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Proceedings of the International Conference on Conference on Business, Management and Finance
Vol. 2, Issue. 1, 2025, pp. 35-44
DOI: https://doi.org/10.33422/icbmf.v2i1.1071

ISSN: 3030-0959 online

Diamond Scientific Publishing

Opportunities for Improving Eco Friendliness and Efficiency in Intermodal Transport: A European Union Perspective

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Abstract

Intermodal transport is at the core of European Union's sustainability agenda, presenting potential solutions to reduce environmental impact and while improving freight movement efficiency. This study explores the opportunities to make EU's intermodal transport more sustainable and operationally efficient. The study identifies opportunities such as adoption of green technologies, infrastructural enhancements and supportive regulatory measures by investigating policy frameworks, technological developments and market trends. The transformative potential of technology is mainly highlighted by developments such as electric and hybrid vehicles, digital platforms for route optimization and energy efficient containers. For intermodal transportation to be seamless, modernisation of infrastructure which includes railway ports and urban logistics hubs is essential. Furthermore, the regulatory backbone for sustainability activities is provided by the supportive policies such as carbon pricing mechanisms, harmonized laws and subsidies for green initiatives. Collaboration among stakeholders through public-private partnerships and industry consortia is another important factor that propels advancement. To take advantage of these opportunities and promote a sustainable ecosystem in the EU, practical recommendations are provided for policymakers, industry stakeholders and practitioners. This research emphasises the importance of coordinated efforts to overcome obstacles and take advantages of opportunities for more sustainable, greener and efficient future in intermodal transport.

Keywords: Sustainability; Transport efficiency; Green logistics; Low carbon transportation; Logistics optimization

1. Introduction

Intermodal transport can be described as the movement of goods using two or more modes of transport. In most circumstances, the movement and handling of freight does not likely require additional handling. According to Ritchie (2020), the world produces approximately 50 billion tonnes of greenhouse gases every year. This is a significant volume that is expected

to contribute to climate change. Intermodal transport is one of the main contributors to greenhouse gases each year. However, since it plays a major role in the logistics industry, the EU has established policies to guide the industry toward low-carbon transportation to promote sustainability in the industry's operations. The EU has intensified its effort to meet the set guidelines by the European Green Deal as well as the Sustainable and Smart Mobility Strategy, which has as its main strategy of improving the sustainability of intermodal transport across all the member states (Schroten, Essen, & Morsink, 2021).

This research study aims to explore the different opportunities that provide sustainability, transport efficiency, and green logistics in intermodal transport from an EU perspective. To achieve transport efficiency, EU's intermodal transport needs an address to its challenges, especially coordination inefficiencies which affect not only the seamless flow of freight but also collaboration and innovation (Notteboom, & Rodrigue, 2022). The research will also explore the various opportunities which the EU intermodal transport offers to its members such as regulatory support, infrastructure development, green tech among other key areas which are for the study. Critical analysis of the literature review offers a practical insight to the audience of the research aim, industry players and stakeholders. The next section of the research paper is the literature review, which will then be followed by a research methodology then a results section. Recommendations of the research study will give the final view of the researcher on the betterment of intermodal transport in EU

2. Literature Review

2.1 Green Tech in intermodal transport

Green logistics in the EU transport system has been an important driver of the supply chain management strategies. Green technology applies across all the handlings of the freight including material management, the conventional dimensions as well as the physical distribution. In the materials management system, the product design, a sustainable sourcing, packaging and packing as well as the circular use of materials gives the intermodal transport a chance to have quality freight consolidation. The system also demands responsive systems for sustainable shipping scheduling and routing (Monios, & Bergqvist, 2020).

Similarly, China's Belt and Road Initiative (BRI) include Green logistics through green finance methods and environmental compliance. The BRI places a significant priority on low-emission infrastructure investment and promotes the use of electric vehicles and blockchain based cargo tracking along intermodal corridors (Green Finance & BRI, 2025). The long-term sustainability of transcontinental supply chains is enhanced by the incorporation of sustainable finance into logistics systems.

2.2 Infrastructural development and integration

TEN-T (Trans-European Transport Network) is a workable policy in the EU which aims at improving the infrastructure of the logistics zone such as the railway terminals, and the intermodal hubs. According to Monios and Bergqvist (2020), there is the need for urban logistics centres, ports and dry ports to shift from road to rail as well as waterway transport. Physical connectivity calls for movement of containers efficiently along the intermodal transport chain while putting into effect the requirements and purpose of intermodalism (European Commission, 2023).

The Sagarmala Project in India aims to improve the port infrastructure and coastal shipping while reducing congestion and carbon emission complementing the Dedicated Freight tracks (DFCs) which are modern high capacity rail corridors devoted to cargo transport (Rajan & Krishnan, 2024).

Through public-private partnerships to cutting-edge digital infrastructure, the Federal Highway Administration in the United States supports the modernization of the intermodal terminals. Recent research (Ferguson et al. 2025) shows how automation and data driven scheduling have resulted in measurable reductions in greenhouse gas emissions and improved freight flow. To increase resilience, container yard operations frequently use AI and predictive maintenance technologies.

2.3 Regulatory and policy frameworks

EU's Fit for 55 package calls for policies which influence freight transport strategies such as strict fuel efficiency standards, emissions trading as well as carbon pricing. Structured regulations promote effective modal choice in the EU and favour regulations across all the jurisdictions in the region despite their uneven support and implementation. EU's intermodal transport system recognises the concerns of different governments and harmonises as well as adequately make the necessary fundamental shifts both locally and globally. Promotion of certification and standardisation in the EU intermodal system also enhances environmental performance of supply chains and productivity (Monios, & Bergqvist, 2020).

Promoting sustainable intermodal transport requires strong legislative frameworks. The Fixing America's Surface Transportation (FAST) Act in the US offers long term financial certainity for surface transportation infrastructure investment and planning. The Act supports the development of multimodal frieght networks and promotes the adoption of innovative technologies to enhance system efficiency and reduce environmental impacts.

India has also taken a number of calculated steps to reduce emissions and improve freight efficiency. The National Logistics Policy (2022) seeks to bring down logistics costs from 8.35% of GDP to 5% while encouraging modal shifts and supply chain digitization (Rajan & Krishnan, 2024).

2.4 Stakeholder collaboration

Kourounioti et al. (2021), states that EU's joint infrastructure calls for a collaboration of rail operators, shippers, and terminal managers. European Rail Freight Corridor Network is critical for sustainable development of the EU's sustainability. Information systems integration such as electronic data interchange are critical in managing a single window portal or rather a port community system. Customs integration improves the movement of goods across all the EU borders since pre-screening and inspection are harmonised (Notteboom, & Rodrigue, 2022). This effect helps reduce damage, tempering, theft and protect the public from risks posed by illicit cargo.

Promoting sustainable intermodal logitics requires efficient stakeholder collaboration. In Brazil, the Green Ports Partnership between Brazil and The Netherlands exemplifies interantional cooperateion that aims to create sustainable port infrastructure. In order to promote ecologically friendly port operations, this effort emphasises on technological advancements, shift to renewable energy and knowledge sharing (Correia & Galves, 2018; Digital Intermodal, 2024).

Cooperative strategies amongst logistics companies have been investigated in Austria to reduce urban freight emissions. A study examined bundled transport deliveries demonstrated that collaborative logistics techniques could result in notable decrease in fuel usage and CO_2 emissions (Validi et al. 2020).

In Japan, managing labour shortages in the logistics industry has sparked innovative teamwork. A notable example is the development of cooperative transportation matching system that enables several businesses to effectively share transportation. More than 150

companies have implemented this technology utilizing advanced algorithms to enhanceload efficiency and reduce impact on the environment (Kira et al. 2023; Lind et al. 2021).

2.5 Blockchain in the intermodal transportation

Improvement of the intermodal transport system in the EU calls for transactional dimensions. Blockchain technology such as distributed electronic ledger is critical for transactional effectiveness in terms of managerial, tracking and settlement dimensions. For example, the bill of landing is fundamental in booking of carriers along a sequence of modes. This component of integrity in the intermodal transport system eradicates costs, errors, and potential tampering. Blockchain tech integration contains a bill of landing which is an electronic chain with verifiable information and transactions that is not easily tempered with and can be used effectively for legal function (European Commission, 2023).

The UAE is incorporating blockchain technology into its DP World Logistics Operations, specifically through Dubai Blockchain Strategy. To enhance intermodal frieght transportation, the Cargoes Flow platform links ports, free zones, customs and shipping companies. The port of Jebel Ali, one of the world's largest, uses blockchain technology for automated paperwork and real-time container tracking to reduce delays and curruption risks (Digital Transformation, 2024).

2.6 Digital transformation and Emerging technologies

The effects of digital transformation on intermodal transport and logistics are examined in recent research. In Saudi Arabia, Mutambik (2024) highlights how digital transformation, including digital competence, process innovation and strategic alignment, acts as a driver of sustainability in freight transportation. Data-driven decision making is supported, administrative errors are reduced and fuel efficiency is directly enhanced by these digital initiatives. Furthermore, container shipping companies are also progressively adopting cloud logistics, AI based scheduling and Internet of things to reduce downtime and improve transparency.

3. Methodology

This research adopts exploratory and qualitative research design which offers the best opportunity for efficiency and eco-friendliness in intermodal transport in the EU transport environment. EU intermodal logistics is diverse and exploratory research with a qualitative approach gives the researcher a diverse perspective to capture all the regulatory, technological and infrastructural developments without being constrained by quantitative generalizations (Flick, 2018). The study's validity is further supported by comparative views from other regions (such as India, China, Brazil) by cross-referncing various regulatory frameworks and infrstructure realities.

3.1 Research design

The aim of this research is to identify the opportunities for improving eco-Friendliness and efficiency in intermodal transport while taking care of the outcomes, development of insights which develop the intermodal systems in the EU.

3.2 Data collection

The researcher commonly used EU policy documents, case studies, industry reports and peer reviewed academic journals. The European commission website provided the researcher with a platform to collect official documents about the EU transport programs such as TEN-T and the Fit for 55 which capture the EU's implementation progress and policy directions therein.

GoogleScholar, SpringerLink, ScienceDirect and other advanvced databases were used. Search terms like blockchain in freight, modal shift policy, sustainable intermodal logistics were included. On the basis of geographical diveRsity, recentness, credibility, and relevancy, approximately above 25 sources were selected.

3.3 Data analysis

In order to identify the recurring patterns and themes across various policy documents, a thematic analysis was used in three iterative phases:

1. Initial coding: Finding pertinent patters (such as policy gaps, or tech applications)
2. Axial coding: classifying codes into dominant categories such as digitalization, infrastructure readiness and governance.
3. Interpretation: Aligning themes with theoretical frameworks on sustainability and logistics.

To enhance validity cross-checking between regions (America, EU, Asia) was done to ensure that the findings were not biassed by area but represented larger trends.Captured themes include digitization, eco-friendliness, efficiency, sustainability and low carbon transportation.

3.4 Ethical considerations

No humans participants were involved. The research ensured that there is proper citation which adhere to APA 7th edition class. The research solely depended on publicly available resources in websites such as google scholar and EU website thus no ethical approval was needed.

3.5 Limitations of the research

Since there is the absence of primary data which gives the research the ability to capture current trends on the ground, the broadness of the research is therefore contained. Future researchers in the same field can consider field-based data collection to help in complimenting this study.

3.6 Future Directions

The study's dependence on secondary data restricts the access to operational issues and stakeholder perspective in real time. However, finding several geographical sources somewhat makes up for this to some extent. Future research studies studies could employ:

- Semi-structured interviews with port operators, policy advisors and logistics managers.
- Surveys targeting regional multimodal transportation suppliers.
- Case-based ethnographic approaches to examine live operational setting.

4. Results

This part of research gives the findings realized based on the thematic analysis of the literature, industry reports and policy frameworks. The results offer the audience a c hance to realize opportunities in the EU intermodal transport system and the chances for eco-friendliness, sustainability in the system.

4.1 Uneven policy support

There is variation in policy support in the Eu's intermodal system. There are hurdles as well as lack of public awareness in the modal shifts such as intermodal technology, eco-friendly measures and incentives offered by different institutions across the EU region. There are regulatory complexities as well as inconsistencies in the EU intermodal system. On the other

hand, there are some regions which face a challenge in implementation of emission technologies.

4.2 Use of Green tech

Currently, the use of green technology is taking shape. There is intermodal shift in technology with stakeholders appreciating the use of hybrid and electronic trucks for delivery in urban areas. There is shift from road transport to rail and inland water transport which are energy efficient and less polluting to the environment. Innovation to get more green techs are ongoing and being appreciated across the region.

4.3 Gaps in infrastructure

The south and east Europe is facing critical gaps in terminal capacity and connectivity which are the main established bottlenecks in this research facing the EU's intermodal transport. Majority of the stakeholders acknowledge that there is need for a balanced infrastructure to enhance a cohesive transition of the intermodal sector to a low carbon emission, sustainable and efficient intermodal transport system which will take care of the environment, stakeholders and freight users.

4.4 Operational efficiency through digitization

An AI driven approach has been acknowledged as a game changer in route optimization since it eradicates idle time, reduces the operational costs and enhances quality utilization of assets. Digitization in the EU intermodal transport system has enhanced real time exchange of data between freight users and terminals

5. Discussion

This study finding's affirm the transformative potential of green technologies, infrastructure enhancement, digitalisation and regulatory harmonization in the EU intermodal tranport system. The study also identifies the persistent obstacles that hinder a smooth transition to sustainability, even when advancements like adoption of electric vehiclesand hybrid trucks and from growing shift from road to rail show improvement (Monios & Bergqvist, 2020).

Digital innovation: Cloud based terminal management system, blockchain enabled cargo tracking, AI based route optimization are just a few examples of digital technologies that are becoming critical enablers of efficiency. Technological solutions are reducing dwell time, cutting emissions and improving freight reliability across regions – from Ports of Brazil to predictive scheduling in Japan.

Regulatory Integration: Inadequate policy support among participating nations continues to be a critical challenge. Variations in infrastructure, particularly in southern and eastern Euirope cause regional discrepancies that limit the operations of intermodal transport (European Court of Auditors, 2020). These results support previous findings that a cohesive and balanced infrastructure is needed to promote modal shifts and improve supply chain's environmental performance (Monios & Bergqvist, 2020). According to insights of India, successful mode shifts necessitate explicitly enforced national coordination, not only policy formation. The EU can adopt a more centralised approach equivalent to India's Dedicated Freight Corridors (DFCs).

Operational efficiency: It is being enabled by digital technologies, particularly by AI- driven route optimization and real time data exchange systems. These tools reduce carbon footprints, enhance asset utilization, and minimise idle time (Rodrigue & Notteboom, 2022). However,

the interoperability issues and absence of universal standards limit the scalability of such technologies.

Infrastructure readiness: The uniformity of intermodal performance is hindered by differences in investment among EU member states. In order to promote sustaible frieght corridors, the EU must prioritize the border infrastructure, dry ports and rural connectivity, taking inspiration from China's Belt and Road Transport hubs.

Stakeholder collaboration also plays a crucial role. The cooperation of train operators, terminal managers, logistics firms and policy organizations is essential for the success of integrated transport systems. Though they are still under utilized in some areas, initiatives such as European Rail Freight Corridor Networks and blockchain- enabled documentation (European Commission, 2023) are instances of cooperation can stimulate innovation. In Austria, community-driven logistics ecosystems has proven efficiency. Innovation labs, collaborative load sharing, and joint-use platforms significantly increase system adaptability and sustainability.

Environmental performance: Reducing emissions remain the ultimate goal. Although, the EU's fuel economy and modal shift targets are praiseworthy. Nations like US and China are making significant stides by tying funding eligibility to emissions metrics. The EU might benefit from adopting performance-based incentives that are closely linked to carbon reduction.

Overall, the findings imply that the EU must accelerate the cross-border harmonization to prioritize infrastructure equity and digital policies as essential components of sustainable EU intermodal transport system. Finally, acceptance and innovation can be scaled throughout the continent with the support of stakeholder education and capacity building programs that are based on Japan's logistics workforce initiatives.

6. Conclusion

This research explored opportunities for improving eco-friendliness and efficiency in the EU's intermodal transport system. The study, which is based on thematic analysis of academic literature, policy frameworks and technolofy developments, concluded that although there has been meaningful progress, there still exist significant gaps that prevent the complete realization of an efficient and sustainable logistics network.

The adoption of green technology, digital transformation, regulatory frameworks like European Green Deal and TEN-T, and the rise of blockchain as the transactional facilitator demostrates the region's low carbon transport (European Commission,2023; Rodrigue & Notteboom, 2022). However, system wide integration and sustainability continue to pose challenges by disparate policy support and uneven infrastructure development across the EU member states (European Court of auditors, 2022).

The EU must adopt targeted infrastructure investments, harmonize regulatory frameworks, and strengthen public-private partnerships so as achieve its sustainability and efficiency goals in intermodal transportation. The insights presented in this research serves as a foundation for future research and policy formulations, with the aim of achieving more greener, smarter and more integrated transport network across Europe.

7. Recommendation and Practical Implications

This section of the research offers proposed recommendations that can enhance opportunities for improving eco-friendliness and efficiency in intermodal transport within the EU.

7.1 Critical stakeholder collaboration

Stakeholders in the EU intermodal transport system need to form industry alliances which can come together and realize the opportunities offered by the EU intermodal transport system and help in innovation and proper dissemination of the right data. Bringing together hubs, logistic firms and ports can help eradicate challenges facing the industry stakeholders and help in co-designing solutions for a sustainable EU intermodal transport system. Promote cooperative logistics projects, living labs and innovation clusters based on Austria's bundled delivery systems to improve local innovation and adaptability.

7.2 Digital infrastructure investment

To improve freight fluidity and reduce emissions, investment in digital twins, blockchain and AI-driven scheduling tools should be increased drawing inspiration from Japan's cooperative logistics platforms.

7.3 Harmonized regulations

While appreciating the various sovereign jurisdictions in the region, a common regulatory framework can help the wide region eradicate burdens in regulatory tracking. A sustainable intermodal transport industry needs to be more transparent and offer the stakeholders an easy process of regulation tracking and monitoring. It could also offer flexibility and a strong modal shift. It also could lead to a reduction in transhipment while at the same time providing economic efficiency. Using the logistics coordination model of India, EU officials should adopt centralised regulatory enforcement mechanisms.

7.4 Regional infrastructure equity

The EU should model itself after China's Belt and Road initiative (BRI) by ensuring uniform investments in intermodal infrastructure across member states especially in underdeveloped regions.

7.5 Green incentives and Monitoring

Introduce performance based carbon invcentives, like those in China and United States, that link funding eligibility and to quantifiable environmental outcomes.

7.6 Icreased awareness of the opportunities in the EU's intermodal system

Training relevant stakeholders in the intermodal system can help change the mindset of different industry operators. It would even be easier to convince them to appreciate the different eco-friendly measures set across in the EU's intermodal transport sector. Knowledge about green freight transport can be a successful benchmark. It could also act as a simulation for data transport in the Scandinavian countries.

7.7 Future Research

Further studeies should adopt mixed-methods, including system modelling interviews and thematic synthesis to uncover dynamic interactions and stakeholder perceptions across regions.

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