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Systematic Review

Empty Container Management in Inland Transport: A Systematic Literature Review

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Abstract

Empty Container Management (ECM) represents a cost-intensive and environmentally impactful component of global container logistics, with its effects most visibly manifested in inland transport systems. Despite extensive academic attention, research on ECM remains fragmented across optimisation, coordination, sustainability, and technology-oriented approaches, often addressing isolated processes or decision problems. As a result, persistent costs, inefficiencies, and emissions continue to characterise inland container logistics. This study applies PRISMA guidelines to systematically review the ECM literature. The analysis focuses on three aspects: the structural causes of container imbalances, the operational activities generating costs and emissions, and the stakeholders influencing ECM decisions. The findings show that empty container imbalances do not arise from a single source. Instead, they result from the interaction of global trade asymmetries, demand uncertainty, fragmented inland operations, and diverse regulatory and institutional environments. The answers to the research questions reveal three fundamental research gaps in the existing literature. First, optimising locally does not always improve the entire system, as it might simply shift costs to other parts of the empty container management (ECM) system. Second, technological solutions cannot operate effectively without appropriate governance mechanisms and data-sharing arrangements. Third, the actors responsible for setting rules and controlling equipment availability often do not bear the full consequences of empty container movements. This review provides a structured foundation for developing integrative decision-support approaches capable of addressing inland ECM under real-world structural constraints.

Keywords: empty container management; inland transport; empty container repositioning; logistics costs; transport emissions; maritime–inland interface

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1. Introduction

Empty Container Management (ECM) represents a major logistics challenge driven by imbalances in global trade and structural limitations of inland transport systems. These conditions generate persistent costs, emissions, and coordination requirements. Empty container flows account for a considerable share of global transport, with estimates ranging from 20% of all containers moved [1] to one-third of global flows [2]. Inland ECM alone is responsible for 50–70% of container movements [3], while the proportion of repositioned empty containers on land is observed to be twice as high as at sea [4]. These flows impose significant financial burdens: repositioning represents over 20% of carriers' operating costs [5], and hinterland transport can account for 40–80% of total container supply chain expenses [6]. Such movements are widely regarded as a major inefficiency in global logistics systems [7]. The problem is further aggravated by the fact that many empty containers are moved from coastal ports to inland locations without carrying cargo [8]. They generate costs comparable to those of full containers but do not generate revenue [9], making ECM an expensive yet unavoidable operation [10].

Like the transport of full containers, Empty Container Management (ECM) spans both maritime and inland transport systems. Literature distinguishes between maritime and inland perspectives on ECM. The maritime perspective focuses on global shipping networks and trade imbalances, while the inland perspective examines how these imbalances are managed within domestic and regional logistics systems.

Maritime perspective: From a maritime viewpoint, ECM is discussed in relation to inland capacity planning and container repositioning. It also involves ensuring the delivery of loaded containers to importers [6], transferring empty units to demand locations [11], balancing container supply and demand [12], responding to structural trade asymmetries [13], and preventing shortages in export-intensive areas [14].

Inland perspective: From an inland perspective, empty container repositioning (ECR) is described as a dynamic multi-period decision process focused on selecting optimal transport routes and ports [5]. It is often formulated as an optimisation problem [15], and as the coordination of container flows across customer sites, depots, terminals, and trucking facilities [16]. This perspective emphasises managing inland flows to meet export demand while minimising redundant movements [17]. These operations range from local depot–customer interactions to regional hinterland connections linking inland terminals, depots, and seaports with global hubs [18].

Despite extensive research on ECM and ECR, empty container logistics continues to generate significant costs, inefficiencies, and environmental impacts. These challenges are particularly visible in inland transport systems, where ECR operations involve greater organisational complexity. These impacts are influenced by both global maritime trade structures and inland operational and institutional conditions. Despite the introduction of various optimisation, coordination, and technology-driven strategies, the persistent increase in empty container movements and related emissions suggests that these methods have yet to address ECM challenges comprehensively at the system level. This situation is further complicated by the methodological heterogeneity of ECM research, which forms part of the broader intermodal transport literature and ranges from highly formalised optimisation models of container relocation and terminal operations [19] to empirical studies examining stakeholder behaviour and environmental awareness within intermodal transport chains [20]. This diversity makes fully standardised classification difficult and highlights the need for a structured analytical framework for examining existing research.

Existing review studies predominantly approach ECM through broad thematic lenses such as optimisation, sustainability, or digitalisation. While these contributions are valuable, they do not adequately explain why locally effective solutions fail to generate system-level improvements. Institutional constraints and stakeholder misalignments are typically addressed only superficially, leaving unclear how rules and conflicting interests limit the effectiveness of proposed approaches in practice. As a result, the literature remains fragmented across structural drivers, operational processes, and governance mechanisms, constraining cumulative system-level understanding of inland ECM. This review addresses this gap by developing an integrative, system-oriented synthesis that connects structural drivers, operational processes, and stakeholder dynamics, thereby providing a unified explanation of why locally effective solutions fail to translate into system-level improvements in inland ECM.

Consequently, this systematic literature review examines Empty Container Management (ECM) by collecting, identifying, and classifying relevant peer-reviewed journal articles. This review is organised into three distinct analytical stages. First, it investigates the fundamental drivers of empty container imbalances reported in the literature. Second, given the cost and emission implications associated with empty container flows, it analyses the key activities and processes that constitute ECM. Third, recognising that these outcomes emerge from decisions made by multiple actors, this review examines the principal stakeholders involved in ECM, their roles, and their interdependencies within inland logistics systems.

Through this three-phase systematic review, this study analyses ECM as a multidimensional phenomenon embedded in global container logistics. Rather than focusing on isolated optimisation problems or individual processes, this review synthesises existing research across three interrelated analytical dimensions: structural trade-related drivers and operational conditions underlying empty container imbalances, the activities and processes through which ECM is performed and costs and emissions are generated, and the stakeholder landscape and decision-making structures that shape ECM outcomes. By considering these various aspects together, this review offers a unified overview of research that is otherwise scattered across different methods, regions, and types of analysis.

The results indicate that ongoing empty container imbalances are not caused only by inefficiencies in inland operations. Instead, the reviewed literature indicates that these imbalances arise from the interaction of global trade dynamics, decentralised inland logistics operations, and heterogeneous regulatory and institutional environments. In this context, ECM refers to a series of linked processes that address these imbalances, managing them within the current limitations of the system rather than resolving them completely. By clarifying these interactions and associated stakeholder asymmetries, this study contributes to a clearer understanding of why costs, emissions, and inefficiencies persist despite extensive optimisation-oriented research, and why isolated, process-specific approaches remain insufficient to address ECM challenges at the system level. Accordingly, this review does not focus on optimising individual process components, but rather explicitly seeks to identify the structural, operational, and institutional conditions under which inland solutions can effectively improve the performance of the ECM system.

This study is subject to certain methodological limitations inherent to systematic literature reviews. This analysis is limited to peer-reviewed English publications from 2015 to 2025, excluding grey literature and industry reports. Furthermore, this study does not develop or empirically validate a new optimisation model but focuses on synthesising and critically structuring existing research. These boundaries define the scope of this review and should be considered when evaluating its conclusions.

The rest of this paper is organised in the following way: Following the introduction, Section 2 describes the research methodology. Section 3 presents the results of the systematic literature analysis. Section 4 discusses the key findings in relation to the defined research questions. Finally, the conclusion summarises the main contributions of this study and outlines its limitations.

2. Methodology

To structure the review process and ensure transparency and replicability, this research applies the PRISMA [21] methodology (Preferred Reporting Items for Systematic Reviews and Meta-Analyses). PRISMA was applied to methodically find, review, and assess relevant studies, creating a thorough and critically evaluated basis for exploring the dynamics, challenges, and institutional setting of inland Empty Container Management. The PRISMA checklist is provided in the Supplementary Materials.

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2.1. Formulating the Research Problem and Research Questions

Despite extensive academic attention to Empty Container Management (ECM) and Empty Container Repositioning (ECR), empty container logistics continues to be associated with high costs, persistent inefficiencies, and significant environmental impacts, particularly within inland transport systems, where a substantial share of container handling, repositioning activities, and associated emissions take place. While these impacts manifest most visibly in inland logistics networks, they originate from interactions between global maritime trade structures and inland operational and institutional conditions. Over the past decade, a large body of peer-reviewed research has proposed optimisation models, coordination mechanisms, digital solutions, and sustainability-oriented approaches aimed at improving ECM performance. Although many studies demonstrate measurable improvements within specific operational settings, inland empty container movements remain a persistent and substantial source of transport activity and emissions, indicating that system-level inefficiencies continue to exist [7]. The literature therefore reflects a persistent gap between the proliferation of ECM/ECR models, and the enduring economic and environmental challenges observed in practice, highlighting the need for a synthesis that examines ECM across its structural, operational, and stakeholder dimensions rather than through isolated or single-layer perspectives. In response to this research problem, this systematic literature review adopts a system-level perspective to examine inland ECM as a coherent logistics function. The objective of this review is to comprehensively examine the problem of Empty Container Management by collecting, identifying, and classifying relevant articles published in peer-reviewed scientific journals. To support a holistic understanding of inland ECM, this study addresses the following research questions:

- RQ1: What are the fundamental causes of ECM imbalances?
- RQ2: Which activities and processes define the scope of ECM?
- RQ3: How do key stakeholders influence ECM processes and outcomes?

Addressing these questions through a PRISMA-based systematic review enables the synthesis of fragmented literature into an integrated analytical framework. By jointly examining causes, processes, and stakeholder roles, this study aims to provide a comprehensive system-level understanding of inland ECM and to identify conceptual and methodological gaps that explain the persistence of costs, inefficiencies, and environmental impacts despite extensive prior research.

2.2. Guidance for This Review

This systematic literature review follows established guidelines for evidence-based reviews to ensure transparency, consistency, and reproducibility. This review follows the PRISMA framework, which provides a standardised structure for identifying, screening, assessing eligibility, and selecting relevant studies.

2.3. Protocol

Before starting this study, a structured review protocol was set up to outline the research objectives, research questions, eligibility criteria, and the methods to be used. The review process followed four main phases in line with PRISMA: identification of relevant studies through database searches, screening of titles and abstracts, full-text eligibility assessment, and final inclusion of studies meeting the predefined criteria [21]. At each step, inclusion and exclusion criteria were applied in a consistent manner, with all choices carefully recorded to ensure transparency and reproducibility.

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2.4. Inclusion Criterion and Eligibility Evaluation

This review includes peer-reviewed studies that explicitly address Empty Container Management (ECM) or Empty Container Repositioning (ECR) in the context of inland transport. Eligible studies examine inland container flows, hinterland operations, or land-based logistics processes related to empty containers, either as a primary focus or as a clearly defined analytical component.

Research that examined only maritime or port-specific ECM/ECR was omitted unless it specifically addressed how maritime and inland container flows interact. To maintain scientific rigor and consistent methodology, only peer-reviewed sources were included.

2.5. Searching Strategy

A structured Boolean search was performed, with search strings tailored for each database platform (Scopus, Web of Science, ScienceDirect, and Google Scholar). The core search string applied in Scopus and Web of Science was:

("empty container repositioning" OR "empty container management")
AND ("inland transport" OR "hinterland transport" OR "inland logistics")
AND (container*)

The search only included peer-reviewed journal articles and conference proceedings written in English, published between 2015 and 2025, and focused on topics such as transport, logistics, maritime studies, operations research, and supply chain management.

The period from 2015 to 2025 was selected to highlight modern advances in optimisation modelling, digitalisation, sustainable practices, and regulatory updates, all of which have a notable impact on current inland ECM research. Studies examining container logistics and transport system optimisation have likewise chosen comparable time frames. The last database search took place in May 2025.

2.6. Data Collection and Extraction

The literature selection was carried out in four steps, based on the PRISMA framework.

1. Identification: From an initial pool of 289 records, 31 duplicates were removed, resulting in 258 unique entries.
2. Screening: Based on titles and basic metadata, 79 entries were excluded for lacking substantive academic content—such as being too short, missing methodological structure, or lacking a clear institutional source. This left 179 articles for full-text review.
3. Eligibility: A detailed review excluding 50 articles that did not address inland container transport in any meaningful way. The remaining 129 articles were examined further.
4. Inland relevance was assessed using explicit analytical criteria based on inland transport modelling, empirical flow analysis, depot-level operations, or governance mechanisms affecting container circulation. References to inland transport were excluded unless they contained analytical discussion.
5. Focused relevance filter: Among the remaining 129 articles, 27 were excluded because inland transport was only mentioned without analytical treatment, while 29 were excluded because they addressed inland container transport but did not focus substantively on ECR/ECM. As a result, 73 articles were retained for inclusion in the systematic review.

The adapted PRISMA flow diagram (see Figure 1) shows each step of the process, making it clear and easy to follow from initial identification to final inclusion.

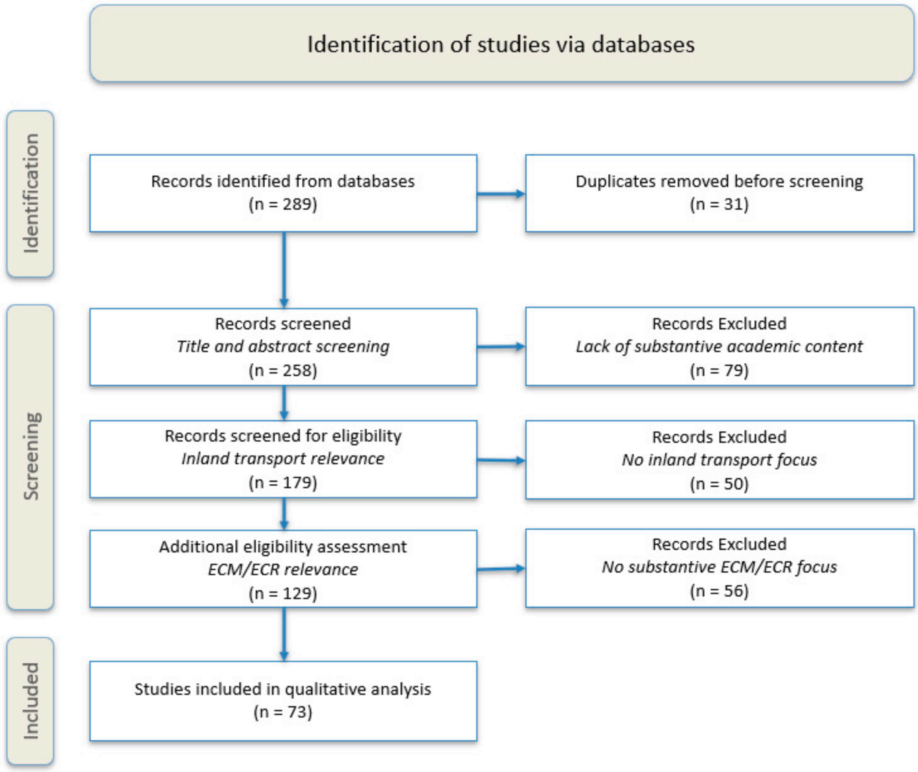

Figure 1. PRISMA Flow Diagram on inland ECM (2015–2025).

The screening process followed a funnel-based approach, guided by predefined inclusion and exclusion criteria. Consistent with the screening phase described above, the initial stage focused on filtering studies based on academic quality and methodological rigor. Studies lacking sufficient structure or clear institutional grounding were excluded. In the subsequent stages, the remaining studies were assessed based on explicit analytical treatment of inland transport and substantive relevance to ECM/ECR. Studies were excluded if inland transport was only mentioned without analytical depth or if ECM/ECR was not a central focus of the analysis.

The final selection of 73 studies reflects the consistent application of this stepwise filtering logic, ensuring that only academically robust studies with direct and substantive relevance to inland ECM were retained for further analysis. This staged selection process is consistent with the PRISMA framework, which emphasises transparent and sequential screening from identification to final inclusion.

The screening and selection process was conducted by the authors, and any uncertainties or disagreements were discussed and resolved through consensus. This approach ensured consistency and transparency throughout the review process. Automation tools were not employed.

3. Results

This section presents the results of the systematic literature review based on a final sample of 73 peer-reviewed studies. Once the key features of the reviewed literature are summarised, the findings are organised based on three key aspects of the research framework: generation causes, ECM processes, and the impact of stakeholders.

Given the scope of the reviewed sample, individual discussion of all 73 studies would reduce analytical clarity. The synthesis presented in Sections 3.1–3.4 therefore follows a structured aggregation logic. The studies were grouped by their primary analytical focus, with notable examples included to showcase important modelling methods, structural factors, and how stakeholders are involved. This approach preserves thematic coherence while avoiding repetitive description of conceptually similar studies.

3.1. Final Sample and Thematic Classification

Following a comprehensive PRISMA selection process, 73 studies made it into the final sample. This section highlights the evolution of inland Empty Container Management (ECM) research between 2015 and 2025. Figure 2 shows the annual distribution of papers, highlighting peaks in 2022 and 2023, followed by a decrease in studies in 2025, since the PRISMA analysis was performed that year.

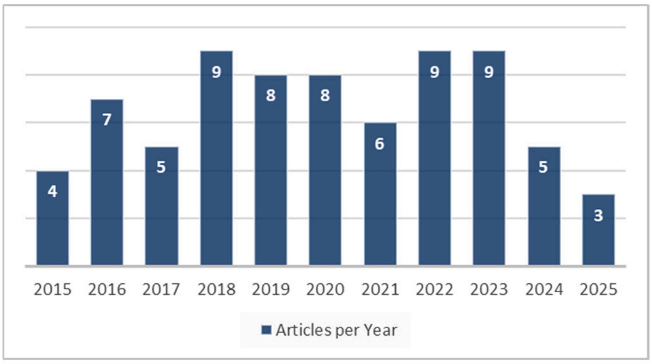

Figure 2. Annual distribution of articles (2015–2025).

Figure 2 illustrates a sustained research interest in inland Empty Container Management (ECM) over the period 2015–2025. Each year, scientific literature continues to cover ECM, showing a regular flow of studies throughout the period reviewed. The noticeable increase in publications in 2022 and 2023 suggests a growing academic focus on inland container imbalances, driven by rising cost pressures, sustainability concerns, and disruptions in global and regional supply chains. The reduced number of studies in 2025 is due to the PRISMA analysis being conducted that year, rather than a decrease in research interest.

ECM and ECR research can be considered a global research topic when viewed through its geographical distribution. The final sample of 73 studies was analysed based on the country of affiliation of the first author, a criterion selected to ensure consistency and comparability across the dataset, particularly in cases where empirical studies were not explicitly country-specific or involved multiple regions. Figure 3 presents the distribution of the analysed studies by country of first-author affiliation.

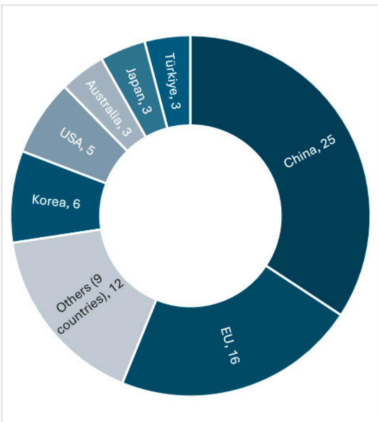

Figure 3. Geographic distribution of studies by first-author affiliation.

The geographical distribution reveals a strong concentration of ECM/ECR research in a limited number of regions. China clearly dominates the literature, accounting for the largest share of publications, followed by the European Union as the second most significant research cluster: Germany (5), Poland (3), Sweden (2), Netherlands (2), France (1), Denmark (1), Spain (1), and the Czech Republic (1). EU countries are aggregated to reflect the integrated nature of European research programmes and collaborative logistics research networks. South Korea and the United States represent additional major contributors, while Australia, Japan, and Türkiye contribute a smaller but still visible number of studies. Together, these regions reflect both their significant role in global container flows and their advanced research capacity in logistics and transport optimisation.

At the same time, a group of additional countries contributes only a limited number of publications, indicating a fragmented and uneven global research landscape. Countries with two publications include the United Kingdom, Singapore, and India, while countries represented by a single publication include Egypt, Qatar, Brazil, South Africa, Chile, and Malaysia. This imbalance suggests that inland ECM/ECR research is shaped by regions with high container volumes, export-oriented economies, and well-developed logistics research ecosystems, while many regions affected by empty container imbalances remain underrepresented in the literature.

In addition to sustaining research interest and broad global geographic dispersion, ECM and ECR research exhibits high scientific quality and a strong publication profile. The 73 selected studies were analysed according to journal quartile rankings based on the Scimago Journal Rank (SJR), chosen for its broad coverage of logistics and transport journals and its consistent availability across the analysed period. Each study was classified into quartiles (Q1–Q4) according to the journal's ranking in the year of publication, while journals not indexed in SJR were identified separately. Figure 4 presents the distribution of studies across journal quartiles.

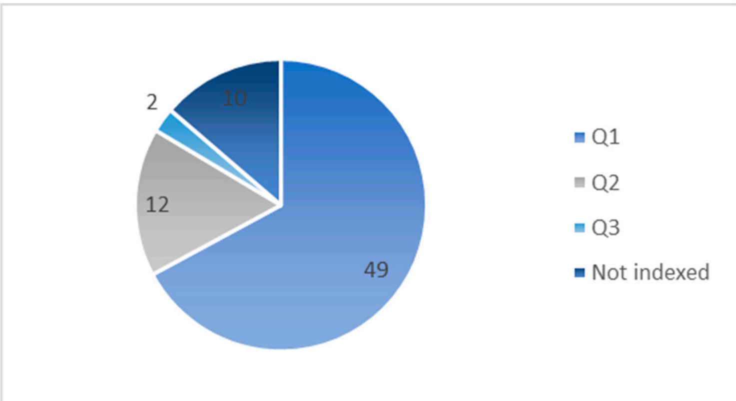

Figure 4. Distribution of ECM/ECR studies by journal quartile (SJR).

The quartile distribution shows that most ECM/ECR studies are published in high-ranked journals. Over half of the articles examined are published in Q1 journals, showing that the issue of empty container management is gaining more attention in leading academic publications. Q2 journals form the second largest group, while Q3 (Q4 = 0) journals represent a smaller share of the literature. There are only a few studies that appear in journals outside of the SJR index.

This distribution suggests that ECM/ECR research is not only growing in volume but is also gaining recognition within high-impact scientific journals. At the same time, the dominance of Q1 and Q2 outlets contrasts with the methodological fragmentation identified in subsequent sections, highlighting that publication quality does not necessarily imply methodological standardisation.

In the absence of a standardised methodological framework, ECM/ECR research has evolved through a variety of approaches, ranging from purely optimisation-oriented models to more integrated, sustainability-driven, and data-based frameworks. This evolution reflects the growing complexity of empty container management and its increasing relevance for transport systems, logistics operations, and policymaking. Moreover, the reviewed studies exhibit substantial variation across thematic categories, highlighting the multidimensional nature of ECM, which spans global supply chain dynamics, digital transformation, and institutional coordination. Table 1 presents the thematic classification of the 73 analysed studies, reflecting the multidimensional nature of Empty Container Management. The studies are grouped into seven thematic categories, ranging from global supply chain dynamics and logistics management to digitalisation and institutional coordination. Given the absence of a standardised methodological framework or shared analytical taxonomy in inland ECM research, the thematic categories were identified inductively during the review process. Rather than being imposed a priori, the classification emerged progressively through cross-comparison of studies until conceptual saturation was reached. This approach ensured that the categories reflect the dominant research orientations observed in the literature while simultaneously revealing the heterogeneity of modelling assumptions, system boundaries, and analytical vocabularies across studies.

Table 1. Classification of 73 studies by thematic focus.

Theme	Number of Studies	Description
Logistics management and services	17	Operational and service-oriented aspects
Operational and process optimisation	17	Technical core (models, algorithms)
International trade and supply chains	12	Global and network-oriented aspects
Environmental and sustainability assessment	11	Environmental approach
Technology and data-driven optimisation	9	Digital and AI elements
Policy, governance and institutional context	4	Institutional and policy dimension
Coordination and stakeholder cooperation	3	Collaborative aspects

Since the main thematic categories in ECM literature (optimisation, digitalisation, sustainability, and coordination) are already well established, they were further refined using analytical criteria to enable a more in-depth synthesis. Within the "optimisation" stream, contributions were distinguished according to the level of decision-making (strategic network design, tactical inventory/capacity management, and operational routing and scheduling), as well as by their treatment of uncertainty (deterministic vs. stochastic/robust models). In the "digitalisation" stream, a distinction was made between solutions that enhance visibility and tracking, demand forecasting, and stakeholder coordination (platform-based solutions). Within the "sustainability" stream, studies were differentiated between studies that focus exclusively on emission estimation and those that analyse cost–emission trade-offs and modal shift or intermodal decision-making. This analytical refinement shows that these themes strongly overlap (e.g., digitalisation often acts as an enabler of coordination or optimisation) and that meaningful comparison between studies requires consideration of decision levels, modelling assumptions, and implementation conditions, rather than relying solely on basic thematic labels.

Taken together, the reviewed studies reveal a diverse research focus, ranging from isolated, cost-driven optimisation models to integrated frameworks that combine operational, environmental, economic, and digital perspectives. The analysis of these works reveals that researchers have progressively uncovered the multidisciplinary nature of Empty Container Management (ECM), a field that bridges logistics optimisation, transport economics, environmental sustainability, and data science.

Although not every article explicitly addresses all these focus areas, each contributes to a broader understanding of ECM by examining a specific aspect such as efficiency, intermodality, collaboration, or digital transformation. Collectively, these studies reaffirm that inland empty container management is not a narrow technical problem but a complex and evolving system that requires the coordinated interaction of technology, institutions, and infrastructure.

However, despite sustained publication activity and high journal quality, inland ECM research does not converge toward a unified analytical structure. The reviewed studies differ in thematic scope, modelling assumptions, system boundaries, and stakeholder representation. This lack of methodological standardisation and shared conceptual vocabulary limits cumulative knowledge development and hinders the integration of findings across operational, structural, and institutional dimensions. Addressing this gap requires a system-oriented framework capable of structuring and connecting these fragmented research streams.

3.2. Factors Generating the Occurrence of Empty Containers

In addition to their multimodal utility, containers possess long-term value as reusable assets circulating through the global value chain. They are designed to protect goods under diverse climatic and operational conditions in both maritime and inland transport, thereby enabling global trade to operate continuously and reliably. However, given the vast volume of container capacity produced to support international trade, logistics faces the demanding task of ensuring their efficient utilisation. A key challenge in this regard is Empty Container Management (ECM), which seeks to address the persistent issue of empty container imbalances.

In practice, the circulation of containers within global supply chains is highly uneven, leading to persistent mismatches between supply and demand. The reviewed literature identifies multiple interacting drivers of empty container imbalances. Based on iterative cross-analysis of the included studies, these drivers can be analytically grouped into three main categories:

1. Generation causes—structural and demand-driven factors creating empty containers.
2. Management inefficiencies—operational shortcomings and coordination failures that exacerbate the problem.
3. Systemic barriers—regulatory, institutional, and infrastructural constraints that limit effective ECM.

These three groups represent distinct streams originating from diverse sources: structural trade flows, operational logistics practices, and systemic institutional frameworks. The reviewed literature indicates that empty container imbalances do not arise from a single dominant factor, but from the interaction of structural trade patterns, operational management practices, and systemic constraints. These determinant groups overlap and reinforce one another, jointly shaping the occurrence, scale, and persistence of empty container flows in inland logistics networks. As a result, empty container imbalances emerge as a multi-causal and structurally embedded phenomenon rather than a purely operational inefficiency.

While the reviewed literature clearly acknowledges that empty container imbalances are shaped by structural trade asymmetries, operational management practices, and systemic institutional constraints, these determinant groups are examined separately. Most studies concentrate on one category of drivers, treating the remaining dimensions as contextual or exogenous conditions rather than analytically interdependent variables. As a

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result, there is limited integration of these three parameter groups within a unified evaluative framework capable of capturing their cross-stakeholder interactions. This analytical separation restricts a comprehensive understanding of how structural, operational, and institutional factors jointly generate and sustain inland empty container imbalances.

3.2.1. Generation Causes

Empty container imbalances fundamentally arise from the dynamics of global goods exchange. The main feature of global trade is the persistence of imbalanced flows that create container surpluses in import-heavy regions and deficits in export-oriented ones [7,22–24]. The key structural drivers of empty container generation are asymmetric import–export flows, economic trade disparities, and one-way shipping patterns, widely recognised in the literature [9,25–27]. For instance, persistent trade deficits between China and Europe have led to large accumulations of empty containers, requiring costly repositioning [28]. Such accumulations occur because containers are emptied after goods arrive at their destination, without corresponding export cargo to refill them [7]. This process is not confined to isolated points but unfolds regionally: containers concentrate in areas with high import activity and remain scarce in export-oriented regions [14]. As a result, some regions face persistent surpluses [29,30], while others struggle with chronic shortages [11,31].

Beyond these trade imbalances and asymmetries, the problem is further compounded by demand-related dynamics. Temporal and seasonal demand fluctuations, demand uncertainty, and unpredictable inland container demand disrupt synchronised flows and create additional mismatches [1,32–35]. Stochastic customer ordering behaviour and inconsistent container return patterns further intensify these imbalances [36,37].

The reviewed literature consistently shows that these generation-related causes of empty container imbalances are rooted in global trade structures and demand-side dynamics [7,22]. As such, they originate outside the direct control of individual logistics operators or inland transport actors. Rather than representing temporary disruptions, they constitute persistent background conditions of international trade, characterised by structural asymmetries, demand uncertainty, and spatial concentration of container flows. Within the ECM literature, these factors are therefore commonly treated as a distinct group of determinants that shape the initial occurrence and scale of empty container imbalances.

From the above, it can be concluded that container imbalances are not merely an operational inefficiency or a logistical problem of resource repositioning. Rather, they are a consequence of the global concentration of production and a lengthy period of economic specialisation, which makes the complete elimination of empty container movements systemically and structurally unrealistic in the long term. This macroeconomic orientation of container flows therefore limits the effectiveness of purely partial optimisation solutions and highlights the need for a more systemic approach to management. Since imbalances in empty container management represent a structural issue, this perspective introduces important directions for future research—namely, not only how empty container management can be optimised, but under which structural conditions such optimisation can be effective.

3.2.2. Management Inefficiencies

The reviewed literature identifies a set of specific factors contributing to inefficiencies in empty container management:

- Fragmented logistics networks without integrated planning frameworks encourage reactive repositioning strategies [38–40].
- Ineffective container circulation cycles, misaligned planning horizons, and poor forecast accuracy [41,42].

- Minimal information sharing, decentralised decision-making, and siloed operations lead to duplicated repositioning efforts [43–45].
- Inconsistencies in container usage patterns and a lack of synchronised decision-making result in underutilised transport capacity [46].
- Uncoordinated return flows, depot saturation, and inefficient truck routing disrupt container circulation and turnover [47].
- Spatial and geographic disparities, although rooted in structural trade patterns, manifest operationally through depot–demand separation, discrepancies in demand and return patterns, and fragmented inland depot networks, all of which hinder balanced container flows [30,37,48,49].
- Lengthy filling/emptying processes at different times and locations—Containers are often emptied and filled at different locations, which results in delays and increases repositioning time and costs [5].
- Repositioning without profit—Shipping companies are forced to reposition empty containers due to trade imbalances, which lead to additional operational costs without generating revenue [50].
- High detention (and, where applicable, demurrage) fees—Shipping companies impose high fees on containers that remain in depots longer than expected, further driving up the costs associated with container storage and repositioning [37].
- Insufficient coordination between importers and exporters—The absence of effective alignment prevents the optimisation of container flow and leads to further inefficiencies [37].
- Geographic mismatch—Containers are not always available where they are needed, causing inefficiencies in repositioning [3].

Taken together, the reviewed studies indicate that empty container imbalances, once generated, are further shaped by a set of operational and management-related inefficiencies within inland logistics systems. These inefficiencies are associated with fragmented networks, limited coordination, logistical mismatches, and cost-intensive practices encountered by stakeholders in day-to-day container management. The literature links these conditions to prolonged turnaround times, increased repositioning costs, reduced transport efficiency, and limited operational flexibility in responding to dynamic trade and demand patterns.

The results therefore indicate that optimising individual processes alone is not sufficient, as the problem is broader and related to the way the entire system is organised and coordinated. Optimisation models alone cannot eliminate inefficient management if they are not supported by improved collaboration and coordination within the logistics system.

3.2.3. Regulatory and Institutional Factors—Systemic Barriers

Beyond operational inefficiencies, systemic barriers rooted in regulatory and institutional frameworks also play a significant role in shaping Empty Container Management (ECM) outcomes. International container value chains operate across national borders and are therefore embedded in diverse regulatory environments, institutional arrangements, and governance structures. This cross-border setting exposes ECM activities to heterogeneous legal requirements, commercial practices, taxation regimes, and logistical standards, all of which influence coordination mechanisms, cost structures, and operational efficiency. The reviewed literature identifies several regulatory and institutional factors that affect ECM performance, including:

- Slow institutional response, fragmented actors, and a lack of joint planning [51,52].
- Different regulations across regions that hinder coordinated repositioning and optimisation [39].

- Limited digital integration, lack of real-time information systems, and insufficient feedback mechanisms preventing responsive adjustments to container flows [11,31,53].
- Leasing inefficiencies, container type mismatches, and modal disintegration further complicate repositioning decisions and integration across transport modes [49].

Taken together, the literature indicates that regulatory, institutional, and systemic factors constitute an additional layer of constraints influencing inland ECM. These factors operate alongside global market forces and operational decision-making by logistics actors, shaping the conditions under which empty containers are managed. In this sense, institutional and regulatory environments emerge in the literature as exogenous determinants that condition coordination, infrastructure development, digitalisation, and environmental compliance within ECM, thereby contributing to persistent inefficiencies and variability in inland container flows.

Although regulatory, leasing, and digital integration constraints are recognised as relevant determinants of inland ECM performance, they are treated as exogenous background conditions rather than structurally embedded components of the optimisation and management architecture. Variations in leasing strategies, digital integration levels, and regulatory frameworks across regions directly influence operational coordination, forecast reliability, container availability, and repositioning efficiency. However, the literature rarely situates these institutional determinants within a structured analytical relationship to generation causes and management inefficiencies. This separation limits a comprehensive understanding of how institutional heterogeneity interacts with structural trade imbalances and operational practices in shaping inland empty container dynamics.

A key finding is that regulatory and institutional factors have been examined far less quantitatively compared with optimisation models. Several studies among those analysed in this PRISMA-based review address them only conceptually or treat them as external constraints in the development of methodological solutions. Only a limited number of studies consider them as the central subject of empirical analysis. This reveals an important methodological gap in ECM research, as the institutional dimension is often underestimated despite its systemic influence.

3.3. Key Activities and Processes in ECM

Empty Container Management (ECM) comprises operations and strategies shaped by external factors such as global trade imbalances and unpredictable container demand. The ECM operations include returning empty containers, transferring them to new loading sites, relocating to depots or storage, cleaning and maintenance, and eventual disposal. The ECM process begins once full containers are unloaded at inland locations and is driven by two requirements:

1. Maritime demand for empties at other locations.
2. Inland need to remove empties from unloading sites.

Both requirements generate the movement of empty containers and the core ECM operation: repositioning, the transfer of empties from surplus to deficit locations across ports, depots, and inland facilities [5,27,29,53]. Although terms vary (repositioning, relocation, redistribution), the essence is the same: shifting empties to where they are needed to address structural imbalances across global and regional networks. As presented in Table 2, repositioning is tightly linked with other ECM complementary processes, decision-making, coordination, storage, leasing, maintenance, and digital innovations, that together shape ECM's operational and strategic landscape.

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Table 2. Processes in ECM.

Process Category	Definition/Description	Authors	Key Effects
Relocation/Repositioning	Transfer of empty containers from surplus to deficit locations across ports, depots, and inland facilities.	[5,27,29,54,55]	Balancing flows, reducing shortages, ensuring equipment availability.
Decision-Making & Optimisation	Decisions on relocation, routing, mode choice, timing, container type/condition, often supported by optimisation models.	[15,33,36,38,46,56–61]	Minimisation of costs, improved routing efficiency, better alignment with demand.
Coordination & Collaboration	Joint planning and coordination between ports, carriers, terminals, truck operators, and shippers; contractual frameworks and container sharing.	[6,34,36,43,44,46,50,62–65]	Reduced empty moves, improved utilisation, stakeholder synergy, lower costs.
Inventory Management & Storage	Storage and inventory control at ports, inland depots, and dry ports; balancing availability and costs; depot management as infrastructural nodes.	[1,3,5,11,14,18,28,31,32,66,67]	Balance between supply and demand, reduced congestion, cost control, improved container availability.
Leasing, Procurement & Maintenance	Ensuring availability through leasing, container substitution, procurement, repair, cleaning, maintenance, and disposal.	[3,23,28,31,44,50,57,66,68,69]	Increased fleet flexibility, cost optimisation, reduced shortages, extended lifecycle of containers.
Innovative Operational Practices	Alternative operational models such as street-turns, foldable/combinable containers, and yard management innovations.	[3,29,31,37,39,43,48,49,51,70,71]	Avoidance of depot storage, cost savings, reduced double-handling, increased space efficiency.
Multimodal & Intermodal Integration	Coordinating rail, road, barge, and sea transport for empty container flows; regional and intermodal routing strategies.	[3,4,6,8,24,27,35,62,72–75]	Lower emissions, reduced costs, improved inland connectivity, sustainable logistics.
Digitalisation & Strategic Innovations	Use of ICT, blockchain, AI, IoT, and real-time platforms for forecasting, coordination, and adaptive decision-making.	[6,10,11,31,44,45,76]	Enhanced forecasting, real-time tracking, decentralised decision-making, improved adaptability and efficiency.

Taken together, the reviewed studies indicate that the effectiveness of Empty Container Management cannot be attributed to repositioning activities alone. Instead, the literature consistently highlights the importance of complementary processes—including decision-making, coordination, inventory management, leasing and maintenance, multimodal integration, and digital support mechanisms—in shaping ECM performance. These processes interact with repositioning activities by influencing when, where, and how empty containers are moved within inland logistics networks.

The synthesis of the reviewed literature therefore suggests that ECM functions as an interconnected system of activities rather than a set of isolated operational tasks. While many studies focus on specific processes or optimisation problems, the combined evidence points to the need for considering the interactions among multiple ECM processes to fully understand persistent costs, inefficiencies, and environmental impacts in inland container logistics.

However, despite recognising ECM as an interconnected system of processes, the reviewed literature rarely provides a structured modelling approach that explicitly evaluates the interdependencies among these activities within a unified analytical framework. As a result, interactions between repositioning, inventory management, leasing strategies, coordination mechanisms, multimodal integration, and digital systems remain analysed in isolation rather than as mutually reinforcing components of a dynamic ECM architecture. Therefore, improving a single process or activity in empty container repositioning does not guarantee overall system efficiency if other processes remain uncoordinated or inadequately managed. The fundamental challenge thus lies in the comprehensive consideration of these activities and their concrete integration into real-world operational environments.

3.4. ECM Stakeholders and Their Influence

Inland Empty Container Management (ECM) represents a particularly sensitive domain of the container logistics chain, where global trade dynamics intersect with fragmented regional infrastructures and heterogeneous stakeholder interests. Unlike the maritime domain, which is shaped by global shipping networks and trade asymmetries, inland ECM is characterised by the interaction of multiple actors whose decisions collectively determine the efficiency of empty container repositioning (ECR).

Based on the reviewed literature, eight key stakeholder groups can be identified in the context of inland ECM. Each group fulfils a distinct role within the container logistics system, and their combined actions shape operational performance, coordination requirements, and system efficiency in inland transport environments, where cross-border operations and institutional fragmentation further increase complexity.

1. Shipping Companies
   Role: Responsible for the ownership, repositioning, and management of empty containers.
   Objectives: Minimise repositioning, storage, and leasing costs, and determine routing and allocation strategies across container networks [7,50,64].
2. Port Authorities and Terminals
   Role: Manage container handling, storage, and redistribution at ports and inland terminals.
   Objectives: Efficient capacity utilisation and smooth operational flows affecting container availability and circulation [8,16,29].
3. Freight Forwarders and Inland Transport Operators
   Role: Responsible for land transportation of containers between ports, depots, and inland terminals.
   Objectives: Execute container transport in line with demand requirements and operational constraints, ensuring timely repositioning of empty containers [14,37].
4. Shippers and Consignees
   Role: End users of containers, where shippers require empty containers for exports and consignees return empty containers after unloading.
   Objectives: Secure timely access to containers, minimise waiting times, and avoid detention and demurrage costs (Exporters and Importers) [5,13,15].
5. Container Leasing Companies
   Role: Provide containers to shipping companies and logistics actors when supply is insufficient.
   Objectives: Generate revenue through leasing while supporting container availability and fleet flexibility [1,22,45].
6. Government and Regulatory Bodies
   Role: Influence ECM through policies, regulations, and environmental standards.
   Objectives: Ensure compliance with sustainability targets, emissions regulations, and transport efficiency goals [8,11,35].
7. Inland Depot and Terminal Operators
   Role: Manage storage, handling, and turnaround of empty containers at inland locations.
   Objectives: Maintain efficient container circulation and availability within hinterland networks [11,13].
8. Logistics Service Providers (3PL)
   Role: Act as intermediaries coordinating information flows, inventory management, and transport activities.
   Objectives: Facilitate coordination among stakeholders and optimise resource utilisation across the supply chain [6,22].

The reviewed literature consistently shows that these stakeholder groups are highly interdependent, with decisions made by one group often shaping the operational conditions faced by others. Freight forwarders and inland transport operators occupy a central operational position, as they execute the physical repositioning of empty containers between ports, depots, and inland terminals. Through this role, they translate upstream decisions into transport activity, directly affecting transport intensity, timing, and performance.

At the same time, the literature indicates that inland transport operations are strongly conditioned by factors beyond the direct control of transport operators. Container routing strategies of shipping companies, handling and processing delays at ports and terminals, demand variability generated by shippers and consignees, container availability managed by leasing companies, regulatory constraints, depot capacity limitations, and coordination practices of logistics service providers all influence transport efficiency. As a result, stakeholder interdependencies and asymmetries emerge as a recurring structural feature of inland ECM, contributing to persistent coordination challenges, delayed container flows, and inefficiencies in inland transport operations despite ongoing optimisation efforts.

Although the literature identifies key stakeholder groups and acknowledges their interdependence, limited analytical attention is devoted to how operational burdens, costs, and risk exposure are distributed across these actors. In particular, inland transport operators frequently function as the executing layer that absorbs variability generated by trade asymmetries, leasing strategies, and upstream allocation decisions. However, the studies included in the PRISMA-based review rarely provide structured models that explicitly examine stakeholder asymmetries or quantify how decision-making power and imbalance generation translate into differentiated operational impacts. This gap constrains a comprehensive understanding of responsibility allocation and systemic inefficiencies within inland ECM.

4. Discussion and Key Findings

The first research question sought to identify the fundamental causes of imbalances in empty container management. Based on the presented results, three key causes can be highlighted. The first is related to the structural imbalance of global trade flows. In regions that are more import-oriented, empty containers tend to accumulate, while export-oriented regions require these containers. As a result, systemic surpluses and shortages of empty containers are generated [9,25–27]. It can therefore be concluded that inland transport cannot eliminate this structural cause of imbalance but can only manage it through greater or smaller volumes of empty repositioning movements [9,24–27]. The literature also emphasises that empty container flows represent a systemic issue within global logistics networks, which is why the management of these imbalances is often transferred to inland transport systems. Through this review of this body of literature, the present study confirms these findings; however, it also highlights that the causes of imbalances are not limited to trade asymmetries but also include demand uncertainty and temporal fluctuations. This represents the second major cause of imbalances, as seasonal variations and stochastic ordering patterns can generate local shortages or surpluses even in regions where the net trade balance is not extreme. Consequently, the timely coordination of container returns and container availability becomes more difficult. Additional repositioning movements are therefore more frequently required, and surplus container inventories are unnecessarily maintained. This observation is supported by stochastic/robust and multi-period modelling approaches [33,36] as well as inventory-based models [2,5,11]. System costs increase rapidly when decisions are made in dynamic environments with limited information, which further reinforces these imbalances.

The third cause of imbalances is more systemic in nature and relates to regulatory and institutional factors. These factors often determine whether coordination is feasible at all. The rules they establish may encourage decisions that are rational for individual actors but increase empty container movements at the system level [17,58]. The concluding finding related to the first research question can therefore be formulated as follows: the fundamental causes of imbalances in empty container management lie in structural mismatches between where and when empty containers become available and where and when they are needed. This mismatch primarily originates from trade flow asymmetries and demand uncertainty [9,25–27,33,36]. The extent to which this imbalance translates into costs, emissions, and additional empty movements in inland transport depends on operational coordination, capacity constraints, and institutional rules that either enable or hinder efficient empty container management [9,17,18,43,58]. Consequently, the practical objective of ECM is not the complete elimination of empty flows. Rather, ECM is more realistically oriented toward reducing these flows and limiting their associated costs and emissions under given structural conditions.

Main direction for future research: Future research should therefore shift its analytical perspective. Proposed solutions need to be assessed more realistically, as they cannot fully eliminate empty container flows. Instead, they should be understood as improvements operating within structural constraints, particularly trade imbalances and demand uncertainty.

The second research question aimed to identify the activities and processes associated with empty container management. The reviewed literature identifies repositioning, relocation, or redistribution of empty containers as the core operational process of Empty Container Management. This process represents the physical movement of empty containers from surplus to deficit locations and constitutes the functional centre of ECM. In addition to this core process, the literature consistently recognises a set of complementary processes that shape its execution. These include decision-making and optimisation [15,33], coordination and collaboration [6,34], inventory management and storage [1,3], leasing, procurement and maintenance [23,28], innovative operational practices [29,31], multimodal and intermodal integration [4,8], and digitalisation and strategic innovations [6,10]. These processes do not operate independently. They define the conditions under which repositioning takes place and directly influence its timing, location, and efficiency. Most existing studies analyse individual costs, isolated processes, or selected activity groups. This review shows that such approaches overlook the systemic character of ECM. The reviewed evidence indicates that ECM consists of one core process and multiple complementary processes that are mutually dependent. Accordingly, this review shifts the analytical focus from cost-based, emission-based, or single-process perspectives toward a holistic process-oriented view. A comprehensive understanding of ECM requires analysing both the core repositioning process and the interactions among complementary processes, as well as their combined influence on repositioning outcomes.

In this respect, our review goes beyond a purely descriptive classification of processes by demonstrating that many optimisation studies address only a narrow segment of the system scope (transport movements), while systemic, infrastructural, and coordination-oriented contributions show that repositioning cannot generate system-level effects without coordination processes, node management, and rules governing container use [9,18,63,70]. Therefore, improving a single process or activity in empty container repositioning does not guarantee overall system efficiency if other processes remain unregulated. Optimisation may improve a specific component, but the associated costs and empty movements are often simply transferred to other parts of the system. The fundamental challenge thus lies in the comprehensive consideration of these activities and their practical integration into operational environments. This implies that optimisation models may demonstrate powerful performance, but often only under assumptions that depots and terminals have no capacity constraints, that rules are clearly defined, and that stakeholders cooperate. If

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these conditions are not present in practice, improvements tend to remain localised (e.g., on a specific route), while the total number of empty movements across the network does not decrease or the problem is merely shifted elsewhere within the system.

Main direction for future research: It is essential to model ECM in a more comprehensive manner, particularly as an interconnected system of processes. Such modelling should explicitly account for real capacity constraints and coordination rules among stakeholders. This approach enables the evaluation of solution impacts at the system level, rather than only at the local level.

The third research question examined how the decisions of key stakeholders influence the processes involved in empty container management and the resulting system outcomes (costs, empty container movements, container and equipment availability, emissions, etc.). The findings indicate that the need to manage empty containers is not the result of decisions made by a single stakeholder, but rather the outcome of interdependent decisions within the network, where structural asymmetries frequently arise. It is shown, for example, that shipping lines, which set operational rules within the network and determine equipment availability, are not necessarily the same actors who execute most empty repositioning movements or bear the largest share of the associated costs and emissions [9,63,70]. This observation is consistent with studies that interpret empty flows because of fragmented decision-making and limited coordination, rather than as the inefficiency of a single process or the actions of an individual stakeholder within the network [9,54].

The response to the third research question therefore highlights the interdependence of stakeholders in empty container management. In practice, improvements are possible when responsibilities and decision-making levers are distributed among stakeholders in accordance with who makes decisions and who bears their consequences. If such alignment is not achieved, inefficiencies persist because of structural asymmetries within the network. Indeed, ECM literature often treats the issue as an optimisation problem for an individual stakeholder, which proves problematic and does not resolve the systemic nature of empty container imbalances. Sustainable improvements are therefore most likely when incentives and rules (e.g., container return policies, detention rules, access to information, and depot usage) are coordinated among actors. Otherwise, optimisation by one stakeholder is likely to manifest as a transfer of costs or emissions to other parts of the network.

Main direction for future research: It is essential to recognise that research on stakeholders, particularly coordination and governance, is not merely a complement to technical optimisation, but a prerequisite for solutions to function at the system level. Future research should therefore place greater emphasis on the empirical investigation of how stakeholder interests are aligned, how responsibilities are distributed, and how governing rules are structured. These rules ultimately determine whether locally effective optimisations can be scaled and sustained across the broader inland network.

The answers to all three research questions highlight three fundamental research gaps in the existing ECM literature:

- local optimisation does not necessarily produce system-level improvements, as costs may simply be transferred to other parts of the ECM system,
- technological solutions do not function effectively without appropriate rules and data-sharing mechanisms, and
- those who determine operational rules and equipment availability often do not bear the full consequences of empty container movements.

An additional important finding is that institutional and regulatory factors remain insufficiently examined empirically, despite strongly influencing whether proposed solutions are feasible in practice.

4.1. Theoretical and Practical Contributions

A systematic literature review enables a better understanding of ECM, particularly in the context of inland transport. The issue is addressed holistically as part of a broader logistics system rather than merely as the optimisation of a single activity or process. On this basis, three key theoretical contributions can be highlighted. The first provides a clearer understanding of the origins of imbalances. The analysis shows that imbalances arise from trade asymmetries as well as from uncertain and fluctuating demand. However, rules and institutional arrangements determine the domains in which cooperation between actors or stakeholders is possible. This implies that ECM can be understood primarily as an activity aimed at limiting imbalances rather than eliminating them. Consequently, empty container movements, associated costs, and emissions persist despite the numerous solutions proposed in the literature.

While the first contribution focused on understanding the origins of imbalances, the second theoretical contribution of the literature review provides a clearer definition of what ECM encompasses. Although repositioning remains the core of ECM, this review shows that several additional processes influence the final system outcome. A key insight is that ECM should not be understood merely as the "movement of containers," but rather as a set of interrelated activities. In many cases, improving one process (for example, transport optimisation) may shift inefficiencies to other processes within the network. As a result, while one component of ECM may improve, overall system inefficiencies may persist.

The third theoretical contribution highlights the importance of stakeholders in addressing process inefficiencies and imbalances in ECM. In practice, stakeholders are highly interdependent, even though those who determine the rules and equipment availability (e.g., shipping lines) do not necessarily experience the largest negative consequences. This review therefore helps explain why optimisation at the level of a single stakeholder often fails to produce improvements at the level of the entire empty container management system.

The key novelty of this review, compared with existing reviews, lies in the comprehensiveness of its analytical perspective on ECM. Previous reviews have primarily focused on how to optimise repositioning, often concentrating on optimisation models and technical solutions. The novelty of the present review lies in systematically linking three analytical perspectives—causes, processes, and stakeholders—and demonstrating that the effectiveness of optimisation depends on institutional rules, coordination mechanisms, and node capacity constraints. In doing so, the contribution goes beyond simple thematic classification and explains the mechanism through which many proposed solutions remain locally effective without improving overall system performance.

This review also provides an important practical contribution, as it helps companies and decision-makers identify realistic measures for improving system performance. It distinguishes between factors that are difficult to influence (e.g., global trade flows) and those where improvements can be achieved (e.g., coordination mechanisms, operational rules, and node management). While such measures cannot eliminate empty flows, they can significantly reduce them, which in turn may lead to meaningful reductions in both costs and emissions.

For companies, this review is also valuable because it helps identify relationships among stakeholders. It highlights where the main dependencies lie and where it is most beneficial to strengthen cooperation agreements among stakeholders (e.g., container reuse, coordinated returns, information sharing, and capacity agreements). The ultimate outcome of such coordination is the reduction in unnecessary empty container movements. Based on these findings, the primary practical contribution of this systematic literature review is not the development of a universal solution to the ECM problem, but rather to help assess which measures are more likely to generate system-level improvements and which are likely to result only in local improvements or the transfer of costs from one part of the system to another.

4.2. Limitations and Future Research

Limitations: This study is subject to limitations inherent to its methodological scope. As a PRISMA-based systematic literature review, it does not develop or empirically validate a specific optimisation or decision-making model for Empty Container Management (ECM) but is intentionally confined to the structured synthesis and analytical integration of existing research. The contribution therefore lies in identifying patterns of analytical segmentation and conceptual separation within inland ECM literature, rather than in proposing a directly implementable operational solution. Furthermore, this review is limited to peer-reviewed academic sources, which may exclude relevant industry practices, policy reports, or emerging modelling approaches not yet reflected in the scientific corpus.

The reviewed studies also differ in their modelling assumptions, decision-making levels, and contextual specificity. Such heterogeneity limits the direct comparability of reported performance improvements across studies and reinforces the need for conditional interpretation of the results, particularly with respect to information availability, node capacity constraints, and governance settings.

Future research: Future research should extend the integrative analytical perspective developed in this study by operationalising the identified interdependencies between determinants, processes, stakeholders, and performance dimensions within empirically grounded modelling frameworks. Further work should focus on designing and validating integrated decision-support approaches that jointly consider logistics costs and transport-related emissions while accounting for stakeholder asymmetries and structural trade conditions characteristic of inland ECM systems. Such efforts would contribute to strengthening the systemic explanatory and practical applicability of inland ECM modelling.

Based on the three identified research gaps, several key directions for future research can be proposed. First, there is a need for more integrated models that simultaneously incorporate the causes of imbalances, inland processes, and stakeholder decision-making, rather than treating these elements separately. Second, future studies should more directly examine whether local optimisation reduces total empty movements and emissions or merely shifts costs and operational burdens to other nodes, actors, or time periods. Third, institutional and regulatory factors should be investigated more empirically as a central explanatory dimension since these conditions ultimately determine whether coordination is feasible and whether the proposed solutions can be implemented in practice.

5. Conclusions

This systematic literature review clarifies the nature of empty container imbalances and the role of Empty Container Management (ECM) as the set of processes through which these imbalances are addressed within inland logistics systems. The reviewed literature consistently shows that empty container imbalances arise from the interaction of global trade dynamics, inland operational conditions, and regulatory–institutional environments. These imbalances are not episodic disruptions, but persistent outcomes of asymmetric trade flows, decentralised decision-making, and heterogeneous governance structures shaping inland container circulation.

The answers to the research questions highlight several fundamental gaps in the existing ECM literature. First, local optimisation does not necessarily produce system-level improvements, as costs may simply be transferred to other parts of the ECM system. Second, technological solutions do not function effectively without appropriate rules and data-sharing mechanisms. Third, those who determine operational rules and equipment availability often do not bear the full consequences of empty container movements. The novelty of the present review lies in systematically integrating three analytical perspectives—causes, processes, and stakeholders—and demonstrating that the effectiveness of optimisation is conditioned by institutional rules, coordination mechanisms, and node capacity constraints. In this way, the contribution goes beyond a simple thematic classification and provides an explanation of the mechanisms through which many proposed solutions remain locally effective without improving performance at the system level.

These findings indicate that inland empty container management should not be approached as a problem that can be fully resolved by eliminating empty movements. Instead, research should focus on how effectively solutions perform under real-world conditions characterised by trade imbalances and demand uncertainty. Future studies should more closely integrate the causes of imbalances, inland processes, and stakeholder decision-making, and assess impacts at the level of the entire network rather than individual routes.

This review also offers an important practical contribution, as it helps companies and decision-makers identify realistic measures for improving system performance. It distinguishes between factors that are difficult to influence (e.g., global trade flows) and those where improvements are feasible (e.g., coordination mechanisms, operational rules, and node management). For companies, this review is also valuable because it helps them better understand the relationships among stakeholders. In doing so, it highlights the main dependencies within the system and indicates where it is most beneficial to strengthen cooperation agreements among stakeholders.

Effective outcomes can therefore be achieved through improved coordination among stakeholders, clearly defined operational rules (such as return policies, detention regimes, and agreements on access and shared use), and by addressing node-related constraints, including capacity and depot or terminal management. Without these conditions, optimisation models and digital tools tend to improve only isolated parts of the system or shift the problem elsewhere rather than reducing the overall volume of empty container movements and associated emissions.

It should also be noted that this study is limited by the scope of its methodology, as the PRISMA-based systematic literature review focuses on the analytical synthesis of peer-reviewed academic studies and does not develop or empirically validate a specific operational model for empty container management. Institutional and regulatory factors remain insufficiently examined empirically despite strongly determining whether proposed solutions are feasible in practice. In addition, the reviewed studies differ in their modelling assumptions, decision-making levels, and contextual specificity, which limits the direct comparability of reported performance improvements across different settings.

Future research should therefore empirically examine institutional and regulatory factors as key explanatory variables and test whether local optimisation reduces the total number of empty container movements and associated emissions at the network level. Future research should therefore explicitly incorporate these factors in further development of ECM research.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/systems14040356/s1, Table S1: PRISMA 2020 checklist.

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Abbreviations

The following abbreviations are used in this manuscript:

ECM	Empty Container Management
ECR	Empty Container Repositioning
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses

References

1. Chi, M.; Zhu, X.; Wang, L.; Zhang, Q.; Liu, W. Multi-Period Empty Container Repositioning Approach for Multimodal Transportation. *Meas. Control* **2024**, *57*, 361–377. [CrossRef]
2. Cai, J.; Li, Y.; Yin, Y.; Wang, X.; Lalith, E.; Jin, Z. Optimization on the Multi-Period Empty Container Repositioning Problem in Regional Port Cluster Based upon Inventory Control Strategies. *Soft Comput.* **2022**, *26*, 6715–6738. [CrossRef]
3. Castrellon, J.P.; Sanchez-Diaz, I.; Roso, V.; Altuntas-Vural, C.; Rogerson, S.; Santén, V.; Kalahasthi, L.K. Assessing the Eco-Efficiency Benefits of Empty Container Repositioning Strategies via Dry Ports. *Transp. Res. Part D Transp. Environ.* **2023**, *120*, 103778. [CrossRef]
4. Funke, J.; Kopfer, H. A Model for a Multi-Size Inland Container Transportation Problem. *Transp. Res. Part E Logist. Transp. Rev.* **2016**, *89*, 70–85. [CrossRef]
5. Cai, J.; Huang, Y.; Diao, C.; Jin, Z. Joint Optimization of Multi-Period Empty Container Repositioning and Inventory Control Based on Adaptive Particle Swarm Algorithm. *J. Mar. Sci. Eng.* **2025**, *13*, 1113. [CrossRef]
6. Mhiri, M.; Al-Yafi, K.; Legros, B.; Jouini, O.; Haouari, M. A Blockchain-based Framework to Optimize Shipping Container Flows in the Hinterland. *Int. Trans. Oper. Res* **2024**, *31*, 3808–3841. [CrossRef]
7. Abdelshafie, A.; Salah, M.; Kramberger, T. The Environmental Impact of Inland Empty Container Movements Within Two-Depot Systems. *Appl. Sci.* **2025**, *15*, 7848. [CrossRef]
8. Feng, X.; Wang, Z.; Wang, Y.; Yin, W.; Chao, Y.; Ye, G. Improving Resilience in an Intermodal Transport Network via Bulk Cargo Transport Coordination and Empty Container Repositioning. *Ocean Coast. Manag.* **2024**, *248*, 106970. [CrossRef]
9. Gusah, L.; Cameron-Rogers, R.; Thompson, R.G. A Systems Analysis of Empty Container Logistics—A Case Study of Melbourne, Australia. *Transp. Res. Procedia* **2019**, *39*, 92–103. [CrossRef]
10. Finke, S.; Kotzab, H. An Inland-Depots-for-Empty-Containers-Model for the Hinterland. *Marit. Bus. Rev.* **2017**, *2*, 126–141. [CrossRef]
11. Wang, Q.-B.; Wang, Z.-W.; Zheng, J.-F. Joint Optimization of Inventory and Repositioning for Sea Empty Container Based on Queuing Theory. *J. Mar. Sci. Eng.* **2023**, *11*, 1097. [CrossRef]
12. An, F.; Hu, H.; Xie, C. Service Network Design in Inland Waterway Liner Transportation with Empty Container Repositioning. *Eur. Transp. Res. Rev.* **2015**, *7*, 9. [CrossRef]
13. Numa-Navarro, I.; Wilmsmeier, G.; Gil, C. Improving Empty Container Management Using Street-Turn: A Case Study of the Colombian Logistics Network. *J. Transp. Geogr.* **2023**, *112*, 103709. [CrossRef]
14. Sommer, B.; Lee, S.; Holst, K.K.; Boomsma, T.K. Markov Decision Processes for Inland Empty Container Inventory Management. *Comput. Manag. Sci.* **2025**, *22*, 4. [CrossRef]
15. Xing, X.; Song, D.; Qiu, C.; Drake, P.R.; Zhan, Y. Joint Tank Container Demurrage Policy and Flow Optimisation Using a Progressive Hedging Algorithm with Expanded Time-Space Network. *Eur. J. Oper. Res.* **2023**, *307*, 663–679. [CrossRef]
16. Shiri, S.; Huynh, N. Optimization of Drayage Operations with Time-Window Constraints. *Int. J. Prod. Econ.* **2016**, *176*, 7–20. [CrossRef]
17. Yu, M.; Fransoo, J.C.; Lee, C.-Y. Detention Decisions for Empty Containers in the Hinterland Transportation System. *Transp. Res. Part B Methodol.* **2018**, *110*, 188–208. [CrossRef]
18. Hjortnaes, T.; Wiegmans, B.; Negenborn, R.R.; Zuidwijk, R.A.; Klijnhout, R. Minimizing Cost of Empty Container Repositioning in Port Hinterlands, While Taking Repair Operations into Account. *J. Transp. Geogr.* **2017**, *58*, 209–219. [CrossRef]
19. Maglić, L.; Gulić, M.; Maglić, L. Optimization of container relocation operations in port container terminals. *Transport* **2019**, *35*, 37–47. [CrossRef]
20. Golnar, M.; Beškovnik, B. Current state of environmental awareness of transport service stakeholders and end-customers in the intermodal transport chain. *Transport* **2024**, *39*, 1–12. [CrossRef]
21. Page, M.J.; McKenzie, J.E.; Bossuyt, P.M.; Boutron, I.; Hoffmann, T.C.; Mulrow, C.D.; Shamseer, L.; Tetzlaff, J.M.; Akl, E.A.; Brennan, S.E.; et al. The PRISMA 2020 Statement: An Updated Guideline for Reporting Systematic Reviews. *BMJ* **2021**, *372*, n71. [CrossRef]

22. Cai, M.; Li, H.; Guo, Z.; Lu, S. Data-Driven Empty Container Repositioning for Large Scale Railway Network With Fuzzy Demands. *IEEE Trans. Fuzzy Syst.* **2023**, *31*, 557–570. [CrossRef]
23. Adetunji, O.; Yadavalli, S.; AlRikabi, R.; Makoena, S. Economic Return Quantity Model for a Multi-Type Empty Container Management with Possible Storage Constraint and Shared Cost of Shipping. *Am. J. Math. Manag. Sci.* **2020**, *39*, 345–361. [CrossRef]
24. Clott, C.; Hartman, B.C.; Ogard, E.; Gatto, A. Container Repositioning and Agricultural Commodities: Shipping Soybeans by Container from US Hinterland to Overseas Markets. *Res. Transp. Bus. Manag.* **2015**, *14*, 56–65. [CrossRef]
25. Sáinz Bernat, N.; Schulte, F.; Voß, S.; Böse, J. Empty Container Management at Ports Considering Pollution, Repair Options, and Street-Turns. *Math. Probl. Eng.* **2016**, *2016*, 3847163. [CrossRef]
26. Basarici, A.S.; Satir, T. Empty Container Movements Arising from Cargo Seasonality: Turkish Terminals. *Marit. Bus. Rev.* **2019**, *4*, 238–255. [CrossRef]
27. Jeong, Y.; Saha, S.; Chatterjee, D.; Moon, I. Direct Shipping Service Routes with an Empty Container Management Strategy. *Transp. Res. Part E Logist. Transp. Rev.* **2018**, *118*, 123–142. [CrossRef]
28. Kuźmicz, K.A.; Pesch, E. Container Depot Location Problem in the Frame of the Polish Part of the New Silk Road. *MATEC Web Conf.* **2020**, *312*, 02004. [CrossRef]
29. Jeong, Y.; Kim, G. Reliable Design of Container Shipping Network with Foldable Container Facility Disruption. *Transp. Res. Part E Logist. Transp. Rev.* **2023**, *169*, 102964. [CrossRef]
30. Kurtuluş, E. Optimizing Inland Container Logistics and Dry Port Location-Allocation from an Environmental Perspective. *Res. Transp. Bus. Manag.* **2023**, *48*, 100839. [CrossRef]
31. You, S.-S.; Long, L.N.B.; Kim, H.-S. Optimal Decision Making for Empty Container Management at Seaport Yard. *Logforum* **2023**, *19*, 6. [CrossRef]
32. Bandara, Y.M.; Garaniya, V.; Chin, C.; Leong, Z.H. Improving Logistics Management Using Foldable/Collapsible Containers: A Case Study. *Asian J. Shipp. Logist.* **2015**, *31*, 161–185. [CrossRef]
33. Zhao, Y.; Xue, Q.; Zhang, X. Stochastic Empty Container Repositioning Problem with CO2 Emission Considerations for an Intermodal Transportation System. *Sustainability* **2018**, *10*, 4211. [CrossRef]
34. Baykasoğlu, A.; Dudaklı, N.; Subulan, K.; Taşan, A.S. An Integrated Fleet Planning Model with Empty Vehicle Repositioning for an Intermodal Transportation System. *Oper. Res. Int. J.* **2022**, *22*, 2063–2098. [CrossRef]
35. Jeong, Y.; Kim, G.; Moon, I. Reliable Container Supply Chain under Disruption. *Ann. Oper. Res.* **2022**, *349*, 1345–1378. [CrossRef]
36. Lee, S.; Moon, I. Robust Empty Container Repositioning Considering Foldable Containers. *Eur. J. Oper. Res.* **2020**, *280*, 909–925. [CrossRef]
37. Legros, B.; Fransoo, J.; Jouini, O. How to Optimize Container Withholding Decisions for Reuse in the Hinterland? *Eur. J. Oper. Res.* **2024**, *316*, 930–941. [CrossRef]
38. Wu, S.; Sun, Y.; Lian, F.; Yang, Z. Reposition of Empty Containers of Different Life Stages Integrated with Liner Shipping Network Design. *Marit. Policy Manag.* **2020**, *47*, 43–56. [CrossRef]
39. Xing, L.; Xu, Q.; Cai, J.; Jin, Z. Distributed Robust Chance-Constrained Empty Container Repositioning Optimization of the China Railway Express. *Symmetry* **2020**, *12*, 706. [CrossRef]
40. Wadhwa, S.S.; Farahmand, K.; Vachal, K. A Deterministic Mathematical Model to Support Future Investment Decisions for Developing Inland Container Terminals. *Res. Transp. Econ.* **2019**, *77*, 100764. [CrossRef]
41. Tang, Y.; Chen, S.; Feng, Y.; Zhu, X. Optimization of Multi- Period Empty Container Repositioning and Renting in CHINA RAILWAY Express Based on Container Sharing Strategy. *Eur. Transp. Res. Rev.* **2021**, *13*, 42. [CrossRef]
42. Tao, X.; Wu, Q. Energy Consumption and CO2 Emissions in Hinterland Container Transport. *J. Clean. Prod.* **2021**, *279*, 123394. [CrossRef]
43. Schulte, F.; Lalla-Ruiz, E.; González-Ramírez, R.G.; Voß, S. Reducing Port-Related Empty Truck Emissions: A Mathematical Approach for Truck Appointments with Collaboration. *Transp. Res. Part E Logist. Transp. Rev.* **2017**, *105*, 195–212. [CrossRef]
44. Shan, W.; Peng, Z.; Liu, J.; Yao, B.; Yu, B. An Exact Algorithm for Inland Container Transportation Network Design. *Transp. Res. Part B Methodol.* **2020**, *135*, 41–82. [CrossRef]
45. Song, W.; Liu, D.; Rong, W. Optimization of Passenger-like Container Train Running Plan Considering Empty Container Dispatch. *Sustainability* **2022**, *14*, 4697. [CrossRef]
46. Kurtuluş, E. Optimizing Inland Container Logistics through Dry Ports: A Two-Stage Stochastic Mixed-Integer Programming Approach Considering Volume Discounts and Consolidation in Rail Transport. *Comput. Ind. Eng.* **2022**, *174*, 108768. [CrossRef]
47. Kersten, W.; Jahn, C.; Blecker, T.; Ringle, C.M. (Eds.) *Changing Tides: The New Role of Resilience and Sustainability in Logistics and Supply Chain Management—Innovative Approaches for the Shift to a New Era*, 1st ed.; Proceedings of the Hamburg International Conference of Logistics (HICL) No. 33; epubli GmbH: Berlin, Germany, 2022; ISBN 978-3-7565-4195-9.
48. Moon, I.; Hong, H. Repositioning of Empty Containers Using Both Standard and Foldable Containers. *Marit. Econ. Logist.* **2016**, *18*, 61–77. [CrossRef]

49. Ogawa, H.; Imai, A.; Shintani, K.; Nishimura, E. The Effect of Geographical Factor on the Use of Combinable Containers. In *Proceedings of the 2020 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM)*; IEEE: Singapore, 2020; pp. 1261–1265.
50. Cai, J.; Huang, Y.; Diao, C.; Jin, Z. Joint Optimization of Empty Container Repositioning and Inventory Control Applying Dynamic Programming and Simulated Annealing. *Appl. Soft Comput.* **2024**, *167*, 112452. [CrossRef]
51. Chakrabartty, S.N. Proposed Models for Empty Container Management. *Int. J. Stat. Appl. Math.* **2018**, *3*, 635–640.
52. De Almeida Rodrigues, T.; De Miranda Mota, C.M.; Ojiako, U.; Chipulu, M.; Marshall, A.; Dweiri, F. A Flexible Cost Model for Seaport-Hinterland Decisions in Container Shipping. *Res. Transp. Bus. Manag.* **2023**, *49*, 101016. [CrossRef]
53. Liang, Z.; Shibasaki, R.; Hoshino, Y. Do Foldable Containers Enhance Efficient Empty Container Repositioning under Demand Fluctuation?—Case of the Pacific Region. *Sustainability* **2021**, *13*, 4730. [CrossRef]
54. Chen, R.; Meng, Q.; Jia, P. Container Port Drayage Operations and Management: Past and Future. *Transp. Res. Part E Logist. Transp. Rev.* **2022**, *159*, 102633. [CrossRef]
55. Chen, K.; Lu, Q.; Xin, X.; Yang, Z.; Zhu, L.; Xu, Q. Optimization of Empty Container Allocation for Inland Freight Stations Considering Stochastic Demand. *Ocean Coast. Manag.* **2022**, *230*, 106366. [CrossRef]
56. Zhang, Z.; Li, X. An Optimization Model of Railway Empty Container Allocation Based on Customer Satisfaction. *MATEC Web Conf.* **2020**, *308*, 04001. [CrossRef]
57. Hosseini, A.; Sahlin, T. An Optimization Model for Management of Empty Containers in Distribution Network of a Logistics Company under Uncertainty. *J. Ind. Eng. Int.* **2019**, *15*, 585–602. [CrossRef]
58. Fazi, S.; Roodbergen, K.J. Effects of Demurrage and Detention Regimes on Dry-Port-Based Inland Container Transport. *Transp. Res. Part C Emerg. Technol.* **2018**, *89*, 1–18. [CrossRef]
59. Li, L.; Wang, B.; Cook, D.P. Enhancing Green Supply Chain Initiatives via Empty Container Reuse. *Transp. Res. Part E Logist. Transp. Rev.* **2014**, *70*, 190–204, Reprint in *Transp. Res. Part E Logist. Transp. Rev.* **2015**, *74*, 109–123. [CrossRef]
60. Wang, K.; Wang, S.; Zhen, L.; Qu, X. Ship Type Decision Considering Empty Container Repositioning and Foldable Containers. *Transp. Res. Part E Logist. Transp. Rev.* **2017**, *108*, 97–121. [CrossRef]
61. He, W.; Jin, Z.; Huang, Y.; Xu, S. The Inland Container Transportation Problem with Separation Mode Considering Carbon Dioxide Emissions. *Sustainability* **2021**, *13*, 1573. [CrossRef]
62. Xing, L.; Yan, H.; Yin, Y.; Xu, Q. Research on the Optimization of Empty Container Repositioning of China Railway Express in Cooperation with International Liner Companies. *Sustainability* **2021**, *13*, 3182. [CrossRef]
63. Xie, Y.; Liang, X.; Ma, L.; Yan, H. Empty Container Management and Coordination in Intermodal Transport. *Eur. J. Oper. Res.* **2017**, *257*, 223–232. [CrossRef]
64. Goh, S.H.; Chan, Y. Operational Shadow Pricing in Back Haul Container Shipping. *Transp. Res. Part E Logist. Transp. Rev.* **2016**, *92*, 3–15. [CrossRef]
65. Zain, R.M.; Rahman, M.N.A.; Ramli, A.; Nopiah, Z.M.; Saibani, N. Using Measures of Agreement to Evaluate a Chronic Problem of Congestion in the Empty Container Depots. *Int. Rev. Manag. Mark.* **2016**, *6*, 843–850.
66. Palacio, A.; Adenso-Díaz, B.; Lozano, S. A Decision-Making Model to Design a Sustainable Container Depot Logistic Network: The Case of the Port of Valencia. *Transport* **2018**, *33*, 119–130. [CrossRef]
67. Sritharan, R. Customers' Opinion about Management of Empty Containers in Liner Shipping. *Asian J. Manag. Sci.* **2016**, *5*, 37–40. [CrossRef]
68. Song, D. A Literature Review, Container Shipping Supply Chain: Planning Problems and Research Opportunities. *Logistics* **2021**, *5*, 41. [CrossRef]
69. Torkjazi, M.; Huynh, N.; Shiri, S. Truck Appointment Systems Considering Impact to Drayage Truck Tours. *Transp. Res. Part E Logist. Transp. Rev.* **2018**, *116*, 208–228. [CrossRef]
70. Irannezhad, E.; Prato, C.G.; Hickman, M. The Effect of Cooperation among Shipping Lines on Transport Costs and Pollutant Emissions. *Transp. Res. Part D Transp. Environ.* **2018**, *65*, 312–323. [CrossRef]
71. Shintani, K.; Konings, R.; Imai, A. Combinable Containers: A Container Innovation to Save Container Fleet and Empty Container Repositioning Costs. *Transp. Res. Part E Logist. Transp. Rev.* **2019**, *130*, 248–272. [CrossRef]
72. Peng, Z.; Wang, H.; Wang, W.; Jiang, Y. Intermodal Transportation of Full and Empty Containers in Harbor-Inland Regions Based on Revenue Management. *Eur. Transp. Res. Rev.* **2019**, *11*, 7. [CrossRef]
73. Kuźmicz, K.A. Impact of the COVID-19 Pandemic Disruptions on Container Transport. *Eng. Manag. Prod. Serv.* **2022**, *14*, 106–115. [CrossRef]
74. Luo, T.; Chang, D. Empty Container Repositioning Strategy in Intermodal Transport with Demand Switching. *Adv. Eng. Inform.* **2019**, *40*, 1–13. [CrossRef]

75. Kolar, P.; Schramm, H.-J.; Prockl, G. Intermodal Transport and Repositioning of Empty Containers in Central and Eastern Europe Hinterland. *J. Transp. Geogr.* **2018**, *69*, 73–82. [CrossRef]
76. Kurtulus, E.; Cetin, I.B. Assessing the Environmental Benefits of Dry Port Usage: A Case of Inland Container Transport in Turkey. *Sustainability* **2019**, *11*, 6793. [CrossRef]