



Intermodal Transport – A Bibliometric Analysis of Contemporary Research Trends in Regulatory Approaches and Sustainability Strategies

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ABSTRACT

Regulatory approaches in intermodal transport are policy-driven frameworks and legal instruments that promote modal shift and sustainability by addressing barriers such as infrastructure deficiencies, pricing mechanisms, terminal accessibility, and coordination among public and private stakeholders. Contemporary research in intermodal transport is fragmented, as varied approaches and themes make it challenging for scholars and industry practitioners to form a clear vision of current regulatory approaches. To address this gap, this study conducts a bibliometric analysis of 84 articles regarding regulatory approaches in intermodal transport. The articles were published in 49 academic journals and authored by 185 scholars. The application of the bibliographic coupling methodology in the VOSviewer software enabled the identification of four clusters: (1) sustainable strategies in intermodal freight transport; (2) modal shift in intermodal freight transport; (3) integration and optimisation in intermodal freight transport; (4) decision-making and policy tools for intermodal transport. Content analysis results highlight infrastructure reforms, collaborative governance, and legal and regulatory measures as critical approaches to enhance modal shift efficiency and strengthen intermodal freight transport systems. The findings offer a scientifically robust foundation for scholars and industry practitioners aiming to improve their understanding of how regulatory approaches and possibilities can strengthen intermodal transport systems.

KEYWORDS

regulatory approaches; policy measures; modal shift; sustainable intermodal transport; infrastructure governance; public-private partnerships; bibliometric analysis.

1. INTRODUCTION

Intermodal freight transport involves the transportation of goods in a single loading unit, such as a container, swap body or semi-trailer, between two or more modes of transport without requiring additional handling of the goods themselves when changing modes. Within the territory of the European Union, combined transport refers to intermodal transport where the main leg is by rail, inland waterway or short sea shipping, and at least one of the pre- and post-transport legs is carried out by road, with the aim of keeping these legs as short as possible. These working definitions are approved by the United Nations Economic Commission for Europe (UNECE) and adhered to by industry bodies, detailing current transport policy and logistics practice [1, 2].

Three contemporary interlocking elements have the potential to transform modern intermodal freight transport systems. The first approach, that of digitalisation and operational integration – represented by synchromodal planning and real-time re-routing, seeks to achieve dynamic coordination of the capacity and routing dimensions as decisions are taken at the network level; recent open-access work reports on reliability

improvements and outlines methodological pathways for operational decision making [3, 4]. Second, the redesign of networks and local nodes inland, including the dry ports and logistics corridors, is singled out as an important enabler for smooth door-to-door intermodal transport chains and trade facilitation, particularly in the ongoing multilateral assessments [5]. Third, the shift away from fossil fuels and disclosure of performance increasingly provides an anchor for regulation: initiatives such as the EU's Greening Freight and the current revision of the Combined Transport Directive aim to clear regulatory bottlenecks and to fine-tune rail capacity management to enable intermodality to compete more fairly with the road transportation mode [6–8].

Within this framework, modal shift means the reassignment of freight from high-emission road transport to lower-emission transport modes such as rail, inland waterways and short sea shipping, including in some cases combinations of these in intermodal chains. EU legislative activity explicitly frames modal shift as a key tool to decrease external costs in terms of congestion, emissions, accidents, and protect logistics performance [2, 9]. The strategic importance of modal shift is highlighted by industry and by the audit community: combined/intermodal services have been the engine of rail-freight growth over the last decade, but remaining structural and regulatory asymmetries still prevent a level-playing field with road, so targeted public action is still required [10, 11].

Diverse scholarly evidence is constantly emerging in relation to sub-topics of modal shift within intermodal freight transport systems. Policy instruments (e.g. temporary subsidies or charges internalising externalities) may be used to trigger cost-effective early adopters, fading by inevitable market mechanisms – some results recently validated on a longitudinal study of road-to-rail transition within China [12]. Methodological innovations for forecasting and network design that identify corridors and origin-destination pairs with the greatest potential for modal shift, and quantify trade-offs between cost, time and emissions, are used to guide investment and service design [13]. Operational research is also driving the field towards more flexible, sustainability-aware intermodal networks with explicit treatment of uncertainty and disruption [14].

Nevertheless, despite increasing scholarly activity on modal shift in intermodal freight transport systems, our understanding of the crossroads of the regulatory approaches and sustainability strategies is underdeveloped. Bibliometric mapping is indeed active in interconnected fields (e.g. green shipping, sustainable transport in general and multimodal logistics), but such open-access syntheses focusing specifically on interconnected systems, jointly structuring regulatory approaches such as: (1) standards, (2) directives and (3) governance mechanisms; and sustainable strategies such as: (1) decarbonisation routes, (2) corridor design, (3) dry-port planning and (4) synchromodal operations; characterises sparsity. This discrepancy can be considered by comparing recent green shipping and sustainable transport bibliometric reviews to the lack of intermodal-specific bibliometric studies pertaining to regulatory instrumentation [15–17].

To address this gap, a bibliometric analysis of intermodal freight transport systems regarding regulatory approaches and sustainability strategies is conducted. This paper thus aims to: (1) investigate the changing patterns and trends of research on the regulatory approaches and sustainability strategies of intermodal transport systems; (2) identify the most impactful articles, journals, institutions and countries within the stated research domain via application of citation-based metrics to identify dominant knowledge sources and top domain contributors; (3) differentiate and investigate the main research clusters in the field of intermodal freight transport systems via utilisation of bibliographic coupling, and to present via content analysis main knowledge insights; (4) elaborate the results of the bibliometric analysis to provide trends in regulatory approaches and sustainability strategies regarding intermodal freight transport systems for policy makers and industry practitioners [1, 3, 10, 13].

The remainder of this study is structured and organised as follows. Section 2 outlines the bibliometric analysis research methodology and elaborates on data collection, analytics tools and Boolean search term utilisation. Section 3 provides the general results of the bibliometric analysis research methodology. Section 4 discusses the principal findings and research insights of the research clusters. Section 5 constitutes the discussion section and provides the trends in regulatory approaches and sustainability strategies in intermodal freight transport systems. The final section offers the conclusion of the paper with seminal findings.

2. BIBLIOMETRIC ANALYSIS RESEARCH METHODOLOGY ELABORATION

Bibliometric analysis is a quantitative, qualitative and interdisciplinary technique adapted within the scientific resume of research disciplines in information and library sciences in order to examine academic research [18]. The interest of bibliometric analysis, in terms of estimating the maturity of the scientific literature, involves scientific literature searching, for the specific research field, judging from the volume, the

scientific quality, the interdisciplinarity or the strength of the network relationship of studies [19]. Bibliometric analysis is conducive to knowledge accumulation because it enables researchers to identify the formation of scientific fields and the dynamics (development trends) of scientific fields [20]. Then, utilising the above instruments and based on the scientometric method, the researcher can explore the most important research in the science works without the subjective intervention in the requested science field. Furthermore, the bibliometric measurement rules guideline statistical algorithms, which can provide a more accurate, objective and reliable scientific analysis, and are indispensable for the systematic, reproducible and transparent literature review [21].

Aria and Cuccurullo (2017) enumerate a number of interests in bibliometric analysis, such as its utility in systematically measuring and reflecting on scientific fields [20]. This kind of structured aggregation of massive, structured corpora of literature, they claim, is not only valuable to understand when tracing the historical development of knowledge structures, but also is conducive to a coherent research landscape. They also argue that by combining qualitative approaches (e.g. content analysis) and quantitative methods, a wider interpretation of multiple types of media sources (i.e. texts, images and symbols) can be made. They suggest that a higher criterion should be implemented, to at least provide some guidance for reproductive power and transparency – reporting and reciting should be consistent in bibliometric outputs to keep it reliable and objective. These principles are also essential in order to increase the quality of literature reviews and make systematic and replicable evaluations with significant implications [19].

2.1 The five-step approach for bibliometric analysis methodology

This section provides the basis of the five-step process of applying the bibliometric analysis research methodology to the intermodal freight transport research domain, as illustrated visually in *Figure 1*.

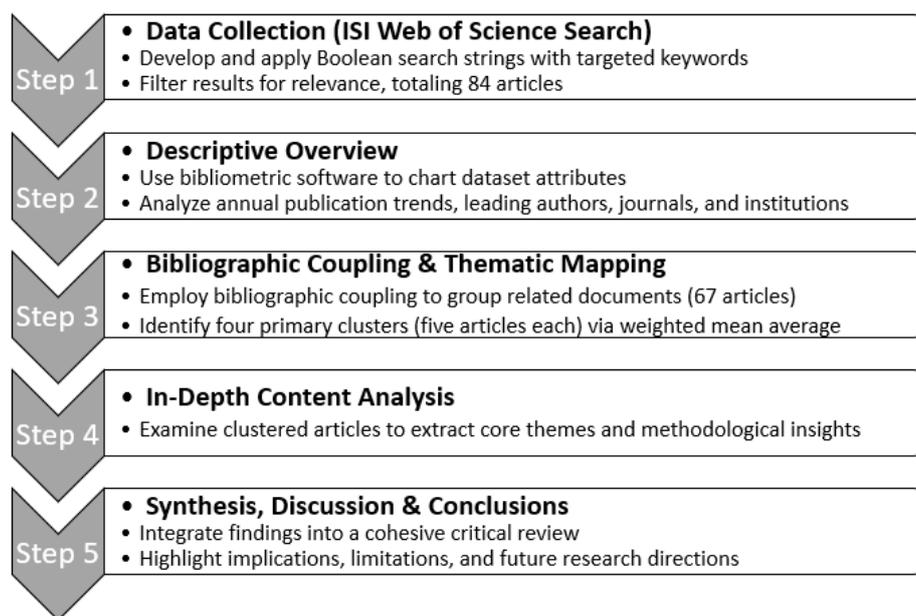


Figure 1 – Bibliometric analysis five-step approach

Figure 1 outlines a five-step bibliometric analysis process to map and assess the intermodal freight transport research domain. The five steps are elaborated as follows:

- **Step 1 – Collect data (ISI Web of Science search):**
Boolean keyword-based search in ISI WoS and relevance filters together reduced the search results to 84 papers included in the study (*Table 1*).
- **Step 2 – Descriptive overview:**
The annual distribution of publications, high-frequency authors, major journals and contributions from institutions was plotted using VOSviewer and the R bibliometrix package. VOSviewer’s user-friendly interface and its ability to handle data from various databases reflect an advantage compared with other software, such as CiteSpace, which is not suitable for emerging fields and Gephi, which involves too much pre-processing [1].

- **Step 3 - Bibliographic coupling and thematic mapping:**
Setting two common references per article as the criterion, we have clustered a set of 40 close documents into the unique four thematically coherent main clusters, which are subdivided into subclusters.
- **Step 4: In-depth content analysis:**
In central clusters, documents were ranked according to their total link strength and total citation numbers, respectively, which are two key VOSviewer cluster formation properties. To inquire into insights and main findings, the top five papers of each cluster (20 in total) were selected and qualitatively assessed.
- **Step 5 – Synthesis, discussion and conclusions:**
We condensed gaps and emerging trends from the content analysis into focused recommendations for future research and practice pertaining to the intermodal freight transport systems development.
The presented systematic, five-step framework delivers a transparent, rigorous mapping of the field, thus enabling a transparent research workflow of the intermodal transport systems research domain.

2.2 Bibliographic data extraction process

The bibliometric analysis relies on the retrieval of the bibliographic records from eminent and scientifically credible databases. Data in this study have come from the last 19 years, and were extracted from the ISI Web of Science on 22 August 2025. *Table 1* describes the search terms and strategies, which present a fourteen-step flow, with Boolean operators applied for proper and selective retrieval of scientific studies.

Table 1 – ISI WoS search findings on intermodal freight transport systems

No	Keyword search	Publication volume
1.	"European Directive*"	2652
2.	("European Directive*" OR "EU Directive*")	5786
3.	("European Directive*" OR "EU Directive*" OR "EU Regulation*")	8961
4.	("European Directive*" OR "EU Directive*" OR "EU Regulation*" OR "European Union Transport Legislation*")	8962
5.	("European Directive*" OR "EU Directive*" OR "EU Regulation*" OR "European Union Transport Legislation*") AND "Maritime Transport*"	1701
6.	("European Directive*" OR "EU Directive*" OR "EU Regulation*" OR "European Union Transport Legislation*") AND "Maritime Transport*" OR "Intermodal Transport*"	1679
7.	("European Directive*" OR "EU Directive*" OR "EU Regulation*" OR "European Union Transport Legislation*") AND "Maritime Transport*" OR "Intermodal Transport*" AND "Modal Shift*"	112
8.	Exclusion Criteria: English Language	111
9.	Exclusion Criteria: Article	87
10.	Exclusion Criteria: Article Manual Screening for Inquired Relevance	84

The search strategy in Web of Science for intermodal freight transport systems shows substantial differences in publication output depending on different keyword combinations. The most comprehensive search, “European Directive*” OR “EU Directive*” OR “EU Regulation*” gave 8,961 records, highlighting the predominant role that European legal frameworks are exerting in transport-based research. Less broad searches, such as that combining directives with “Maritime Transport*” or “Intermodal Transport*”, returned between 1,701 and 1,679 publications respectively, achieving a thematically relevant degree of refinement. Further and specific inclusion of “Modal Shift” cut the outputs to 112, suggesting a fairly niche literature that is part of wider intermodal freight transport policy scientific debates. The application of exclusion criteria, including language and article types, enabled the results to be further honed, guaranteeing thematic accuracy and validity. Excluded studies are related to: (1) free-floating bike sharing life cycle assessment; (2) interregional passenger bus services, and (3) European Union ship recycling licence design [2–4].

3. BIBLIOMETRIC ANALYSIS: FINDINGS AND RESEARCH INSIGHTS

In this section, we conduct a consolidated bibliometric analysis of the intermodal freight transport systems research domain to explore the main trends, collaboration and determinants of research in the domain. This section presents an overall summary of information for the database (Section 3.1), annual scholarly output (Section 3.2), rankings (Section 3.3 and Section 3.4), top scholars (Section 3.5), institutional contributions (Section 3.6), country-level productivity (Section 3.7) and a visual three-fields plot showing interactions among authors, keywords and countries (Section 3.8).

3.1 Bibliometric overview of intermodal transport

The bibliometric dataset includes 84 items publicly available from 2006 to 2025, published in 49 sources. There has been a notable annual increase trend, with the average age of documents being 7.15 and producing 21.42 citations per publication, suggesting a great academic impact. The resultant dataset contains 206 keywords and 295 author keywords; the total number of references is equal to 3,494, which illustrates the variety of themes studied. Authorship is reflected by 185 contributors, 11 single-authored documents, indicating that the study and practice is a team sport. On average, a document was signed by 2.77 authors, 22.62% of the papers were written in cooperation with foreign researchers. Most of the contributions consist of journal articles (80), followed by book chapters, early accesses and papers in the proceedings. In general, the database represents a growing, citation-rich and globally connected area of research.

3.2 Annual scholarly output

The annual publication counts provide insights into the development of research on intermodal freight transport systems. The annual publication counts are presented in *Figure 2*.

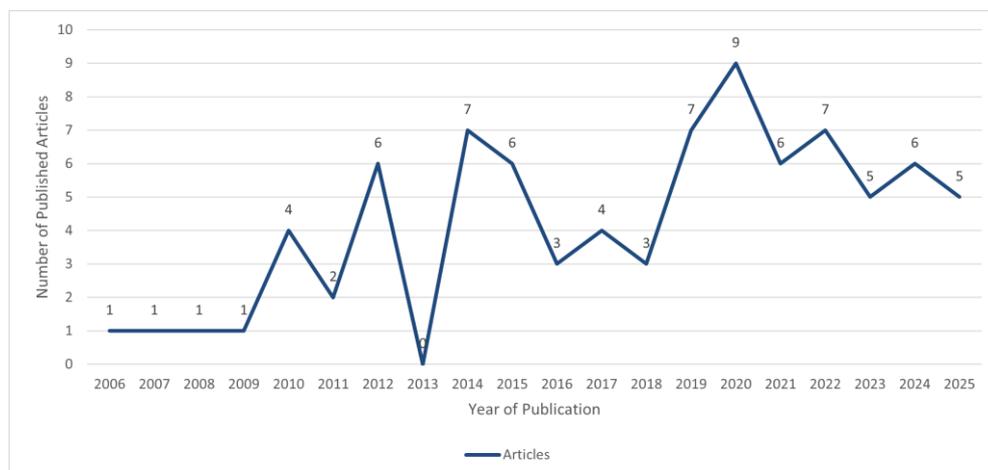


Figure 2 – Annual scholarly output in the intermodal transport systems research domain

The yearly distribution of papers from 2006 to 2025 depicts a slow increase in the number of studies conducted, with remarkable fluctuations in different periods. Early output was low, with a single paper per year until 2009. Scholarly output also showed clearly increased growth from 2010, with 2019 (nine publications) being the most fruitful year in the dataset. Follow-up years maintained high productivity, with between five and seven publications per year, indicating a continuous research interest. In general, the trend in the discipline can be seen as a reflection of the increasing maturity of the field, from the early stage of cases of isolated interest to the emerging norm of sustained scholarly presence.

3.3 Ranking of publication outlets by bibliographic indices

The key publication sources for intermodal freight transport are summarised in *Table 2*. Key bibliometric indicators, including the number of articles, local citations, local citation to number of articles ratio, h-index and starting publication year, highlight the impact and thematic relevance of each publication outlet. It provides important implications for understanding how the academic interests and publishing trends related to intermodal freight transport systems have changed among a variety of journals over time.

Table 2 – Publication outlet rankings by bibliographic indices

No.	Publication outlet	NA*	LC*	LC/NA*	h-index	PY start
1.	Research In Transportation Business and Management	11	65	5.91	8	2012
2.	Sustainability	7	49	7.00	5	2014
3.	Transport Policy	5	65	13.00	5	2012
4.	Journal of Cleaner Production	3	42	14.00	3	2009
5.	Journal Of Transport Geography	3	100	33.33	3	2010
6.	Transportation Research Record	3	52	17.33	2	2015
7.	European Transport Research Review	2	40	20.00	2	2022
8.	International Journal of Logistics Management	2	41	20.50	2	2018
9.	International Journal of Logistics-Research and Applications	2	34	17.00	2	2012
10.	International Journal of Physical Distribution & Logistics Management	2	18	9.00	2	2014

* NA (Number of Articles); LC (Local Citations); LC/NA (Local Citation-to-Number of Articles Ratio); PY Start (Publication Year Start).

The ranking of publication outlets shows that the Journal of Transport Geography is the leading one with 100 local citations and the highest LC/NA ratio (33.33), which means that it has a high impact on the driving network, although only three articles have been published since 2010. Other journals that had more relevance in terms of impact were the European Transport Research Review (LC/NA = 20.00) and the International Journal of Logistics Management (LC/NA = 20.50), which demonstrated a considerable number of citations in comparison with outputs. In productivity, Research in Transportation Business & Management sets the pace with 11 papers, followed by Sustainability, with seven. In general, the distribution shows a reasonable tension between very high-impact dedicated journals and broader, interdisciplinary channels advancing the field.

3.4 Ranking of publications by bibliographic indices

This subsection reports the top-most cited works in the research area of intermodal transport systems and provides an overview of the citation recognition of each work, both locally (i.e. within the current set of studies) and globally (i.e. across all scholarly works). The bibliometric ranks by citation impact are listed in Table 3.

Table 3 – Publication rankings by bibliographic indices

No.	Publication	Year	LC*	GC*	LC/GC*
1.	Eng-Larsson F, 2012, Int J Phys Distr Log	2012	14	75	18.67
2.	Tsamboulas D, 2007, Transport Res A-Pol	2007	13	94	13.83
3.	Blauwens G, 2006, Transport Rev	2006	9	69	13.04
4.	Macharis C, 2009, J Transp Geogr	2009	8	72	11.11
5.	Bergqvist R, 2011, Transport Rev	2011	6	24	25.00
6.	Macharis C, 2010, Transport Res A-Pol	2010	5	85	5.88
7.	Eng-Larsson F, 2014, Int J Phys Distr Log	2014	5	27	18.52
8.	Bouchery Y, 2015, Int J Prod Econ	2015	5	75	6.67
9.	Meers D, 2017, Res Transp Bus Manag	2017	5	36	13.89
10.	Macharis C, 2012, Res Transp Bus Manag	2012	4	20	20.00

* LC (Local Citations); GC (Global Citations); LC/GC (Local Citation-to-Global Citation Ratio).

The list of important papers is topped by Eng-Larsson (2012) in the International Journal of Physical Distribution & Logistics Management, with an LC/GC ratio of 18.67 representing strong local relevance compared to global citations. In the same way, Eng-Larsson (2014) also shows the same impact with an LC/GC of 18.52. Bergqvist (2011) obtains the highest value (25.00) as well (fewer international citations), highlighting a “narrow local then broad significance”. Exemplary cases are Macharis (2010) (85 global citations) and Bouchery (2015) (75), but their LC/GC ratios are lower and thus more international than regional in the reception and dissemination of the ideas inherent in the papers. These articles in aggregate represent the juxtaposition of internationally renowned and regionally important research informing research into intermodal transportation.

3.5 Ranking of scholars by bibliographic indices

The research domain of intermodal freight transport includes a group of highly active and influential researchers, many of whom have made significant contributions to sustainability and maritime studies. Table 4 presents the list of leading contributors in publication quantity, citation impact and the chronological initiation of their involvement.

Table 4 – Ranking of scholars by bibliographic indices

No.	Author	NA*	LC*	LC/NA*	h-index	PY start
1.	Macharis C	11	29	2.64	8	2009
2.	Meers D	6	15	2.50	5	2012
3.	Monios J	5	8	1.60	4	2015
4.	Bergqvist R	4	9	2.25	4	2011
5.	Santos TA	4	5	1.25	4	2017
6.	Van Lier T	4	16	4.00	2	2010
7.	Hanaoka S	3	7	2.33	2	2009
8.	Mommens K	3	7	2.33	2	2023
9.	Pekin E	3	17	5.67	3	2009
10.	Vermeiren T	3	6	2.00	3	2014

* NA (Number of Articles); LC (Local Citations); LC/NA (Local Citation-to-Number of Articles Ratio); PY Start (Publication Year Start).

Scholars' ranking shows that Macharis C is the most productive author with 11 publications and an h-index value of 8, while the reputation among other is started in 2009. Meers D and Monios J have both followed with six and five papers, respectively, and have served as contributing a great deal to the development of the field. Upon citation impact, the most prominent local citation receiver is Van Lier T (16 local citations) and an LC/NA ratio of 4.00, indicating high citation efficiency. Subgroup Analysis Pekin E also shows a considerable effect, with an LC/NA ratio of 5.67. Finally, our data show that well-established authors with continuous output are in balance with new contributors who bring new and impactful high-quality papers.

3.6 Institutional contribution to publication volume

The research area of intermodal freight transport has received much attention worldwide, as indicated by the diversity of organisational backgrounds of current researchers in this domain. In Table 5, institutions are enumerated where scholars are publishing, providing the sample's international coverage.

Table 5 – Institutional rankings by publication volume

No.	Institution	Publication volume
1.	Vrije Universiteit Brussel	12
2.	Universidade De Lisboa	7
3.	Universidad De Almeria	6
4.	University Of Gothenburg	6
5.	Chalmers University of Technology	3
6.	Delft University of Technology	3
7.	Edinburgh Napier University	3
8.	Universita Carlo Cattaneo - Liuc	3
9.	University Of Antwerp	3
10.	Beijing Jiaotong University	2

In terms of institutions, the analysis indicates that Vrije Universiteit Brussel has the largest publication output (12 articles), which affirms its position as a core institution for intermodal and transport research. Universidade de Lisboa comes next with seven productions, and Universidad de Almería and University of Gothenburg, with six articles each, stand out for their intense insertion in this thematic. The same list of institutions, as well as Italian and Belgian ones (Universita Carlo Cattaneo – LIUC, and University of Antwerp), make up the group with three publications along with three additional ones, including Chalmers University of Technology, Delft University of Technology and Edinburgh Napier University. Beijing Jiaotong University is one of the new participants this year, reflecting increased international participation outside Europe.

3.7 Rankings of countries by bibliographic indices

Intermodal freight transport systems research shows clear cross-national differences and several core nations of output and collaboration. The subsequent numbers in Table 6 illustrate how computing each country's contribution, average citation impact and relative frequency of multi-country co-authorship effectively influence the global distribution of intermodal freight transport research.

Table 6 – Country rankings by bibliographic indices

No.	Country	PV*	APC*
1.	Belgium	21	26.1
2.	Sweden	15	33.4
3.	China	11	3.5
4.	Italy	10	19.6
5.	Poland	10	9.3
6.	Spain	10	12.2
7.	Netherlands	8	16.3
8.	France	7	27.8
9.	Japan	7	33.7
10.	Portugal	7	13.8

Country-specific analysis indicates that Belgium is the most productive with 21 publications, and a high average citation per paper of 26.1, indicating the leadership of the country in the field. Sweden and Japan are the two countries with the highest citation impact, with 33.4 and 33.7 cites per paper by product, respectively, despite a lower number of publications than Belgium. The number of publications for China is in the 3rd position (11 articles), but the citation impact is lower, being 3.5. Other significant contributors are Italy and Spain with 10 publications each, and France with 7 publications, but with a much higher citation rate (27.8). In general, the data show a balance between productivity and impact by citation among the top European and Asian countries.

3.8 Three-field plot diagram

A flow representation of the three-field plot diagram is a Sankey diagram, which shows the structural relationship of the flows as well as the magnitude by thickness. These maps use weighted, directed graphs with weight functions satisfying flow conservation, where for every node the flow in equals the flow out [26]. A Sankey diagram (Figure 3) is proposed to characterise scientific activity on the green shipping corridor domain that visualises the collaboration focal points of the most active scholars (left), the main keywords (central region) and the contributing countries (right).

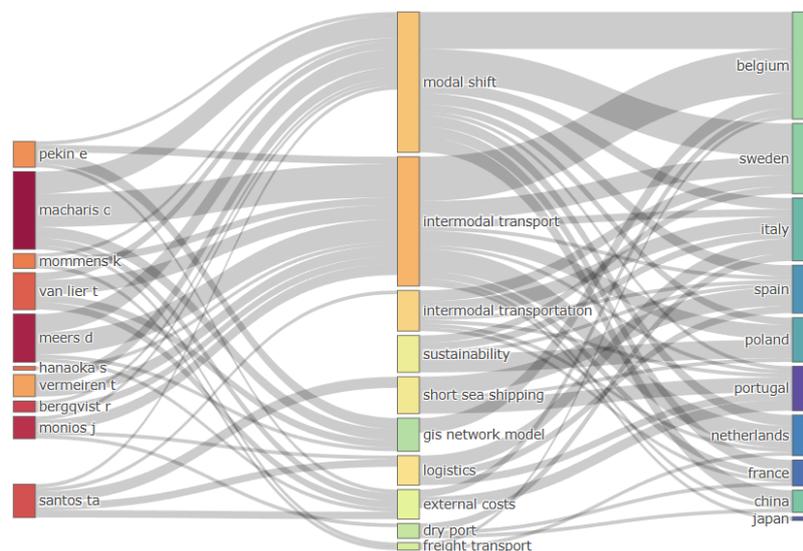


Figure 3 – Three-fields plot diagram in the intermodal freight transport domain; most influential scholars (left); principal keywords (centre); and contributing countries (right)

The Sankey visualisation shows how prominent researchers, topical research areas and issuing countries are linked in studies related to intermodal transport. Macharis C, Pekin E, Meers D come to the foreground as central, clearly related to modal shift and intermodal transport, which are the prevailing topics in the domain. Sustainability, short sea shipping and GIS network models are the other major themes, representing methodological and environmental dimensions. At the national scale, Belgium, Sweden and Italy most intensively research the issue and explore its diversity of themes, while countries such as China and Japan present less variety and size of the contributions for the time being. In conclusion, the diagram draws out the interface between academics, research issues and national productivity.

4. RESEARCH CLUSTERS: CONTENT ANALYSIS

Following an extensive search on the ISI Web of Science platform, an initial set of 84 papers focused on the operational dynamics of naval autonomous surface ships was selected. Additionally, only papers with more than two citations per document were included in the VOSviewer software, and therefore, in total, this dataset contained 67 papers. Bibliographic coupling is a bibliometrics technique for relating documents that cite the same reference and can be applied for grouping sets of documents [27]. This means a higher probability that the linked documents are involved in the same domain (i.e. in a research cluster). The graph of the 67-article source and topic dataset displays the clusters in Figure 4.

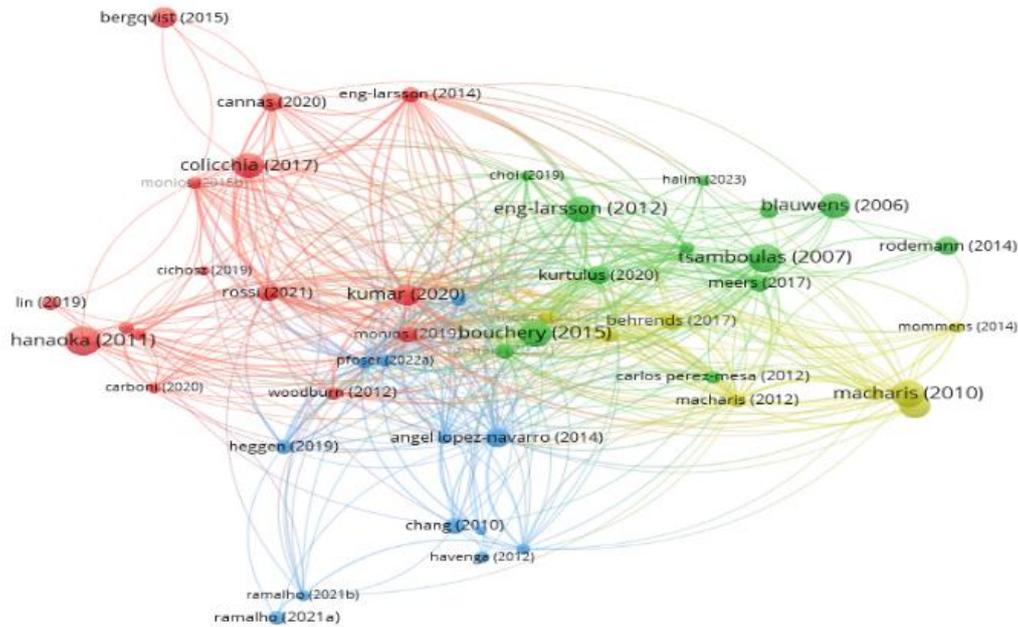


Figure 4 – The 67-article dataset graphical representation regarding cluster formation. Red cluster: sustainable strategies in intermodal freight transport. Green cluster: modal shift in intermodal freight transport. Blue cluster: integration and optimisation in intermodal freight transport. Yellow cluster: decision-making and policy tools for intermodal transport.

A follow-up cross-sectional analysis, including the total link strength and the citation count, used each publication’s rank based on its average to examine its relative importance and centrality. This integrated measure helped in selecting 20 top-ranked articles that were recognised as most important for more detailed content analysis. These articles were further grouped into four clusters, each with five articles (see Table 7).

Table 7 – Identified and selected articles for content analysis allocated to respective research cluster

Cluster 1: Sustainable strategies in intermodal freight transport	Cluster 2: Modal shift in intermodal freight transport	Cluster 3: Integration and optimisation in intermodal freight transport	Cluster 4: Decision-making and policy tools in intermodal freight transport
Kumar et al. (2020) [5]	Eng – Larsson et al. (2012) [6]	Angel Lopez–Navarro et al. (2014) [7]	Macharis et al. (2010) [8]
Colicchia et al. (2017) [9]	Tsamboulas et al. (2007) [10]	Heggen et al. (2019) [11]	Meers et al. (2015) [12]
Monios et al. (2019) [13]	Bouchery et al. (2015) [14]	Monios et al. (2015) [15]	Macharis et al. (2012) [16]
Hanaoka et al. (2011) [17]	Kurtulus et al. (2020) [18]	Pfoser et al. (2022a) [19]	Behrends et al. (2017) [20]
Rossi et al. (2021) [21]	Meers et al. (2017) [22]	Pfoser et al (2022b) [23]	Macharis et al. (2009) [24]

Table 7 assigns the selected articles to four thematic clusters, each representing a distinct aspect of intermodal transport research, as follows:

- Cluster 1: Sustainable strategies in intermodal transport: Sustainable intermodal strategies realisation via policy, technology, infrastructure and collaborative logistics solutions.
- Cluster 2: Modal shift in intermodal freight transport: Explores cost, reliability, policy and infrastructure factors affecting the adoption of sustainable modal shift.
- Cluster 3: Integration and optimisation in intermodal freight transport: Integration and optimisation in intermodal transport of freight: Deals with environmental, operational and managerial approaches that contribute to efficiency and sustainability of intermodal transport systems.
- Cluster 4: Decision-making and policy tools for intermodal freight transport: Focuses on GIS tools and planning theories improving the effectiveness of modal shift capabilities.

Figure 5 portrays the clusters and their subclusters, including the relation between the subclusters and the main research theme.

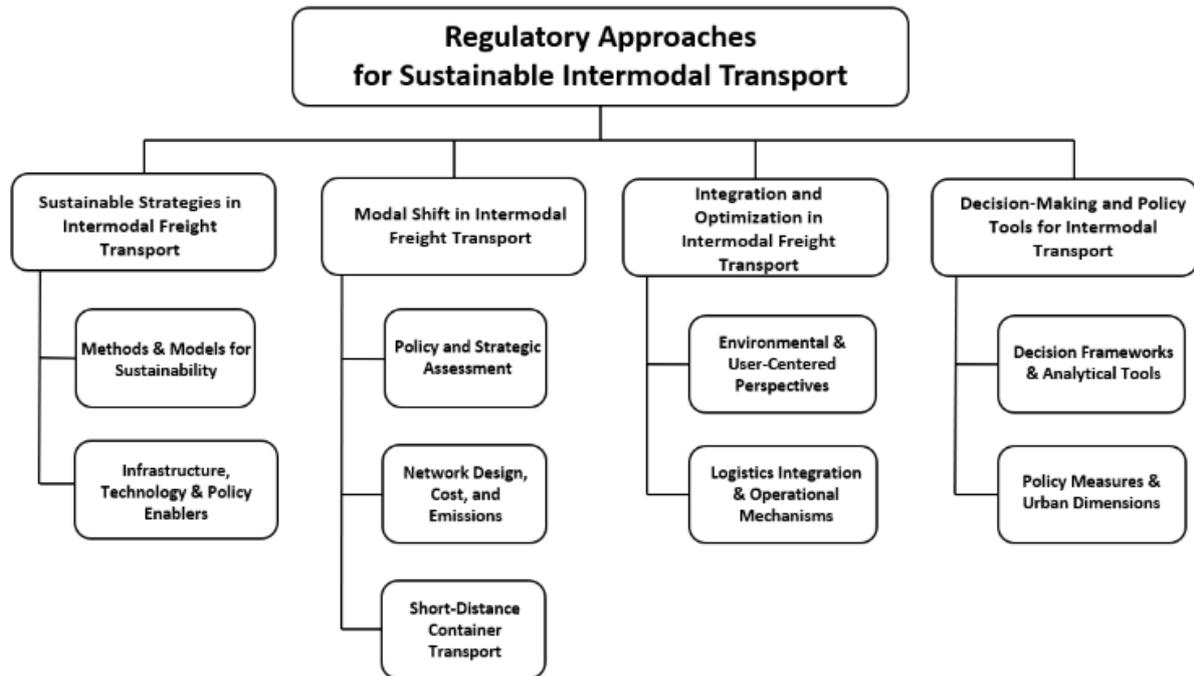


Figure 5 – Intermodal freight transport research domain clusters and subclusters

As the intermodal freight transport systems research domain is complex, each of these clusters further includes various subclusters, which will be elaborated in the following section of the article.

4.1 Cluster 1. Sustainable strategies in intermodal freight transport

Cluster 1 focuses on sustainability strategies represented as optimisation models for enhancing policy, technology and infrastructure of intermodal freight transport systems.

Subcluster 1. Methods and models for sustainability

This subcluster addresses sustainability-oriented models that optimise for cost efficiency, carbon reduction and intermodal freight. Kumar et al. (2020) developed an optimisation model for improving intermodal services under an optimal balance of transportation cost and carbon emission [28]. Empirical results indicate that the development of dedicated freight corridors (DFC) would improve the intermodal railroad (IRR) services. Concludingly, for improving the computational efficiency of the analytic hierarchy process (ANP), an integration of grey DEMATEL and ANP provides successful results in reaching strategic managerial decisions. Rossi et al. (2020) developed a novel logistics mathematical model for perishable food transportation preservation [44]. Results indicate that transporting perishable food for about 1,100 km, the CO₂ emissions are reduced by about 125 kg any time the proposed intermodal transportation is used, thus resulting in obtainment of environmental sustainability. Main contributions stem from the fact that the model opens the possibility of overcoming adoption issues regarding the utilisation of intermodal rail-road transportation for perishable food SCs, thus providing new advancement opportunities for researchers, practitioners and policymakers.

Subcluster 2. Infrastructure, technology and policy enablers

This subcluster focuses on infrastructure, technological and policy enablers facilitating sustainable intermodal freight transport. Colicchia et al. (2017) adopt a twofold methodology that combines a quantitative and qualitative approach [32]. The scholars' results show that it is possible to shift demand from road to rail by scenario quantification of Procter and Gamble pilot achieving a 17% shift from road to rail. The pilot test implementation lasted from July 2013 to April 2015 on the Novara/Milano–Pomezia O/D relation, covering 1,625 loads, of which 17% were shifted to rail transport. These approaches and results can enable a wider collaboration between intermodal corridors, thus fostering the adoption of an integrated intermodal network vision. Monios and Bergqvist (2019) develop an analytical framework using intermodal transport literature to guide the content analysis on electric automated vehicles adaptation [36]. The results indicate that electric

automated vehicles (EAVs) require interchange terminals, charging infrastructure and regulator-led network planning. Thus, policy enablers must address: (1) grid capacity, (2) standardisation, (3) taxation reform and (4) open-access terminal governance. Haonaka and Regmi (2011) conducted a case-study review combining policy analysis with empirical dry-port examples [40]. Results indicate rail-linked dry ports reduce road congestion and CO₂ emissions when connectivity is adequate. Conclusions emphasise coordinated policy, infrastructure investment, PPPs and ICT modernisation to enable sustainable intermodal freight transport.

4.2 Cluster 2. Modal shift in intermodal freight transport

This cluster analyses how policies, network design and short-distance strategies influence the cost, reliability and emissions of the modal shift element within intermodal transport freight transport systems.

Subcluster 1. Policy and strategic assessment

This subcluster focuses on policy reviews and strategic actions supporting efficient, demand-driven and sustainable intermodal freight transport modal shifts. Eng – Larsson and Kohn (2012) conducted a multiple-case, natural-experiment study of six firms' modal shifts empirically [29]. Research results indicate that carrier performance, centralised control and low demand volatility enable intermodal shifts without transport service loss. Concludingly, policy should incentivise: (1) carrier investment, (2) simplify purchase processes, and (3) integrate transport-inventory decision-making systematically and equitably. Tsamboulas et al. (2007) propose a three-part approach which includes (1) macro-scan; (2) sensitivity analysis; and (3) policy action plan [33]. The findings of the academics show that terminal reliability, working hours and CO₂ internalisation are the factors with the highest impact on modal shift potential. In conclusory comments, it can be said that supply chain-specific policy assessment should include demand-side factors and also targeted segmental interventions for greater effectiveness.

Subcluster 2. Network design, cost and emissions

The focus of this subcluster is intermodal network design for intermodal terminal location, demand and emissions with an objective to maintain cost sustainability [37]. Bouchery and Franssoo (2015) design an intermodal network model with continuous demand approximation and optimisation. The findings show that cost and emissions increase when the pursuit of modal shift is maximised; carbon-optimal shift is around half, that is, fifty per cent. Finally, and overall, network-driven design must have to care about: (1) volume-driven terminal location, and (2) precise train emission modelling, to avoid biases.

Subcluster 3. Short-distance container transport

This subcluster studies local-regional short-distance container transport with a focus on reducing costs, enhancing reliability, and improving infrastructure and services to encourage modal shift. Kurtuluş and Çetin (2020) conduct a stated-choice experiment analysing short-distance container mode choice in Turkey [41]. The results indicate cost dominates choice; doubling frequency and halving transit time yield the largest shift. Concludingly, short-distance intermodal container transport requires corridor-specific infrastructure, reliability and service-quality enhancements to be competitive. Meers et al. (2017) applied a choice-based conjoint experiment in a hierarchical Bayes setting with Belgian shippers and LSPs [45]. This outcome shows that price is the prevailing reason for the decision, while reliability, time and frequency would have a lower impact as a whole. Concludingly, increasing reliability, daily services provision, competitive pricing and improvements in information will encourage the adoption of short-distance travel modal shift.

4.3 Cluster 3. Integration and optimisation in intermodal freight transport

This cluster focuses on environmental assessments, user-oriented policies and logistic integration arrangements, which can promote sustainable intermodal freight transport.

Subcluster 1. Environmental and user-centred perspectives

This subcluster focuses on route-specific environmental impact studies and user-based policies to stimulate the uptake of sustainable multimodal freight transport. López-Navarro et al. (2014) combine the literature review and analysis of the Marco Polo calculator across 72 trade routes [30]. Intermodal MoS was found preferable in 48 routes, and road was preferable in 24. Implications call for: (1) route-based environmental

assessment, (2) operator-centric decision support, (3) improved technologies, and (4) green shipping. Pfoser (2021) investigated ten LSPs longitudinally ISM-based multiple-case design with the use of interviews, focus groups and archival data [42]. Results suggest: (1) considering external costs, (2) efficient information provision, and (3) education strongly encourages multimodal uptake for freight. User-oriented, demand-focused policies ultimately result in positive environmental effects; however, a strong transnational coordination of demands and legal guarantees is necessary for their realisation.

Subcluster 3. Logistics integration and operational mechanisms

This subcluster studies logistics integration, synchromodality and dynamic planning to improve the intermodal efficiency and long-term sustainability. Monios (2015) conducted multiple semi-structured interviews alongside document analysis to investigate retail intermodal logistics operational mechanisms [38]. Results show that 3PL-driven vertical integration improves the service viability in the context of container imbalance and backhaul scarcity. Public funding and multi-user consolidation hubs are still a key to (1) integration; (2) operations scalability; and (3) viability over the long-term. Pfoser et al. (2021) conduct both a systematic and a content analysis-based literature review to conceptualise synchromodality [46]. Four mechanisms: (1) real-time switching, (2) integrated planning, (3) collaboration, (4) mode-free booking, distinguish synchromodality, according to the findings. Concludingly, technical elements are dominant within the literature, with the managerial, legal and empirical elements being minuscule, thus resulting in gaps hindering the adoption of integrating factors. Heggen et al. (2019) develop an integrated intermodal routing model with a large-neighbourhood search heuristic [34]. The model shows that integrated planning achieves cost savings for drayage, and the higher utilisation rates of long-haul trucks when demand clusters. Conclusions suggest that logistics integration calls for dynamic, scalable models that connect capacity and drayage trade-offs.

4.4 Cluster 4. Decision-making and policy tools for intermodal transport

This cluster covers policy measures and decision support tools supporting sustainable, efficient and integrated intermodal freight transport.

Subcluster 1. Decision frameworks and analytical tools

This subcluster creates GIS decision platforms with a cost-emission-network nexus for guiding inter-modal transport policies. Macharis et al. (2010) employ the GIS-based LAMBIT model that includes networks, prices and containerised flows [31]. The results suggest the internalisation of external costs stimulates more barge and rail freight shifting than fuel price increases. It is the combination of GIS-based decision tools with economic internalisation that gives policy guidance on intermodal systems. Meers and Macharis (2015) perform a macro-scan using a GIS application by integrating transport flow analysis and location assessment [35]. The results show that the best scoring regions are the ones which are located by short post-haul distance near intermodal terminals. Finally, MCDA-GIS applications are useful but bounded by data quality, parameter weights and scope limitations. Macharis et al. (2012) develop GIS-based LAMBIT decision-support web tool for CO₂ and cost computing integration [39]. The outcomes suggest that barge intermodal alternatives are cost-competitive for many of the Flemish-Brabant communes and reduce CO₂. Conclusions indicate that the model has practical decision-support utility, but requires a broader scope and additional control variables.

Subcluster 2. Policy measures and urban dimensions

This subcluster emphasises that urban planning and a consistent set of policies are basic pillars for sustainable intermodal freight transport. Behrends (2017) carried out desk research and conceptual analysis to connect urban planning and rail freight [43]. The efficiency of IRRT and the environmental impacts can be improved by local policy practices, as shown by the results. Finally, the measures and actions need to be coordinated across scales and empirically validated in order to lead to feasible, sustainable modal shifts. Macharis and Pekin (2009) developed a GIS-based method (LAMBIT) integrating road, rail and waterway transport networks [47]. The findings suggest that fragmented policies and subsidies divert traffic away from the inland waterways to rail terminals. Integrated, consistent policies are required to integrate urban and regional policies and to prevent modal competition.

5. DISCUSSION: TRENDS IN REGULATORY APPROACHES AND SUSTAINABILITY STRATEGIES IN INTERMODAL FREIGHT TRANSPORT SYSTEMS

Countries are increasingly acknowledging that the modal shift – from road to rail, inland waterways and short-sea shipping – is the final criterion for evaluating intermodal freight transport systems as it results in the greatest marginal external cost reductions and greenhouse gas emissions while sustaining service level competitiveness [25]. Recent scholarly evidence suggests that road freight's external costs may be substantially higher than those of maritime or rail transport, reinforcing the policy argument for a systemic modal shift [26]. At the regulatory level, the EU's 2024 TEN-T Regulation shifts corridor development to smooth multimodal capacity, in support of emerging shift framework proposals and the proposed recast of the Combined Transport Directive and forthcoming CountEmissionsEU attempts to standardise carbon accounting and eliminate barriers that disadvantage intermodal chains [27, 28]. Simultaneously, research indicates that targeted incentives and phased subsidies can trigger permanent change, with quantifiable CO₂ reductions in corridor- and commodity-specific cases [29, 17]. On that basis, this is followed by Section 5 which addresses how current regulatory approaches such as: (1) standards, (2) incentives and (3) capacity management; and sustainability strategies such as: (1) infrastructure investments, (2) digital integration, and (3) emissions disclosure can be combined to foster modal shift as the ultimate goal of intermodal freight transport systems.

5.1 Regulatory approaches influencing modal shift in intermodal freight transport systems

Regulatory approaches in intermodal freight transportation systems have long been seen as one of the key drivers of modal shift, but their effectiveness is hampered by the fragmented application, institutional barriers and cross-border coordination issues.

Kumar et al. (2020) show that regulatory instruments – taxation, incentives, corridor governance – attempt to encourage the modal shift, but they experience fragmented implementation and lack of funds [28]. But in practice, regulatory effectiveness is typically severely limited by fragmented implementation, bureaucratic institutions and capacity shortfalls. Colicchia et al. (2017) show regulatory tools may drive some modal shift, but there remain institutional barriers [32]. Pilot schemes, incentives and corridor governance with collaborative hubs are needed to overcome the hurdles related to cross-border barriers. Monios and Bergqvist (2019) discuss regulatory mechanisms, such as taxation and corridor governance, that enable modal transfer [36]. Findings show harmonisation, infrastructure investment and regulatory restructuring partly bridging institutional, cross-nationality and operational barriers. Hanaoka and Regmi (2011) illustrate that combined regulatory structures and intergovernmental agreements support the development of dry ports [40]. They suggest that regulatory interventions have had limited efficacy in the absence of operational cooperation, cross-border facilitation and institutional integration. In research by Rossi et al. (2020), regulatory requirements underpin mode shift but are constrained by institutional operations [44]. Progress is limited, although cross-border governance, cost and reliability are persistent challenges when it comes to the introduction of large-scale modal shift.

Eng-Larsson and Kohn (2012) argue that regulatory incentives are mitigated by both the difficulty of purchasing and the choice of carrier [29]. Studies indicate that regulatory barriers have not been sufficiently removed; efforts to overcome institutional, cross-sectoral and operational barriers remain inadequate, and policy frameworks should play a stronger guiding role in directing investment. Tsamboulas et al. (2007) present a system with three components – macro-scan, sensitivity analysis and policy action plan [33]. The findings suggest that carbon pricing, harmonisation of working hours and terminal reliability adequately and reasonably bypass the regulatory impediments. Bouchery [2] and Fransoo [3, 4] show that policy instruments impact modal shift but depend on economic instrumentation [37]. Their study demonstrates that financial instruments and corridor management remove a barrier but transfer the cost to society. Kurtuluş and Çetin (2020) show that deregulation and orders can support the modal shift, but institutional barriers persist [41]. The findings suggest cost measures and governance address PoCs, but cross-border institutional hurdles remain. Meers et al. (2017) suggest that EU policies favour modal shift but also long-distance over short-distance [45]. They find that regulatory mechanisms are largely unsuccessful in overcoming the institutional, cross-border and operational challenges of short-haul transport.

The literature identifies several key regulatory approaches to foster modal shift, yet persistent barriers constrain their implementation:

- **Taxation and fiscal measures (e.g. carbon pricing, road charges)**
Barriers: Transfer of costs to society; limited effectiveness without accompanying operational reforms [37].
- **Incentives and subsidies for intermodal services**
Barriers: Fragmented implementation, insufficient or temporary funding, limited scalability across corridors [28, 32].
- **Corridor governance and collaborative hubs**
Barriers: Cross-border governance deficits, institutional fragmentation, and coordination difficulties among multiple stakeholders [36].
- **Harmonisation of working hours and regulatory standards**
Barriers: Bureaucratic structures, slow policy alignment, and lack of consistent enforcement across national boundaries [33].
- **Infrastructure funding and investment programs**
Barriers: Persistent infrastructure deficits, slow project execution, and reliance on public financing without sustained long-term strategies [38].
- **Deregulation and supportive directives**
Barriers: Institutional limitations and uneven policy uptake across countries, leading to partial or short-lived effectiveness [41].
- **Coordinated intergovernmental agreements (e.g. dry ports, cross-border facilitation)**
Barriers: Limited success without simultaneous operational agreements, insufficient institutional coordination, and weak cross-border facilitation [40].

Overall, regulatory approaches reveal strong potential, yet persistent institutional, operational and cross-border barriers limit effectiveness.

5.2 Sustainability strategies influencing modal shift in intermodal freight transport systems

In sustainable-transport strategies for intermodal freight transport, the importance of infrastructure, incentives and digitalisation has played a more prominent role as modal shift facilitators.

López-Navarro et al. (2014) show that infrastructure investment and incentives such as Marco Polo are modal shift facilitators [30]. Findings are that trade-offs between cost, emissions and reliability are known to be route specific; however, they may be reduced with cleaner fuels and alternative operational strategies. Monios (2015) finds that infrastructure investment, subsidies and digitalisation support the feasibility of mode shift and demand coordination [38]. Pilots show that subsidies and consolidation centres increase reliability and reduce emissions, but overall cost efficiency remains limited. Pfoser et al. (2021) show that the infrastructure investment, digitalisation and incentive mechanisms are efficient for the modal shift [42]. Results show that cost efficiency, emission reductions and reliability are traded off, and pilots require governance and adaptation. Pfoser (2021) shows that accommodating modal shift effectively necessitates a mix of infrastructure investment, digitalisation and incentive schemes [46]. In other words, suggesting the need to balance costs, emissions and reliability via externality pricing, digital transparency and infrastructure investment. In work by Heggen et al. (2019), under integrated planning, digitalisation stimulates modal shift wherein costs and reliability are balanced [34]. The findings suggest that the integrated routing enables emissions and trucking costs mitigation, particularly in clustered high-demand scenarios.

Macharis et al. (2010), as well, developed a GIS-based LAMBIT to assess the fuel-price and other external-cost policies for intermodal sustainability [31]. It is, however, suggested that internalising external costs is superior to raising fuel prices, though the evidence provided (and pilot) is scarce. Infrastructures, incentives and digital tools are found to increase the potential for modal shift (Meers and Macharis, 2015) [35]. Their findings suggest that pricing, through terminal dispersion and time reliability, aligns cost, emissions and level of service. Macharis et al. (2012) show how to combine CO₂ metrics, cost and GIS in the evaluation of sustainability strategies [39]. Their results show that infrastructure, incentives, digitalisation and monitoring effectively trade off costs, emissions and service reliability. Macharis and Pekin (2009) note that investment and subsidy policies fundamentally alter modal split impacts [47]. The scholars' findings suggest that cost-based analyses overlook reliability and emissions trade-offs, resulting in the need for integrated policy responses.

The literature identifies several key sustainability strategies for modal shift fostering, even though allocated barriers constrain their implementation:

- **Infrastructure investment (terminals, corridors, dry ports)**
Barriers: High capital intensity, slow project execution, and fragmented coordination across corridors [30] [38].
 - **Financial incentives and subsidies (e.g. Marco Polo, consolidation centres)**
Barriers: Limited long-term cost efficiency, temporary nature of funding, and scalability constraints beyond pilots [30] [38].
 - **Digitalisation and ICT tools (real-time routing, transparency, integrated planning)**
Barriers: Governance and adaptation requirements, lack of interoperability, and uneven adoption [34] [42].
 - **Integrated planning and routing optimisation**
Barriers: Computational complexity and difficulty balancing cost, emissions, and reliability in clustered demand [34].
 - **External cost internalisation (carbon pricing, CO₂ metrics, monitoring tools)**
Barriers: Political feasibility concerns, limited pilot evidence, and risk of raising system-wide transport costs [31] [39].
 - **Cleaner fuels and operational adjustments**
Barriers: Fuel availability, infrastructure readiness, and reliability trade-offs in long-haul operations [30].
- Sustainability strategies demonstrate strong potential, yet barriers in cost, governance and scalability limit widespread implementation.

6. CONCLUSIONS

Contemporary intermodal freight transport systems integrate digitalisation, infrastructure redesign and sustainability measures to foster effective modal shift. This bibliometric analysis aims to integrate fragmented studies and provide an overview of contemporary trends in regulatory approaches and sustainability strategies. A systematically constructed Boolean search term query in the ISI Web of Science Core Collection (August 2025) enabled a bibliometric data sample of 84 English-language journal articles that serve as the empirical focus of the analysis.

Citations indices are utilised as the foundational pillars for scientifically and critically clarifying the intermodal transport freight transport systems research domain. The three most influential studies in the dataset are Eng – Larsson et al. (2012) in the *International Journal of Physical Distribution & Logistics Management* (LC/GC ratio 18.67), Tsamboulas et al. (2007) in *Transport Research A: Policy* (LC/GC ratio 13.83), and Blauwens et al. (2006) in *Transport Reviews* (LC/GC ratio 13.04). The top three contributing journals are the *Journal of Transport Geography* (100 local citations, LC/NA ratio 33.33), *Transport Policy* (65 local citations, LC/NA 13.00), and the *Journal of Cleaner Production* (42 local citations, LC/NA ratio 14.00). The top three contributing authors are Macharis C. (11 publications, h – index 8), Meers D. (6 publications, h – index 5), and Monios J. (5 publications, h-index 4).

The research domain is further clarified via network visualisation techniques. Bibliographic coupling of at least 10 common references per document reduced the dataset to 67 articles, resulting in the identification of four independent research clusters: (1) sustainable strategies in intermodal freight transport; (2) modal shift in intermodal freight transport; (3) integration and optimisation in intermodal freight transport; and (4) decision-making and policy tools for intermodal freight transport. Filtering by a weighted-mean average of total link-strength and citations identified the five most influential papers for each cluster (20 articles in all). Furthermore, the detailed content analysis identified seven regulatory approaches and six sustainability strategies as trends for advancing the sustainability of contemporary intermodal freight transport systems.

However, several limitations moderate these results. First, the analysis is based on a single database, namely, the ISI Web of Science, resulting in omission of studies indexed in other relevant scientific repositories such as Scopus and IEEE Xplore. Second, citations constitute a lagging indicator and will naturally advantage older publications, and so may not be a complete accounting of the immediate impact of very recent studies or industry papers. Thus, future research should include multiple scientific repositories in order to expand the option space for database retrieval and incorporate alternative impact metrics to overcome possible temporal or repository limitations. This can enable researchers to further develop evidence-based studies with the possibility of supporting and strengthening the sustainability of contemporary intermodal freight transport systems.

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