints. Section 6.4 then considers demand-side conditions and their implications for the scalability of CEHs over time.

Overall, the chapter argues that CEHs should not be understood as standalone charging facilities, but as governance arrangements whose performance depends on how resource scarcity, coordination, and strategic incentives are managed in practice.

6.1 Interpreting Hub Formation through RDT

This section addresses (RQ1) by interpreting the four specific governance archetypes (fully public, private with extra capacity, semi-private, and provider-driven) identified in Chapter 5 through the lens of Resource Dependence Theory (RDT). This theoretical perspective posits that organizations become structurally constrained when they rely on resources that are scarce and critical to their operations (Pfeffer & Salancik, 2003). In the transition from diesel-based freight to electrified logistics, high-capacity grid connections have emerged as exactly this type of vital, highly constrained resource (IEA, 2024).

The empirical findings in Chapter 5 indicate that this dependence extends beyond electricity provision alone. It includes access to grid capacity, land, capital, operational coordination, and institutional permissions required to deploy and operate charging infrastructure at scale.

Taken together, these elements form a composite resource bundle that is difficult for individual firms to secure independently.

In this context, CEHs can be interpreted not as purely technical infrastructure solutions, but as governance responses to structural resource dependence. The findings show that LSPs do not respond passively to these constraints. Instead, they adopt different sharing configurations that function as bridging strategies, enabling access to critical resources while maintaining operational viability under conditions of infrastructure scarcity (Hillman et al., 2009; MIT Climate & Sustainability Consortium, 2024).

From an RDT perspective, these configurations reflect attempts to manage external dependence while limiting exposure to uncertainty. However, such arrangements do not eliminate dependence. Rather, they reorganize it, shifting constraints from the broad external environment into the shared governance structures of the collaborative hub. This shift introduces new forms of network-level interdependence among the participating firms, which must now be actively governed.

6.1.1 Archetypes of Configuration as Constraint Absorption

The four archetypes identified in the empirical material, fully public, private with extra capacity, semi-private, and provider-driven models, represent distinct governance responses to environmental constraint (Casciaro & Piskorski, 2005; MIT Climate & Sustainability Consortium, 2024). They differ in the degree of exclusivity they permit, the level of commitment they require, and the extent to which they redistribute dependence away from the public grid and toward internal or intermediary coordination structures. Interpreted through RDT, these archetypes can be understood as alternative configurations for managing and reallocating dependence under conditions of infrastructure scarcity.

The fully public model represents the least commitment-intensive configuration. It provides broad access and minimizes participation barriers, but it also offers limited control over access priority, utilization patterns, and coalition stability. In the literature, public charging is primarily described as open-access infrastructure designed to support replenishment, but not necessarily to resolve coordination problems among users (Karlsson, S., & Grauers, A. 2023; Gillström et al., 2024). Through the lens of RDT, this limits its effectiveness as a dependence-management strategy, because exposure to congestion, uncertainty, and resource contention remains largely unchanged.

The private with extra capacity configuration reflects a more active bridging approach. In this model, LSPs monetize proprietary chargers during idle windows, thereby converting excess capacity into financial resilience and reducing reliance on external subsidies (Melander & Wallström, 2023). This arrangement directly addresses the capital intensity associated with megawatt-scale charging infrastructure. This archetype is empirically validated by early market adopters (see Section 5.1.1). In RDT terms, the firm partially mitigates environmental dependence by leveraging controlled resources to strengthen both utilization and economic viability.

The semi-private model represents an intermediate configuration in which resource reliance is neither fully external nor fully internalized. Chapter 5 identifies this model as a versatile arrangement for balancing exclusivity and asset utilization, including member-exclusive hubs as well as public-facing variants that grant priority access to a core group (MIT Climate & Sustainability Consortium, 2024). While this reduces exposure to public grid congestion, it simultaneously introduces mutual dependence among the participating firms. As Casciaro and Piskorski (2005) note, constraint absorption strategies often replace external vulnerabilities with internal network reliance, since the charging behaviour of one participant directly impacts the peak costs and operational uptime of the others. Consequently, the semi-private model does not eliminate resource constraint; rather, it reconfigures it, shifting the burden from the external macro-environment to internally governed coordination structures.

The provider-driven model, including charging-as-a-service and infrastructure-as-a-service variants, represents a more centralized response to resource dependence. In this configuration, a specialized third party assumes responsibility for infrastructure investment, grid access, and operational management.

The empirical material shows a clear shift toward such centralized arrangements because they enable demand aggregation and reduce coordination burdens among competing firms. As A. Grauers (personal communication, May 13, 2026) highlights, shared provider-driven hubs benefit from statistical diversification; because heterogeneous fleet movements naturally smooth simultaneous charging peaks, these larger ecosystems can outperform isolated depot charging even as local battery storage matures. In line with RDT arguments, this model redistributes dependence away from individual firms toward an intermediary that absorbs capital risk, operational complexity, and coordination burdens.

Taken together, the four archetypes show that CEH configurations do not eliminate dependence but reorganize it. The empirical material suggests, however, that the semi-private model occupies a particularly important position within this typology, because it combines partial exclusivity with shared coordination and therefore most clearly captures the transition from external dependence to managed interdependence. For that reason, it warrants closer examination in the next subsection.

6.1.2 The Semi-Private Model as Managed Interdependence

The semi-private model identified in the findings is the clearest expression of a meso-level organizational response within the Systemic Interdependence Model. It balances the need to reduce dependence on an uncertain and congested public grid with the necessity of managing the internal mutual dependence that arises when infrastructure is shared (Casciaro & Piskorski, 2005; MIT Climate & Sustainability Consortium, 2024). In practice, member-exclusive access or priority scheduling allows LSPs to pool demand and secure grid connections that would be difficult or impossible to obtain individually (EY, 2024; MIT Climate & Sustainability Consortium, 2024).

Viewed through the lens of RDT, this configuration exemplifies dependence displacement. As firms mitigate their reliance on a constrained external grid, they simultaneously construct new internal dependencies among the hub participants (Casciaro & Piskorski, 2005). However, the primary interview data reveals that this mutual reliance introduces severe operational frictions. For instance, representatives from the construction logistics sector emphasize that their operations are highly time-sensitive, often dictated by legally mandated driver breaks; consequently, guaranteed charging access is viewed as a non-negotiable condition for participation (B. Christensson & P. Lindholm, personal communication, May 18, 2026).

Thus, the semi-private model therefore reveals an important shift in the nature of dependence. External scarcity is partly relieved, but the resulting internal interdependence creates new coordination demands that cannot be resolved by infrastructure sharing alone. As a result, attention moves from the configuration of access itself to the governance mechanisms required to make shared charging workable in practice.

6.1.3 The Orchestrator as a Coordinating Mechanism

A further implication of the empirical material is that shared charging does not become viable through physical infrastructure alone. Chapter 5 shows that CEHs depend on a neutral orchestrator that manages the tension between efficiency, coordination, and competitive secrecy. This role is particularly important because the model requires operational information such as vehicle state-of-charge, charging needs, and route schedules, yet the firms involved are reluctant to exchange such information directly with one another. As established in Chapter 5, commercial actors exhibit profound hesitancy toward real-time telemetry sharing due to regulatory constraints and competitive sensitivities.

In this sense, the orchestrator functions as a meso-level mechanism that makes collaboration operationally possible without requiring full transparency between competitors (Gillström et al., 2024). Interestingly, deep data integration may not always be a strict prerequisite. As A. Grauers (personal communication, May 13, 2026) suggests, hub operators can eventually forecast demand fluctuations through operational learning and repetitive usage patterns, meaning orchestrators can coordinate effectively without demanding overly intrusive data that might trigger governance and trust concerns. The orchestrator, therefore, absorbs coordination complexity and limits direct exposure between participants, acting as a structural response to the informational and relational frictions inherent in shared infrastructure.

The empirical findings also suggest that the orchestrator supports the practical stability of the hub by translating sensitive operational data into coordination outputs, such as charging windows, access priority, and capacity allocation. This is important because the literature review identifies the orchestrator as the actor that mediates between the algorithmic ideal of grid efficiency and the competitive realities of market actors. In other words, the orchestrator does not remove dependence, but makes it governable by converting raw interdependence into rule-based cooperation (Gillström et al., 2024; MOVE21 Consortium, 2024).

Taken together, the orchestrator should be understood as a central enabling condition for the semi-private and provider-driven configurations discussed above. Without such a coordinating function, the trust deficit identified in Chapter 5 would likely weaken participation, intensify concerns over opportunism, and make shared charging difficult to sustain. The orchestrator therefore represents the mechanism through which CEHs can preserve strategic autonomy while still achieving the coordination required for collective infrastructure use.

While the orchestrator helps make shared charging workable within a given hub, its effectiveness remains contingent on the wider institutional and infrastructural context, particularly grid capacity constraints and tariff structures. This shifts the focus away from the internal coordination among the hub participants, and toward the external macro-conditions, such as grid capacity and power tariffs that shape how dependence is redistributed across the broader logistics system

6.1.4 Contextual Limits and Redistribution of Dependence

The empirical findings indicate that CEHs are not universally applicable solutions, but context-dependent arrangements shaped by local infrastructure conditions, regulatory frameworks, and market structures. Evidence from Chapter 5 shows that access to high-capacity grid connections, the role of grid operators, and the structure of tariff regimes influence both the feasibility of hub development and the choice of governance configuration. These variations affect how and where different configurations can be implemented in practice.

As outlined in RDT literature, this reinforces the view that dependence is not an abstract condition but is embedded in specific institutional and infrastructural environments (Pfeffer & Salancik, 2003). As a result, governance configurations cannot be treated as standardized templates. Instead, the empirical patterns suggest that CEH formation reflects adaptation to localized resource constraints rather than a uniform transition pathway.

This interpretation is consistent with the empirical variation observed across the pilot projects and secondary case studies analysed in Chapter 5. Hub configurations differ not only in their internal structure, but also in the external conditions required for their viability. In highly constrained grid environments where individual logistics firms face severe capacity bottlenecks, highly coordinated arrangements (such as semi-private hubs) emerge out of necessity. Conversely, in regions with different regulatory structures or alternative power solution such as the microgrid-powered hubs analysed in Chapter 5; more centralized or market-based solutions become feasible. This proves that a firm's choice of configuration is ultimately dictated by its specific geographic and infrastructural structure of dependence, rather than by a single, universally optimal model.

At the same time, the findings show that while CEHs can reduce dependence on public infrastructure, they introduce new forms of dependence within the system. Semi-private configurations increase reliance on internal governance rules and coordination among participants, while provider-driven models shift dependence toward intermediaries that control infrastructure and operational decisions. The orchestrator, discussed in the previous section, becomes a focal point of this new dependence, as it mediates access, information, and coordination across actors.

In RDT terms, this reflects a redistribution rather than an elimination of dependence, where control is relocated across different actors and institutional arrangements (Casciaro & Piskorski, 2005). This redistribution introduces a secondary layer of vulnerability. While shared configurations may improve access to scarce resources, they also create exposure to new risks, including reliance on third-party providers, potential power asymmetries within the coalition, and sensitivity to changes in governance rules or pricing structures.

The empirical findings suggest that these vulnerabilities must be actively managed if the hub is to remain stable over time. Consequently, the effectiveness of CEHs depends not only on their ability to secure access to charging infrastructure, but also on their capacity to govern the interdependencies that arise from collaboration.

6.1.5 Concluding Interpretation

The findings indicate that CEHs can be understood as organisational responses to structural constraints related to grid scarcity, capital intensity, and coordination complexity. Rather than eliminating dependence, these configurations reorganise it into structured forms of interdependence involving infrastructure providers, orchestrators, and participating firms.

In this sense, the viability of CEHs depends less on the availability of charging capacity itself and more on how coordination, control, and incentive alignment are organised across actors. Configurations that combine access provision with effective coordination and allocation mechanisms are more likely to sustain participation under conditions of shared resource use.

To summarise these dynamics, Table 12 provides a structured overview of how the four identified governance archetypes redistribute resource dependence across different configurations. The table brings together the key elements discussed in this section by outlining, for each archetype, the primary constraint it addresses, the governance response it adopts, the new dependencies it creates, and its interpretation within RDT. This synthesis highlights that each configuration represents a different way of managing, rather than removing, dependence.

Dimensions	**Fully Public**	**Private with Extra Capacity**	**Semi-Private**	**Provider-Driven**
Primary Dependence Constraint	Access scarcity, congestion	High CAPEX, low utilization	Need for controlled shared access	Capital intensity, grid access, coordination burden
Governance Response	Open access	Selective sharing of idle capacity	Member-exclusive access	Centralized CaaS/IaaS governance
New Dependence Created	Queueing exposure, limited control	Continued dependence on grid capacity	Mutual interdependence	Dependence on intermediary
Orchestrator Need	Low	Low–moderate	High (coordination-critical)	Very high (system-critical)
RDT Interpretation	Weak constraint absorption	Asset-based bridging strategy	Managed interdependence	Dependence displacement

Table 12: How CEH configurations redistribute resource dependence across governance structures.

Overall, CEHs can be seen as governance structures that transform external constraints into internally coordinated forms of interdependence. What differs across configurations is how this interdependence is organised and stabilised.

This provides a basis for the next section. While the discussion so far has focused on how governance configurations emerge in response to resource dependence, it does not yet explain whether these arrangements remain stable over time. This shifts the focus toward the internal functioning of the hub, and in particular how costs are allocated among participants.

6.2 Cost Allocation and the Game-Theoretic Stability of Hubs

This section addresses RQ2 by examining how cost allocation mechanisms affect the stability of CEHs. Empirical findings from Chapter 5 show that hub performance is not primarily constrained by technical capacity or utilisation levels, but by whether cost structures are perceived as stable, predictable, and fair across heterogeneous users. In particular, fixed grid charges, peak power tariffs, and capacity-based pricing introduce interdependencies such that one actor’s behaviour directly affects the cost exposure of others. From a Game-Theoretic perspective, allocation rules therefore function as enforcement mechanisms for coalition stability rather than passive accounting rules.

Within CEHs, cost formation is inherently non-separable. Demand peaks are jointly produced, yet cost incidence is individually borne. This creates a structural tension between individual optimisation and collective efficiency, consistent with the Price of Anarchy problem outlined in Chapter 2. The central stability question is whether a cost allocation mechanism exists that resides within the 'Core' of the cooperative game? a state where no individual participant or sub-group would find it cheaper to leave the hub and build their own private infrastructure.

This search for stability is complicated by the temporal correlation of charging demand across firms, as users have different charging needs and schedules. A key friction point arises when coincident high-load events contribute to the system peak within a billing period. In a shared environment, a single firm's decision to charge a heavy-duty truck during a high-demand window can materially increase the aggregate peak demand, which in turn drives the monthly peak power tariff (effekttariff) at the hub level. If the resulting bill is then allocated using simplified rules such as equal splitting or energy-volume proportionality, a mismatch may emerge between each user's contribution to peak formation and their share of the cost. As a result, firms with consistently off-peak charging profiles may perceive that they are subsidizing the more costly peak-time behaviour of others. From a game-theoretic perspective, this allocation misalignment can create incentives for deviation from the coalition when alternative charging options or exit possibilities are available.

These challenges to coalition stability are most pronounced in the allocation of fixed and capacity-based costs, where interdependence is most direct and difficult to manage. Consequently, the following subsection examines these cost components through the lens of cooperative game theory, focusing on the conditions under which stable and mutually beneficial allocations can be sustained.

6.2.1 Fixed Grid Fees, Retrospective Power Tariffs, and the Core

The empirical evidence indicates that the most difficult cost items to allocate are not variable charging costs, but fixed and semi-fixed charges associated with grid access and retrospective power tariffs (effekttariffer). Chapter 5 shows that collaborative hubs are exposed to ex post capacity-based pricing, where the charging behaviour of individual participants can increase the tariff exposure of all users. This becomes particularly destabilising when fixed grid fees are combined with volatile peak charges, as the resulting cost structure is no longer proportional to energy consumption but jointly determined by timing, intensity, and collective load effects.

Recent policy and regulatory developments in Sweden suggest that peak-demand-based network tariffs are still evolving, with distribution system operators (DSOs) applying differing design approaches in how capacity costs are defined and allocated under a nationally regulated but decentralised framework (Sweden Herald, 2026). This implies that, rather than a fully standardised pricing model, capacity-based tariffs are implemented through heterogeneous regional practices, reflecting both regulatory discretion and ongoing debate regarding fairness and complexity. As a result, the institutional basis for capacity-based pricing is itself variable, introducing additional uncertainty into how these cost components are translated into allocation rules within collaborative charging hubs.

At EU level, the relevant concept is network tariff design rather than a single harmonised “power tariff.” EU law requires network charges to be cost-reflective, transparent, and non-discriminatory, while Member States apply a mix of volumetric, capacity-based, and fixed tariff elements, with national regulators retaining discretion over implementation. This regulatory structure reinforces the heterogeneity observed in Sweden and situates it within a broader European governance model where tariff design is standardised in principle but decentralised in execution.

Under the game-theoretic framework developed in Chapter 2, this problem is captured by the concept of the Core. A cost allocation is stable only if neither an individual actor nor a subgroup can lower its costs by leaving the coalition and reorganising independently. In practical terms, this requires that both individual and group rationality constraints hold across a heterogeneous set of users. The interview material illustrates why this is difficult in real-world charging systems. As V. Falkenklev (personal communication, April 28, 2026) notes, external observers often underestimate the full cost of charging by focusing on low electricity spot prices while overlooking network fees, taxes, maintenance costs, and peak power tariffs. This matters because such hidden cost components make it harder to design allocations that are both transparent and acceptable to all participants.

Furthermore, the allocation of CAPEX adds another layer of complexity to the cost structure. Shared infrastructure upgrades, such as transformer reinforcements or substation expansions, do not increase gradually with usage but tend to arrive in discrete steps when aggregate demand crosses a capacity threshold (A. Grauers, personal communication, May 13, 2026). In practice, this means that even small changes in participation or charging behaviour can trigger large additional costs for the whole hub. When these investment costs are spread across users together with peak-load charges, participants with little contribution to peak formation may still end up bearing part of the burden associated with system expansion. This can create a perception of cross-subsidisation, even when total costs are fully recovered at the system level. From a game-theoretic perspective, such cost discontinuities make stable allocations harder to sustain, because the attractiveness of staying in the coalition becomes more sensitive to who is included and how the costs are divided.

This pattern is consistent with observed behavioural responses in Chapter 5, where dissatisfaction is driven less by absolute cost levels and more by misalignment between cost responsibility and behavioural contribution. In such configurations, the coalition moves toward a near-empty Core condition, in which stability cannot be ensured under allocations that fail to reflect heterogeneous peak contributions. The findings align with Saygın et al. (2025) and Luo et al. (2022), who show that technologically efficient shared systems may remain organisationally fragile when cost structures are not incentive compatible.

Consequently, fixed grid fees and retrospective power tariffs function as strategic governance variables rather than neutral accounting elements. Their allocation determines whether the hub operates as a stable cooperative equilibrium or as a redistributive mechanism perceived to transfer costs from low-impact to high-impact users. Once this perception of cross-subsidisation emerges, trust erosion and free-riding concerns intensify, increasing the likelihood of coalition exit and destabilisation of the CEH structure.

Building on this stability constraint, the analysis next turns to allocation mechanisms that can mitigate these incentive conflicts, with particular attention to marginal contribution-based and regret-minimising solutions within CEH governance design.

6.2.2 Dynamic Pricing, Priority Scheduling, and the Shapley Logic of Fairness

The empirical material indicates that cost allocation in CEHs is increasingly embedded in operational control mechanisms such as dynamic pricing, priority scheduling, and corrective tariff adjustments. These mechanisms are not derived directly from cooperative game-theoretic solution concepts, but they consistently reproduce a comparable logic: cost exposure is adjusted in relation to marginal system impact under congestion-sensitive conditions.

In the theoretical framework established in Chapter 2, the Shapley Value defines fairness through marginal contribution across all possible coalition formations. In the empirical CEH context, marginal contribution is not abstract but system-relevant: it is expressed through the incremental effect of individual charging decisions on peak load formation, queuing delays, and capacity saturation. This implies that cost causality is state-dependent rather than linear, since identical energy consumption can generate different system impacts depending on temporal clustering and aggregate demand conditions.

Dynamic pricing operationalises this state dependence by adjusting tariffs according to real-time system stress. When local capacity constraints become binding, additional demand is priced at higher marginal levels, thereby internalising congestion effects at the point of use. Priority scheduling complements this mechanism by allocating charging access in a way that reduces inefficient simultaneity and mitigates peak amplification effects. Together, these mechanisms approximate a marginal contribution logic by linking cost responsibility to incremental system burden rather than uniform allocation rules.

The empirical findings further indicate that these mechanisms also function as interpretive devices. Cost allocation is more readily accepted when users can relate charges to observable system-relevant behaviour such as peak-time charging or congestion contribution. This introduces a second dimension of fairness beyond distributional proportionality, namely interpretability of causality. In this sense, Shapley-based reasoning serves primarily as a design reference rather than a computational implementation, guiding the construction of allocation rules that are intelligible under operational complexity.

The empirical evidence confirms that charging hubs rarely implement "pure" mathematical formulas, such as the Shapley Value, to split costs. Instead, they rely on hybrid pricing models, a practical combination of monthly subscriptions, time-variable rates, and ex-post penalties. Aligning these theoretical allocation models with commercial realities requires balancing the infrastructure provider's need for capital security against the user's demand for variable flexibility. As highlighted by the empirical divergence between academic pricing recommendations and commercial end-user preferences (see Section 1.2.2), preventing free-riding while maintaining participation from margin-sensitive logistics fleets is a significant structural hurdle. Consequently, cost allocation in a hub is not a perfect mathematical science;

it is a practical "best guess" designed to maintain group stability while satisfying the conflicting financial incentives of the cooperating actors. The following Table 13 summarizes the three main structural hurdles that complicate the calculation of a firm's exact 'fair share'.

Structural Hurdle	**Description**	**Impact on Cost Allocation**
Interdependent Demand	Overlapping charging needs driven by strict, shared delivery deadlines and labor regulations.	Prevents the isolation of individual usage patterns, making baseline energy allocations difficult.
Blurry Data	A persistent lack of high-speed data transparency and sharing among competing firms.	Hinders the exact attribution of sudden power spikes to specific vehicles or users.
Overlapping Side Effects	Simultaneous charging by multiple trucks triggering massive peak-load fees.	Creates a "last straw" scenario where marginal cost responsibility cannot be cleanly divided.

Table 13: Summary of structural hurdles preventing exact fair share calculation in CEHs.

Finally, the findings reinforce the distinction between fairness and stability. Even when allocation rules are perceived as behaviourally justified, they do not necessarily satisfy coalition stability conditions. Some actors may still obtain payoffs below their outside options under independent operation, particularly in configurations with heterogeneous demand volatility or asymmetric flexibility. This confirms that fairness-oriented mechanisms improve legitimacy and interpretability but are not sufficient conditions for stable coalition formation. The next section therefore shifts the focus from fairness-oriented allocation logic to the structural conditions under which coalitions remain viable despite these residual stability tensions.

6.2.3 Pricing Sensitivity, Queuing Sensitivity, and the PoA

The empirical findings in Chapter 5 reveal a persistent coordination tension between price sensitivity and queuing sensitivity in CEH operation. Time-variable pricing can redistribute demand across time by incentivising users to shift charging activity away from high-cost periods. However, its effect depends on whether users differ in their operational constraints, charging flexibility, and tolerance for waiting. Where such heterogeneity exists, pricing may generate a degree of complementarity in demand, since not all actors respond to price signals in the same way. Where users are more similar, however, the same pricing signal can produce synchronized behaviour, as multiple actors converge on the same low-cost intervals.

This behaviour reflects a structural property of decentralised optimisation rather than an anomaly in user decision-making. When actors respond to identical price signals under similar operational constraints, individual optimisation functions become correlated. As a result, demand is not dispersed across available time slots but clustered around shared cost-minimising periods, producing queuing congestion that is not directly reflected in the price signal itself.

This reveals a fundamental asymmetry in CEH coordination. Pricing primarily governs economic scarcity through temporal variation in marginal cost, whereas queuing emerges from physical and temporal scarcity in access to limited charging capacity. Unlike energy allocation, which is divisible and time-shiftable, charging access is discrete and constrained by simultaneity. Consequently, improvements in price-based efficiency can be offset by inefficiencies in access coordination.

The empirical material further indicates that this interaction generates a feedback loop. Pricing signals reshape demand timing, clustered demand produces queues, and observed queues subsequently influence future behavioural adjustment. Over time, queueing becomes an endogenous coordination signal alongside pricing, reducing the ability of tariffs alone to stabilise system behaviour. Importantly, this feedback is reactive rather than preventive, since congestion is only revealed after behavioural synchronisation has already occurred. This cyclical relationship between pricing incentives, clustered demand, and physical congestion is visually represented in Figure 8.

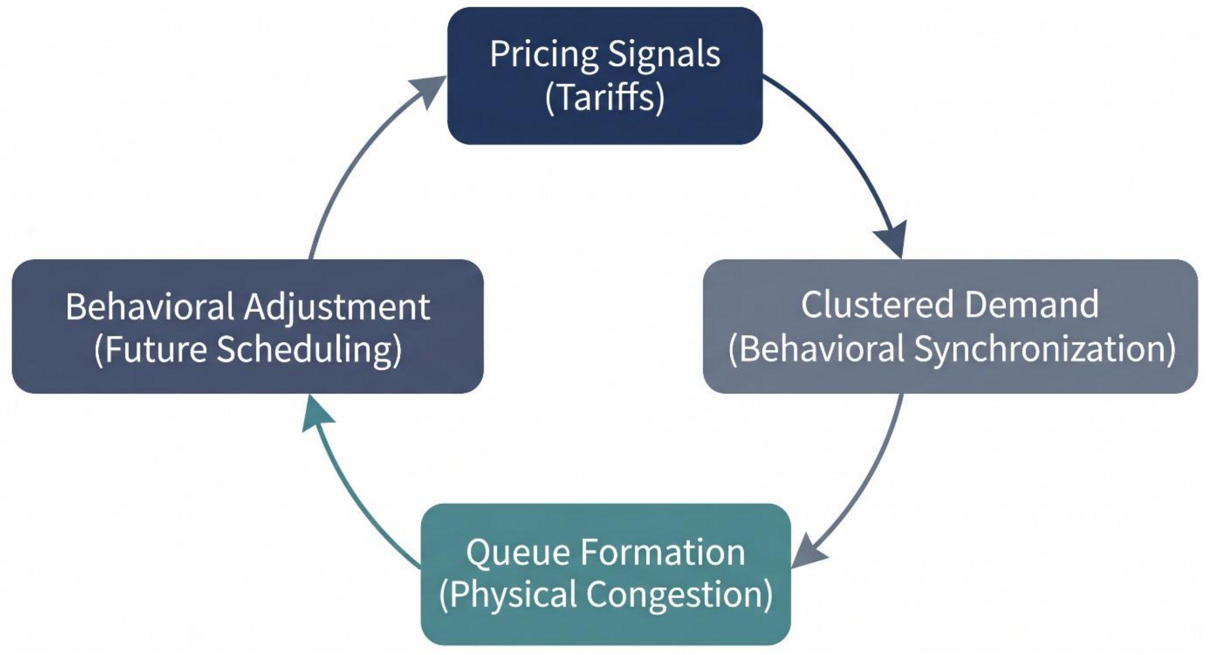


Figure 8: Schematic representation of the feedback loop demonstrating the endogenous coordination effect of queueing and pricing signals.

In game-theoretic terms introduced in Chapter 2, this dynamic corresponds to decentralised optimisation under shared constraints. Each actor minimises private cost without internalising cross-user externalities associated with simultaneous demand. The resulting equilibrium therefore diverges from the system-optimal allocation due to synchronisation effects rather than irrationality or incorrect incentives.

This divergence can be interpreted through the Price of Anarchy lens: system-level inefficiency arises because equilibrium behaviour under independent decision-making does not account for collective congestion externalities. The primary distortion does not arise from mispricing itself, but correlated response to identical signals, which amplifies congestion in predictable intervals.

The implication is that pricing alone is not sufficient to coordinate charging in CEHs. Even well-calibrated tariffs can lead to instability when users respond in similar ways, particularly in cases where fleets share comparable operational patterns. In such situations, demand tends to concentrate in the same low-cost periods rather than being distributed over time. This suggests that pricing needs to be complemented by other forms of coordination. Differences in user behaviour may help spread demand more naturally, while scheduling or priority-based mechanisms can more directly manage simultaneity. Together, these approaches address the temporal dimension of scarcity that pricing alone cannot fully capture.

From a systems perspective, CEH performance is therefore constrained not only by infrastructure capacity or tariff design, but by behavioural correlation under decentralised optimisation, which directly shapes the conditions for coalition stability and sustained participation.

6.2.4 Implications for Coalition Stability

Coalition stability in CEHs depends on how cost and capacity allocation translate system conditions into individually sustainable payoffs under interdependent operation. With-in a cooperative game-theoretic setting, stability corresponds to allocations remaining within the Core, where no subset of actors benefits from deviation.

The empirical findings in Chapter 5 indicate that this condition is sensitive to how costs are distributed across fixed charges, usage-based tariffs, and congestion-related adjustments. When allocation is weakly linked to marginal system responsibility, perceived legitimacy declines and deviation incentives increase.

Dynamic pricing and priority scheduling partially address this by linking cost exposure and access rights more closely to marginal system impact, approximating a Shapley-consistent allocation logic. This improves interpretability and reduces perceived free-riding, supporting continued participation in the coalition.

However, as shown in Sections 6.2.2 and 6.2.3, these mechanisms also introduce trade-offs: pricing can induce demand synchronisation and queuing, while scheduling can constrain perceived flexibility or fairness. As a result, improving one coordination dimension may shift instability risks rather than eliminate them.

Coalition stability is therefore conditional, requiring simultaneous satisfaction of (i) alignment between cost and marginal responsibility, (ii) mitigation of congestion and synchronisation effects, and (iii) sufficient individual payoff above outside options. If any condition is violated, cooperation becomes less robust even if the system remains operational.

Overall, CEHs function as fragile cooperative structures where stability emerges from continuous balancing between decentralised optimisation and collective coordination constraints.

6.2.5 Synthesis: Cost Allocation, Fairness, and Coalition Stability

Cost allocation in CEHs cannot be reduced to a single optimisation principle. The findings indicate that allocation decisions must simultaneously account for fairness considerations, operational feasibility, and the need to maintain stable participation within the coalition. These objectives do not align perfectly, and trade-offs are therefore inherent in any practical allocation design.

Shapley-based reasoning offers a reference point for thinking about fairness in terms of marginal contribution, but it is difficult to implement directly in operational settings. As a result, CEHs rely on combinations of mechanisms such as dynamic pricing, priority scheduling, and ex post adjustments. These approaches approximate marginal effects while remaining compatible with limited data availability and the need for simple operational execution.

At the system level, pricing and scheduling jointly influence behaviour. Pricing can improve efficiency by shifting demand over time, but it may also unintentionally concentrate usage in specific low-cost periods. Scheduling reduces this simultaneity but limits flexibility for individual actors. System efficiency, therefore, cannot be achieved through a single mathematical rule; rather, it requires the active orchestration of pricing incentives, scheduling constraints, and a complementary, heterogeneous user base.

From an economic perspective, these governance arrangements are only effective if participants perceive the resulting cost distribution as acceptable relative to their independent outside options (such as private depot charging). Crucially, however, this stability is not a static achievement. Collaborative hubs are dynamic environments characterised by growing fleet electrification, fluctuating demand, and the continuous entry or exit of participating firms. For instance, if a major actor exits the coalition, the remaining participants face a sudden increase in their share of fixed grid fees; a shock that could trigger a cascading collapse if the pricing model cannot quickly adapt. Therefore, coordination mechanisms may function perfectly under current operational conditions, but they will fail to sustain long-term participation unless they possess the structural resilience to continuously rebalance fairness and cost-competitiveness amid shifting coalition dynamics.

Ultimately, CEHs are much more than just passive infrastructure. They are dynamic cooperative systems where the natural conflicts between fairness, efficiency, and stability cannot be permanently solved, but must instead be continuously managed through active, hands-on orchestration.

6.3 The Orchestrator as a Governance Mechanism in CEHs

This section addresses RQ3 by applying the Systemic Interdependence Model developed in Chapter 3 to explain how macro-level constraints translate into meso-level organisational arrangements and subsequently produce micro-level operational challenges. At the macro level, regulatory pressure and resource scarcity increase incentives for shared electrification infrastructure. At the meso level, CEHs emerge as organisational responses that pool infrastructure while embedding interdependence among competing logistics firms. At the micro level, this interdependence becomes operationally consequential through coordination frictions related to charging access, scheduling, queueing, and cost allocation.

Empirical findings from Chapter 5 indicate that scalability is shaped by this multi-level configuration rather than by isolated technical or organisational factors. A persistent trust deficit among LSPs is reflected in reluctance to share operational data, including route schedules, charging demand profiles, and cost structures. From a RDT perspective (Pfeffer and Salancik, 2003; Casciaro and Piskorski, 2005), this behaviour represents a rational attempt to reduce vulnerability under interdependence, where operational information may reveal competitive positioning and constrain strategic autonomy.

The central constraint, therefore, lies in a fundamental information paradox. On one hand, the shared nature of the hub theoretically requires highly reliable coordination to function efficiently; to avoid massive peak-power fees and physical bottlenecks, the system must know when trucks will arrive and how much power they need. On the other hand, the logistics companies using the hub remain fierce competitors. Sharing this detailed operational data risks exposing strategic business secrets. As validated by primary empirical data in Chapter 5, the refusal to share real-time location tracking creates a structural deadlock: physical infrastructure demands predictability, but market realities prevent absolute transparency.

Within this configuration, the orchestrator functions as a meso-level governance mechanism that mediates the translation between structural interdependence and operational execution. Crucially, the administrative costs and conceptual novelty of this role need not be prohibitive. As A. Grauers (personal communication, May 13, 2026) points out, the orchestrator does not have to be an entirely alien entity; it can function as an extension of existing cooperative structures, such as traditional Swedish truck-centers, that already manage shared billing and administrative services. By leveraging these existing trust frameworks, the orchestrator restructures information into aggregated, rule-based outputs (e.g., dynamic pricing signals) that allow system functionality while protecting sensitive operational data.

A key mechanism enabling this function is data abstraction. The orchestrator processes granular operational inputs, such as state-of-charge levels, routing requirements, and charging demand signals, and translates them into system-level coordination artefacts, including charging windows, prioritisation rules, and capacity allocations. This transformation reduces the need for bilateral disclosure between firms and mitigates risks of strategic inference. The orchestrator therefore functions as an informational intermediary that enables coordination without requiring transparency among competitors.

This abstraction mechanism also addresses micro-level operational frictions identified in Chapter 5. These include uncertainty over queue position, access timing, and charging availability, which arise from the tightly coupled nature of parking and charging operations. Rather than relying on interpersonal trust between firms, the orchestrator introduces procedural standardisation that stabilises interaction through predictable allocation rules. This replaces relational uncertainty with rule-based predictability, enabling participation under conditions of competitive coexistence.

The literature on platform-based coordination and electrified logistics provides supporting evidence for this interpretation. Gillström et al. (2024) show that charge point operators reduce system complexity by managing interactions between routing and grid constraints, while Sternberg et al. (2022) demonstrate that horizontal collaboration is undermined when information exchange is perceived as exposing firms to competitive risk. These findings suggest that intermediary governance structures can reduce coordination complexity in environments characterised by informational sensitivity, although their effectiveness depends on contextual conditions such as trust, market structure, and system design.

The implications for scalability are therefore structural. Chapter 5 indicates that provider-driven or third-party coordinated arrangements are more viable than peer-managed structures because they reduce coordination burden and limit direct exposure between firms. This aligns with RDT in that organisations prefer governance forms that reduce uncertainty while maintaining access to critical resources.

Accordingly, the orchestrator should not be interpreted as a universally sufficient solution, but rather as an enabling governance condition that becomes necessary under three specific structural constraints: the physical scarcity of grid capacity, the operational reality of highly synchronized logistics schedules, and the informational deadlock caused by competitive trust deficits. Its function is to reduce the coordination and informational costs associated with this interdependence, thereby increasing system stability without eliminating underlying competitive tensions.

In sum, the scalability of CEHs is constrained by informational sensitivity, competitive interdependence, and coordination complexity generated through systemic interdependence across macro, meso, and micro levels. The orchestrator contributes to addressing these constraints by structuring information and operational flows in a way that reduces exposure, increases predictability, and enables coordination under conditions where direct cooperation between competitors is structurally limited.

While the orchestrator makes shared charging workable at the hub level, its effectiveness still depends on how firms operate in practice. Coordination can ease some of the frictions, but it cannot remove the operational constraints that shape when and how logistics companies charge. In that sense, the viability of CEHs is not determined by governance alone, but also by the flexibility and routines of the users themselves. The next section therefore shifts to the demand side and looks at how user behaviour and increasing charging demand affect the scalability of CEHs.

6.4 Demand-Side Constraints and System-Level Implications

The previous sections have shown how governance and coordination shape the viability of CEHs, but these arrangements still depend on the users who actually operate within them. This section therefore turns to the demand side. The focus here is on how limited flexibility, different usage patterns, and growing demand affect whether CEHs can scale in practice. Rather than assuming that logistics firms can simply adjust themselves to the hub, it is more realistic to ask how their own operational routines and constraints shape the conditions under which a shared hub becomes useful compared to charging arrangements that are fully private.

6.4.1 User Behaviour and the Limits of Flexibility

The empirical findings suggest that LSPs operate under fairly tight constraints. Routing schedules, service-level agreements, and rules such as Hours-of-Service requirements limit how much they can actually change their charging behaviour. In this sense, flexibility is not just a matter of choice; it is something built into, and limited by, the transport operation itself. For instance, in time-sensitive sectors like construction logistics, drivers frequently rely on legally mandated lunch breaks to charge; if chargers are unavailable during these narrow windows, entire project delivery timelines are disrupted (B. Christensson & P. Lindholm, personal communication, May 18, 2026).

This has direct consequences for how the hub can be coordinated. As discussed in Section 6.2, price-based incentives only work if users possess the operational elasticity to react to them. When flexibility is structurally constrained by labor laws and client SLAs, firms cannot simply shift their charging to off-peak periods, rendering time-variable pricing insufficient on its own. The challenge is therefore not only about calibrating mathematical incentives, but about working within the rigid, real-world limits of user behaviour.

6.4.2 CEHs within a Mixed Charging Ecosystem

The findings also suggest that CEHs should not be seen as a one-size-fits-all solution. In practice, logistics firms are likely to use several charging options at once: charging at their own depots, charging at customer sites, public charging, and shared hubs.

Within this mix, CEHs still have a clear role. They provide access to high-capacity charging that many firms would not be able to secure on their own because of grid limits, cost, or lack of space. In that sense, CEHs do not replace private charging. They complement it. They fill the gaps where individual firms are blocked by infrastructure constraints or where charging independently would be too expensive or inefficient. This makes the CEH a context-dependent solution rather than a universal one. Its value lies in what it makes possible when individual charging arrangements are not enough.

6.4.3 Demand Growth and Governance Scalability

As freight electrification continues to grow, demand will place increasing pressure on both private and shared infrastructure. If the network expands mainly through uncoordinated private depots, local grids are likely to face stronger bottlenecks. That kind of growth risks creating the kind of strain described in the literature as a “Tragedy of the facilitated commons” (Sternberg et al., 2022), where individually rational decisions eventually create system-wide problems.

CEHs offer a more coordinated path by pooling demand and smoothing the load on the grid. At the same time, this makes governance more demanding as the network grows. The more actors that join, the more complicated coordination becomes, and simple scheduling may eventually need to give way to more formal and possibly algorithmic systems. Private setups still offer more control for a single firm, but they are limited by high costs and grid availability. CEHs, by contrast, make resource sharing possible, but only if the governance structure is strong enough to manage the tensions that come with growth.

Overall, the success of the CEH model depends on how well it can adapt as demand changes over time while still maintaining coordination, fairness, and operational stability.

6.5 Chapter Conclusion

This chapter has provided an integrated discussion of the governance, stability, and scalability dynamics of CEHs. Across the three research questions, the analysis has demonstrated that these systems are shaped by interdependent organizational and operational constraints rather than isolated technical or economic factors.

The examination of RQ1 showed that collaborative hub configurations emerge as structured responses to resource dependence, where access to critical electrification infrastructure requires shared governance arrangements. These configurations transform dependence into coordinated systems that require continuous interaction among participating actors.

The analysis of RQ2 demonstrated that the stability of these arrangements depends on how costs and charging capacity are allocated under conditions of joint usage and heterogeneous contribution. Allocation mechanisms can improve perceived fairness and reduce incentive conflicts, but they remain sensitive to congestion effects, limited observability, and behavioural responses. As a result, coalition stability is conditional and requires ongoing governance effort.

The discussion of RQ3 further highlighted that scalability is constrained by operational coordination complexity and informational asymmetry. While shared infrastructure improves utilisation of scarce resources, it simultaneously increases coordination requirements in scheduling, access management, and cost allocation. At the same time, firms restrict information sharing due to competitive sensitivity, creating persistent tension between coordination demands and strategic autonomy.

Taken together, the findings show that CEHs function as structured systems of interdependence rather than purely technical infrastructures. Their performance depends on the ability to manage coordination requirements, incentive alignment, and information constraints within a shared operational environment.

In summary, this chapter ties the three research questions together by proving that governance, stability, and scalability depend entirely on one another. You cannot achieve them in isolation; rather, you must use active governance to manage the hub, which secures the financial stability needed to finally scale the operation.

7. Conclusions

This final chapter brings together the main empirical findings and theoretical insights of the thesis and presents the overall conclusions on CEHs. By integrating mathematical cost-allocation simulations with primary qualitative data from expert interviews and pilot projects, the study has shown that CEHs are not simply technical charging solutions, but governance arrangements shaped by resource scarcity, coordination demands, and interdependence between actors.

The chapter first provides an integrated synthesis of the findings, followed by a consolidated answer to the research aim. It then discusses the theoretical contributions of the study and the main governance and policy implications. The chapter ends by reflecting on the study's limitations, outlining directions for future research, and offering a final system-level concluding insight.

7.1 Integrated Synthesis of Findings

The overarching aim of this thesis was to examine how CEHs can be governed so that shared high-power charging becomes both operationally viable and organisationally stable in electrified freight logistics. The study addressed this by analysing why firms form such hubs under conditions of infrastructure scarcity and how these arrangements can be sustained over time.

The findings show that CEHs emerge as responses to structural dependence on scarce and unevenly distributed resources. Access to grid capacity, charging power, land, and operational coordination is not uniformly available, which limits firms' ability to act independently. Collaboration therefore becomes a practical response to constraint rather than a purely efficiency-driven choice. In effect, dependence is reorganised into shared systems of interdependence that require continuous coordination. Empirically, this coordination coalesces around four primary governance archetypes, ranging from fully public to centralized provider-driven models, with the semi-private configuration emerging as the most versatile compromise for balancing asset utilization and operational exclusivity.

However, the existence of shared infrastructure does not guarantee stability. The analysis shows that continued participation depends heavily on how costs and capacity are allocated. When fixed charges, grid costs, and peak usage burdens are perceived as fairly distributed relative to actual use, collaboration tends to remain stable. When this alignment breaks down, trust weakens and participation becomes more fragile.

As systems scale, coordination demands increase further. Scheduling, access management, and real-time balancing become more complex, while firms simultaneously restrict operational transparency to protect competitive positions. This creates a structural tension between the need for coordination and the limits of information sharing. Scalability is therefore constrained as much by governance capacity as by physical infrastructure.

Across the three research questions, a consistent pattern emerges: CEHs are governance-dependent systems shaped by interdependence, incentive alignment, and informational constraints rather than purely technical configurations.

The patterns identified are not isolated outcomes but interconnected manifestations of a broader governance challenge. This synthesis therefore leads directly into a consolidated answer to the research aim.

7.2 Consolidated Answer to the Research Aim

The research aim of this thesis was to understand how CEHs can be governed to enable both operational viability and organisational stability in electrified freight logistics.

The findings indicate that such viability is not achieved through infrastructure provision alone, but through the governance of interdependence between firms. Collaborative hubs become viable when dependence on scarce resources is pooled into shared systems that allow access to grid capacity and charging infrastructure. However, this structural arrangement only remains stable when governance mechanisms ensure that access, costs, and usage are aligned in ways that participants perceive as legitimate.

Organisational stability depends on whether the allocation of costs and capacity maintains incentive compatibility among heterogeneous actors. Where allocation rules are perceived as balanced, cooperation persists; where they are not, instability emerges through withdrawal, reduced participation, or strategic behaviour.

Overall, CEHs can be understood as governance systems that convert structural scarcity into managed interdependence. Their success depends on whether coordination mechanisms can sustain cooperation under conditions of limited resources, asymmetric information, and competing commercial interests.

This understanding of collaborative hubs as systems of managed interdependence provides the basis for interpreting their implications for existing theoretical frameworks.

7.3 Theoretical Contributions

This thesis contributes to research on infrastructure governance and organisational interdependence by integrating RDT and Game Theory into a unified explanatory framework.

From a RDT perspective, the findings extend existing understanding by showing that collaboration in electrification contexts does not eliminate dependence but restructures it. Instead of reducing external constraints, firms redistribute dependency across a network of actors through shared infrastructure. The key shift is from dependency reduction to dependency management within collective systems.

Game Theory provides the framework to evaluate strategic interaction within these shared infrastructures. Decisions are not made independently; each firm's charging behaviour impacts others through peak-load tariff triggers, queuing, and capacity constraints. The empirical integration of these models reveals that theoretical concepts like the PoA and the Core are operationally critical: stability is threatened when users with homogenous schedules respond to identical dynamic pricing, causing demand clustering. Conversely, coalitions achieve stability when participant heterogeneity naturally distributes demand, and fairness-based allocation mechanisms mitigate the risk of defection.

The main theoretical contribution is therefore the integration of structural dependence and strategic interaction within a single framework. RDT explains why collaboration emerges under conditions of scarcity, while game-theoretic logic explains how cooperation is sustained or destabilised once firms begin to share infrastructure. In this context, strategic interaction highlights that outcomes are jointly determined by interdependent decisions among participants, making stability contingent on how incentives shape behaviour under shared constraints. Electrification hubs are therefore best understood as governance systems whose outcomes depend on how well resource structures and incentive structures are aligned.

In addition, the thesis clarifies the multi-level nature of electrification governance. Macro-level constraints such as regulation and grid limitations shape the conditions for collaboration. Meso-level hub governance translates these constraints into operational rules, while micro-level decisions determine daily coordination outcomes. Instability often arises from misalignment across these levels rather than from any single factor. This theoretical framing is visually summarized in Figure 9, which maps the interactions and dependencies across the three governance levels.

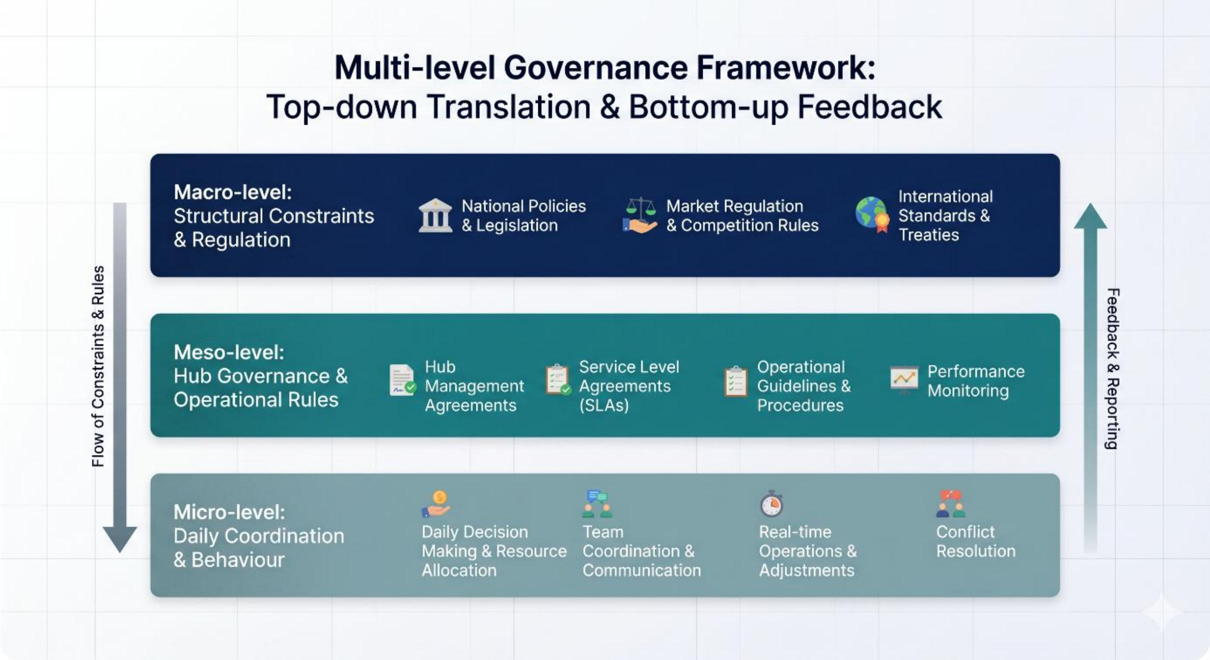


Figure 9: Multi-level governance framework of CEHs.

This theoretical framing naturally leads to implications for governance and policy, where the focus shifts from abstract explanatory contributions to actionable design principles for coordinating shared electrification infrastructure under real-world institutional and operational constraints.

7.4 Governance and Policy Implications

The findings indicate that governance design is central to the success of CEHs. Infrastructure alone does not ensure stable cooperation; rather, sustained performance depends on how access, coordination, and cost distribution are managed.

A key implication for managers is that orchestration is a critical governance function required to overcome pervasive trust deficits and data-sharing hesitancy among competing LSPs.

Rather than relying solely on novel third-party tech platforms, empirical evidence suggests this role can be successfully fulfilled by existing cooperative structures (e.g., truck-centrals). By acting as a neutral data-abstraction layer, the orchestrator manages access rules, priority scheduling, and peak-load allocations without forcing direct exposure of sensitive routing telemetry.

For policymakers, the results suggest that electrification frameworks need to explicitly account for shared infrastructure models. Standard tariff structures and grid access rules that treat all demand uniformly may unintentionally undermine collaborative systems. In particular, policies should distinguish between uncoordinated peak demand and managed shared load, as these represent fundamentally different forms of system usage.

Regulatory frameworks that support flexible tariff design, streamlined grid connection processes, and recognition of neutral orchestration roles can improve the viability of collaborative hubs. Without such adjustments, policy may inadvertently discourage cooperation even when it is operationally efficient.

While these governance and policy implications outline actionable directions for improving system viability, they remain contingent on contextual assumptions and modelling boundaries, which are addressed in the following section.

7.5 Limitations and Directions for Future Research

While this study establishes a foundational understanding of CEHs, the transition to electrified freight is still in its infancy. Consequently, this thesis is bounded by its specific empirical, institutional, and technological context. To fully map the trajectory of governed interdependence, future research must address critical unknowns across the macro, meso, and micro levels of the logistics system. Table 14 outlines the empirical and institutional boundaries of the current study alongside the corresponding critical unknowns that future research must address.

Governance Level	Current Study Boundaries	Key Unknowns	Future Research Directions
Macro	European context, Swedish focus, and	Global transferability; impact of relaxed systemic scarcity (e.g.,	Cross-regional comparative studies; modeling spatial

	current AFIR regulations.	massive grid upgrades, MCSs).	demand shifts under MCSs).
Meso	Hub dynamics captured at their inception.	Long-term institutional resilience; risk of market monopolization by tech platforms extracting outsized rents.	Longitudinal comparison of orchestrator models, such as carrier-led, neutral third-party, or CPO-led systems.
Micro	Analytical framing integrating theoretical models (e.g., Shapley value) with primary qualitative expert insights, within the paradigm of human-driven fleets.	Behavioural realities in live operations; impact of autonomous freight on algorithmic scheduling and constraints.	Testing logistics manager and driver trust in complex pricing; analyzing autonomous system efficiencies and new algorithmic realities.

Table 14: Limitations and proposed directions for future research across governance levels.

7.5.1 Macro-Level Unknowns: Structural Boundaries and Regional Contexts

At the macro level, this study is bounded by its empirical focus on the European context, with a particular emphasis on Sweden. The findings reflect specific regional grid capacity constraints, tariff structures, and the regulatory implementation of AFIR (European Union, 2023; ENTSO-E, 2025). What remains unknown is how this governance models translate globally. Future cross-regional studies beyond Europe are needed to understand how different institutional environments affect the transferability of CEHs. Furthermore, future research must investigate what happens when systemic scarcity relaxes for instance, if national grids are massively upgraded or if MCS fundamentally alter spatial demand and charging times.

7.5.2 Meso-Level Unknowns: Orchestrator Models and Market Power

At the meso level of governance, this thesis captures hub dynamics at their inception. What remains unknown is the long-term institutional resilience of these configurations. Future longitudinal studies should explicitly compare different orchestrator models such as carrier-led, neutral third-party, or CPO-led systems to clarify how different power dynamics influence hub stability. Additionally, as these models scale, research is needed to understand the risk of market monopolization. We do not yet know if the vital role of the "Orchestrator" will lead to a few dominant tech platforms extracting outsized rents, effectively replacing grid dependence with platform dependence.

7.5.3 Micro-Level Unknowns: Behavioural Frictions and Autonomous Freight

At the micro level, this study analytically framed operational viability around cost allocation and scheduled access, relying on theoretical models (such as the Shapley value) and empirical interviews. However, because collaborative hubs are still emerging, the behavioural realities of these constraints remain untested in live, scaled operations. Future empirical research must test whether logistics managers and human drivers actually trust and accept these complex algorithmic pricing mechanisms during daily, high-stress operations. Furthermore, because this thesis is firmly bounded by the current paradigm of human-driven fleets, future research should examine the impact of autonomous freight systems. We do not yet know how the removal of human constraints (such as strict resting time regulations) will reshape the algorithmic reality of charging schedules, potentially unlocking entirely new operational efficiencies.

7.6 System-Level Concluding Insight

This thesis demonstrates that electrified freight logistics constitutes not only a technological transition, but a governance problem defined by coordination under structural scarcity. CEHs emerge as one institutional response to this condition, but their viability is contingent on whether governance structures can sustain cooperation among interdependent actors with partially aligned and partially conflicting incentives.

The central insight is that electrification shifts the logistics system from relatively independent operations toward forms of managed interdependence that require ongoing coordination. In this setting, infrastructure availability alone is insufficient; stability arises only when governance mechanisms align access to scarce resources, cost distribution, and coordination rules in a way that preserves both system efficiency and organisational autonomy.

At a broader system level, electrified freight logistics is not moving toward one single hub model. It is more likely to develop as a mix of different hub types that sit alongside each other and serve different needs in different locations. Depending on the setting, firms may benefit from fully public, private-with-extra-capacity, semi-private, or provider-driven arrangements. The geographical dimension of CEHs is also critical. Hub viability is likely to vary significantly across freight corridors, urban logistics zones, ports, and peripheral regions depending on grid capacity, land availability, traffic density, and the concentration of freight activity. As a result, the governance structures required for stable collaboration may differ substantially between locations. Densely connected logistics regions may support highly shared and coordinated hub configurations, whereas geographically dispersed or lower-volume regions may favour more exclusive or semi-private arrangements. The future development of CEHs is therefore likely to reflect not only technological and organisational conditions, but also the spatial structure of freight systems themselves. What matters is that electrification is not only a technical shift, but also a governance question, because system performance depends on how access, coordination, and local conditions are organised.

Appendix A: AI Use Declaration

This appendix details the extent and nature of Artificial Intelligence (AI) assistance utilized during the research and writing of this thesis, in strict adherence to academic integrity and transparency guidelines.

Textual refinement and proofreading: AI tools, specifically Gemini, were utilized exclusively for proofreading, vocabulary enhancement, and refining the overall linguistic structure of the manuscript. No textual content, underlying ideas, or academic arguments were generated by AI. The core research, original text, and intellectual contributions presented in this document remain entirely our own.

Figures and visual illustrations: The figures and illustrations included in this thesis were entirely generated using Gemini. The use of AI for graphical generation was previously discussed and formally agreed upon with our thesis supervisor. These images serve strictly as visual and conceptual support to complement the academic text.

Human oversight and accountability: Throughout the development of this thesis, the authors maintained full and continuous human oversight. Every AI suggestion, whether textual or visual, was critically reviewed, evaluated, and independently verified before integration. The authors assume full and sole responsibility for the accuracy, integrity, and authenticity of the final content of this thesis.

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