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Environmental, financial, and accessibility analysis of low-density high-value goods shipment

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ABSTRACT: In recent decades finished and semi-finished commodities are the most common and fastest-growing cargo categories for transportation in Europe. These commodities usually have low density and are of high value. This paper aims to assess the CO_2 emissions, cost, and availability of road, rail, and railroad intermodal transportation used to deliver LDHV goods in a case study involving chemical goods transportation throughout the EU27 countries in 2020. The findings indicated that most chemical goods were transported via road, which emits more CO_2 than a railway. Furthermore, road transport cost is significantly higher than rail. In order to reduce CO_2 emissions and costs, four railroad intermodal scenarios were suggested. According to the analysis, these scenarios for delivering LDHV goods may be feasible to mitigate environmental concerns while also significantly lowering costs. Additionally, the availability and accessibility of intermodal terminals for shipping LDHV goods were analyzed to evaluate these scenarios.

KEYWORDS: LDHV goods, rail-road Intermodal transportation, CO2 emission, Intermodal terminal density, Intermodal terminal accessibility

1. INTRODUCTION

Greenhouse gases (GHG) trap heat and cause global warming. Carbon dioxide (CO_2), methane (CH_4), nitrous oxide (NO and NO_2, together called NOx), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6), and nitrogen trifluoride (NF_3) (the last four gases are known as fluorinated gases) are significant GHG that are generated by a wide range of human activities such as transportation, electricity generation, industrial, commercial and residential activities, agriculture, land utilization, and forestry. The transportation sector's primary source of GHG emissions is burning fossil fuels for vehicles, trucks, ships, trains, and planes. Therefore, quantifying CO_2 emissions across all modes of transportation is critical. Several studies have been conducted in this area, including those that establish transportation emission estimation models (Berne et al., 2019; Hickman et al., 1999; Kirschstein & Meisel, 2015; Scora & Barth, 2006) and that primarily assess the factors affecting the generated emissions (Ebadian et al., 2020; Lin & Ng, 2012; Liu et al., 2021; Stelling, 2014; Xu et al., 2018; J. Zhang et al., 2021; X. Zhang et al., 2021; Zhao et al., 2022). In particular, the researchers established some guidelines, stating that their solutions would primarily focus on technical developments in fuel consumption (including fuel efficiency, fuel taxes, fuel labeling, and biofuel funding) and distribution systems (including utilizing multimodal[1], intermodal[2], comodal[3], and synchromodal system[4]).

1.1. Intermodal transportation

According to the European Commission's White Paper, 30% of road cargo shipments (over 300 kilometers) should be converted to more environmentally friendly modes of transport by 2030 (Commission, 2011). To this end, rail transportation offers the best opportunity for absorbing a portion of goods movement in the coming years (Kramarz, Przybylska, & Wolny, 2021) and can provide a superior alternative in situations where it may be challenging to accomplish via the road system (Alotaibi, Quddus, Morton, & Imprialou, 2021). However, Due to the lack of adequate infrastructures or significant investment costs, a complete switch to rail is not feasible for many countries. Nonetheless, to maximize the benefits of unimodal modes within a single integrated transport chain, a combination of individual modes of transport could be used.

A frequent recommendation is to replace a part of road shipment with rail via an intermodal road-rail transportation system. This system has to perform interdependently (both technically and administratively). In the unimodal system, empty back-loading (especially for long distances road trips) is crucial and can reduce system efficiency. Conversely, when traffic converges at intermodal terminals, load factors and transit frequency in the intermodal system can be increased, resulting in improved network performance (Rodrigue et al., 2019). However, an intermodal transportation system is not feasible for short distances unless natural barriers exist.

A critical element of any intermodal system is intermodal terminals. They are freight transportation infrastructures that can be utilized by several modes of transportation and can be used for freight entering, exiting, and switching (between one mode to others), therefore serving as a link between different modes of transportation. Hence, they play an essential role in enabling access to intermodal transportation services. Nowadays, numerous intermodal rail terminals can be found throughout the EU27, though their distribution is not uniform.

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[1] When a supply chain system utilizes more than one mode with various storage units (Crainic & Kim, 2007 as cited in Pinto et al.)
[2] When a supply chain system utilizes more than one mode with the same storage units (Crainic & Kim, 2007 as cited in Pinto et al.)
[3] When several shippers work cooperatively (Crainic & Kim, 2007 as cited in Pinto et al.)
[4] When transport mode is changeable in response to operational requirements (Crainic & Kim, 2007 as cited in Pinto et al.).

1.2. LDHV goods

By examining freight market demand and cargo typology over the last few decades, it is possible to observe significant changes in cargo composition; finished and semi-finished commodities are in high demand, and they are the most prevalent and fastest-growing cargo categories for transportation in Europe. Due to the low density and high value of these goods, which require faster and more dependable modes of transport, and the dynamic and customer-oriented service offerings of road transportation, the majority of LDHV items are currently transported by road transportation, which is not eco-friendly (Zunder, 2012).

Several studies have been conducted to evaluate the shipment of LDHV goods. One of the most significant was the Spectrum project, funded by the European Union's Seventh Framework Programme (Zunder, 2012). Its objective was to develop a freight vehicle that would aid the market for LDHV goods and improve rail freight networks and infrastructure to compete with the road freight network. Based on the results of this project, if 10% of the LDHV freight is transferred to rail (over ten years), the program could mitigate 20 million tons of CO_2 emissions. Furthermore, it could save 2.9 billion euros in external costs. The researchers stated that future demand for LDHV goods (over distances of 200 kilometers or more) could be transferred to a more environmentally friendly mode of transportation, i.e., rail, and described the process of developing the new rail freight concept for LDHV goods transportation. According to the study conducted by Siciliano et al. (2016), conventional freight trains can be used in SPECTRUM terminals but not in reverse; thus, some capital expenditure is required to modify terminals to operate the SPECTRUM system.

Moreover, (Shackleton et al., 2016) developed a novel running gear system for the SPECTRUM vehicle that increased speed and enabled the vehicle to operate alongside passenger services, improved vehicle quality to minimize damage to LDHV commodities, and decreased track damage. Another study analyzed the rail freight market demand for LDHV goods based on ETISplus and iTREN project outcomes (Jackson et al., 2013). According to the findings, LDHV goods account for 12% of the existing road freight market (200 kilometers or more) in the EU27 and Switzerland. They also found that LDHV goods transported by road are projected to increase by 23% by 2020 and 53% by 2030 (compared to 2009). Additionally, they revealed that utilizing rail to transport freight while decreasing reliance on road transportation could result in significant economic, environmental, and social benefits. However, some significant obstacles to implementing the new rail freight transportation for LDHV goods were identified, including additional processing costs and time, unreliability at terminals, extended operating hours, and low network density.

When evaluating the previous research, it should be noted that the majority of studies focused on using rail transportation to deliver LDHV commodities. Islam (2014) examined the competitiveness of European rail freight transport operators as a supply chain partner in a changing market environment and then recommended a variety of strategies and activities to help them improve their competitiveness. In another study, an online survey was developed to assess rail freight transportation systems for LDHV goods transportation (Zunder et al., 2016). They employed innovative technology in order to integrate freight and passenger systems. The findings indicate that the novel technology would enable freight transportation to perform similarly to passenger transportation. In addition, they stated that implementing innovative technologies for LDHV goods rail freight transportation would encourage customers to transition from less sustainable modes of transportation to more sustainable modes. Boehm et al. (2021) proposed a fully electrified, large-scale, high-speed rail freight transport system in Europe and compared it to road transportation to determine the feasibility of shifting goods transportation from road to rail. According to the findings, a fully electrified transportation network offers significant time and CO_2 savings but is 70% more expensive than road transportation.

Some studies have attempted to address the challenges associated with employing rail transportation to deliver LDHV goods. Zunder and Islam (2018) defined the barriers to intermodal rail services for LDHV goods transportation using four case studies. According to the results of their study, LDHV goods could be transported more cost-effectively via intermodal railroad transportation. However, technical, financial, and industrial challenges must be addressed to satisfy consumer demands. Zunder and Islam (2018) conducted a follow-up study in which they surveyed industry experts to ascertain current and prospective rail freight strategies for shipping LDHV goods. The investigation concentrated on three areas: "Wagon," "Train and hubs," and "Commercial, Service Quality, and Planning." According to the findings for the 'wagon' theme, providing electrical power to each rail freight wagon is necessary for the delivery of LDHV refrigerated products, while terminal access and efficiency are critical for the 'train and hubs' theme. From another point of view, in the "business quality and planning" theme, the importance of efficiently combining freight and passenger services is seen as the most fundamental issue. Although combining freight and passenger services is complex, the authors assert that technological innovation can enable freight services to operate at comparable performance levels to passenger services. Ehret et al. (2020) developed a Model-Based Systems Engineering approach for analyzing the transshipment infrastructure for the Next Generation Train CARGO to increase rail freight competitiveness, particularly for LDHV goods. The analysis identifies a diverse range of stakeholders and emphasizes the complexity of the terminal's operational systems. The method used in this study was demonstrated to be feasible for the analysis of an intermodal transportation hub's entire system.

1.3. Research aim

This research aims to evaluate the current transportation system for shipping LDHV goods as a high-demand commodity in terms of environmental, financial, and accessibility across the EU27 countries. To this end, CO_2 emissions from rail and road modes associated with the transportation of LDHV goods, particularly chemical goods, will be calculated for the EU27 countries in 2020. Four intermodal railroad scenarios will be proposed as environmentally friendly alternatives to LDHV freight transportation. Then, based on economic considerations, availability, and accessibility, these alternatives will be analyzed and compared to unimodal road transportation.

The remainder of this study is structured as follows: The methodology for analyzing LDHV goods shipment is detailed in Section 2. Section 3 summarizes the findings, emphasizing the environmental, financial, and availability perspectives. Section 4 discusses the theoretical implications and compares the findings to previous research. Finally, the concluding section discusses the findings, limitations, and future research.

2. METHODS

This study analyzes unimodal and intermodal LDHV goods transportation in terms of environmental, economic, and availability. As implied by the name, the LDHV goods have been chosen for their density and value. According to the

SPECTRUM project (Zunder, 2012), LDHV goods fall under groups 0, 1, 5, 8, and 9 of the main NST/R goods classification (Eurosat, 1967). However, after 2008, the most recent data for the freight flow employ the NST 2007 classification (Eurostat, 2007). Comparatively, LDHV goods fall under groups 01, 04, 05, 06, 08, 10, 11, 12, 13, and 16 of the NST 2007 commodity class. The study's target group is NST Group 8, which includes chemicals, chemical products, manufactured fibers, rubber and plastic products, and nuclear fuel. The following parameters influenced the selection of chemical goods as a case study for LDHV goods across the EU27 in 2020:

- Chemical goods transportation across the EU27 countries can be an appropriate model for LDHV transportation in Europe.
- Chemical goods are a significant component of the EU27 economy. Innovative approaches are required to develop a more cost-effective and environmentally-friendly system for transporting such goods.

Appendix A summarizes the transportation data of group 8 commodities by road and rail in the EU27 countries in 2020, as determined by (Eurosat-statistic, 2020a, 2020b). Table 1 contains the equations used to calculate CO_2 emissions, transportation costs, and intermodal density.

2.1. Environmental analysis

Generally, two methods are utilized to estimate freight transportation operations emissions (TE_{CO2}); (1) Activity-based, (2) Energy-based approaches. For this study, CO_2 emissions were calculated using the activity-based method, and the emission factors (EF) were the chemical good transportation average emission factor suggested by CEFIC and ECTA (2011). The emission factor for each mode of transportation is presented in Table 2.

The next step in the environmental analysis is introducing railroad transportation scenarios to mitigate CO_2 emissions generated by road transport. The emission factors of the unimodal transportation modes are used to obtain composite emission factors (CEF) for each intermodal transportation scenario based on unimodal contribution (C_{Road}/ C_{Rail}), as shown in Table 3.

2.2. Transportation cost analysis

The Railrates (2018) website was used to gather all necessary data for calculating total transportation costs (TTC). Four random routes were chosen to provide a more precise cost estimate for each country. Road transportation costs were calculated in terms of cost per ton (LTL= Less than truckload), while costs associated with rail transportation were calculated in terms of cost per wagon (FWL= 40′ standard wagonload) and then converted to cost per ton based on the maximum cargo weight of a 40-foot standard wagon (26.7 ton).

2.3. Availability and accessibility analysis

Two parameters are introduced to evaluate the intermodal transportation of LDHV goods in terms of availability and accessibility: intermodal terminal density (ITD) and space accessibility (SA). Uniform data regarding the availability of each type of intermodal terminal in the EU27 countries were extracted from the Rail Facilities Portal (2020). The density of an intermodal terminal network (ITD) for a specific country is calculated by dividing the total number of intermodal terminals within the country (N_{IT}) by the country's geographic area (A) (Zunder, 2012).

The quantity and geographical distribution of intermodal terminals are often described as the network's space accessibility (SA). If there are numerous intermodal terminals along the railway network, SA will be rated high (Zunder, 2012). A database including locations of intermodal terminals and rail freight corridors within EU27 countries is obtained from the rail facilities portal (2020).

Equation number	Equation	Abbreviations	Definition	Units
Equation (1)	$TE_{Co2}=V\times D\times EF$	TE_{CO2}	Transportation CO_2 emission	Ton CO_2
		V	Transported goods volume	Million Ton
		D	Average transport distance	km
		EF	CO_2 emission factor	g CO_2/ ton-km
Equation (2)	$IE_{Co2}=\Sigma(V\times D)_{Road}\times CEF$	IE_{CO2}	Intermodal transportation CO_2 emission	Ton CO_2
		CEF	Composite emission factor	g CO_2 / ton-km
Equation (3)	$TTC=ATC\times V\times D$	TTC	Total transportation cost	Million $
		ATC	Average transport cost	$/ton-km
Equation (4)	$ITC=(C_{Road}\times TTC_{Road})+(C_{Rail}\times TTC_{Rail})$	ITC	Intermodal transportation cost	Million $
		C_{Road}/C_{Rail}	Road/rail contribution in an intermodal scenario	%
Equation (5)	$ITD=N_{IT}/A$	ITD	Intermodal terminal density	Number/km²
		N_{IT}	Total number of intermodal terminals in a country	Number
		A	country's geographic area	km²

Table 1. Summary of the equations, variables, and units

Mode	EF (g CO_2/ton-km)	Consideration
Road	62	The road emission factor is calculated using an average load factor of 80% of the vehicle's maximum capacity and 25% of empty running.
Rail	22	The rail emission factor is derived from an approximation of a variety of emission factors published by reputable sources across Europe.

Table 2. Average CO_2 emission factor for each transportation mode (CEFIC & ECTA, 2011)

Scenario	Road contribution C_{Road} (%)	Rail contribution C_{Rail} (%)	Composite Emission factor (CEF)
I1	5	95	24
I2	10	90	26
I3	15	85	28
I4	20	80	30

Table 3. Detail of the proposed intermodal scenarios

3. RESULTS

3.1. CO_2 emission estimation

The CO_2 emissions generated by road and rail are depicted in Figure 1 using the emission calculation methods described in the methodology section Equation (1) for selected LDHV goods. The findings demonstrate that transporting chemical goods by road emits significantly more CO_2 than rail in all EU27 countries in 2020. This is because road transportation has a higher emission factor and is a frequently used mode of transporting commodities. Additionally, this value varies by country. This occurs due to the disparity in the volume of goods transported (V) and the distance traveled (D). According to this case study, Poland, Germany, Spain, France, Italy, and the Netherlands generate more CO_2 than the other EU27 countries. On the other side, the highest rail mode CO_2 emissions are generated in Germany, Lithuania, and Poland; however, these emissions are still significantly lower than those generated by road in these countries. Thus, substituting proper rail transportation for road transportation will result in a significant reduction in CO_2 emissions. But in most cases, the transit destination is not served by rail; in these cases, intermodal railroad transportation could benefit atmospheric emissions.

CO_2 emissions are calculated and plotted in Figure 2 for the four intermodal scenarios using Equation (2) as described in

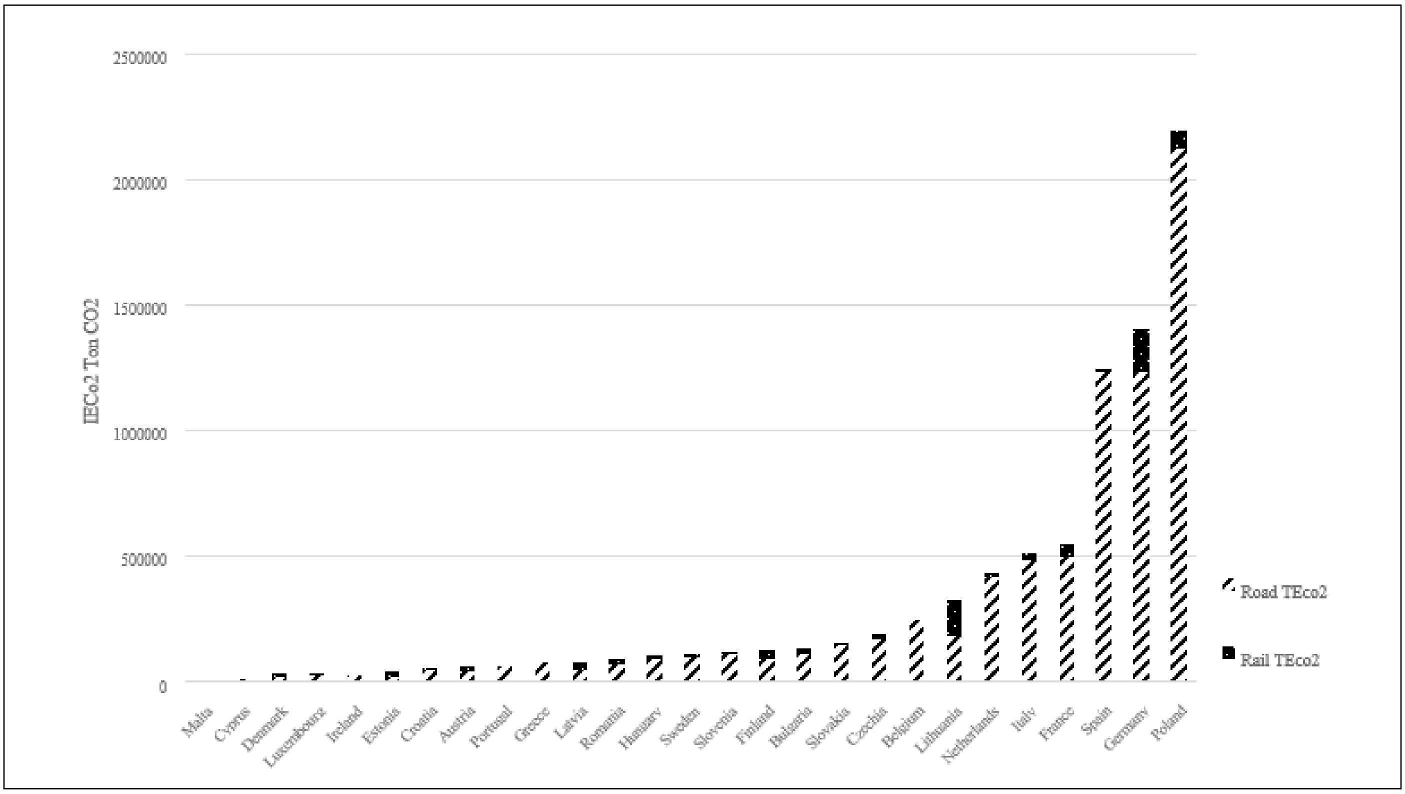

Figure 1. Total CO_2 emissions generated by road and rail

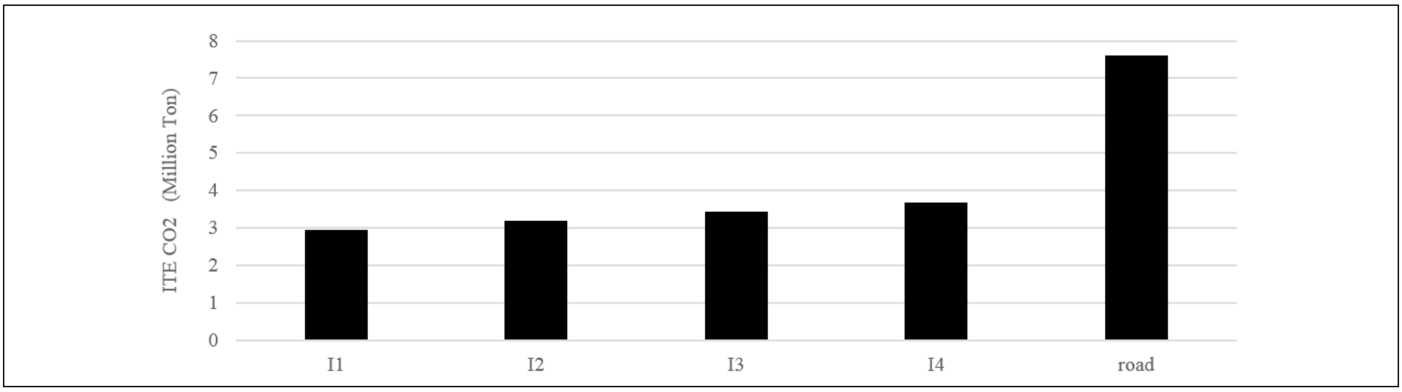

Figure 2. Total CO_2 emissions from intermodal transportation scenarios

the methodology section. The results indicate that increasing the rail mode contribution (C_{Rail}) in an intermodal scenario reduces total CO_2 emissions by 61%, 58%, 55%, and 52% for I1, I2, I3, and I4, respectively.

3.2. Cost estimation

To analyze the shipping costs of LDHV goods, the total rail and road transportation costs (TTC) for the six EU27 countries that generate the highest total CO_2 emissions, namely Poland, Germany, Spain, France, Italy, and the Netherlands, are calculated using Equation (3) and presented in Figure 3 (details can be found in Appendix B and C). The results in Figure 3 demonstrate a significant cost differential between road and rail travel in each of the six countries. For example, in France TTC_{road} is 30,056 million dollars, while TTC_{rail} is 225 million dollars or approximately 130 times as much. Germany has the highest total road and rail TTC, while Italy and Spain have the lowest.

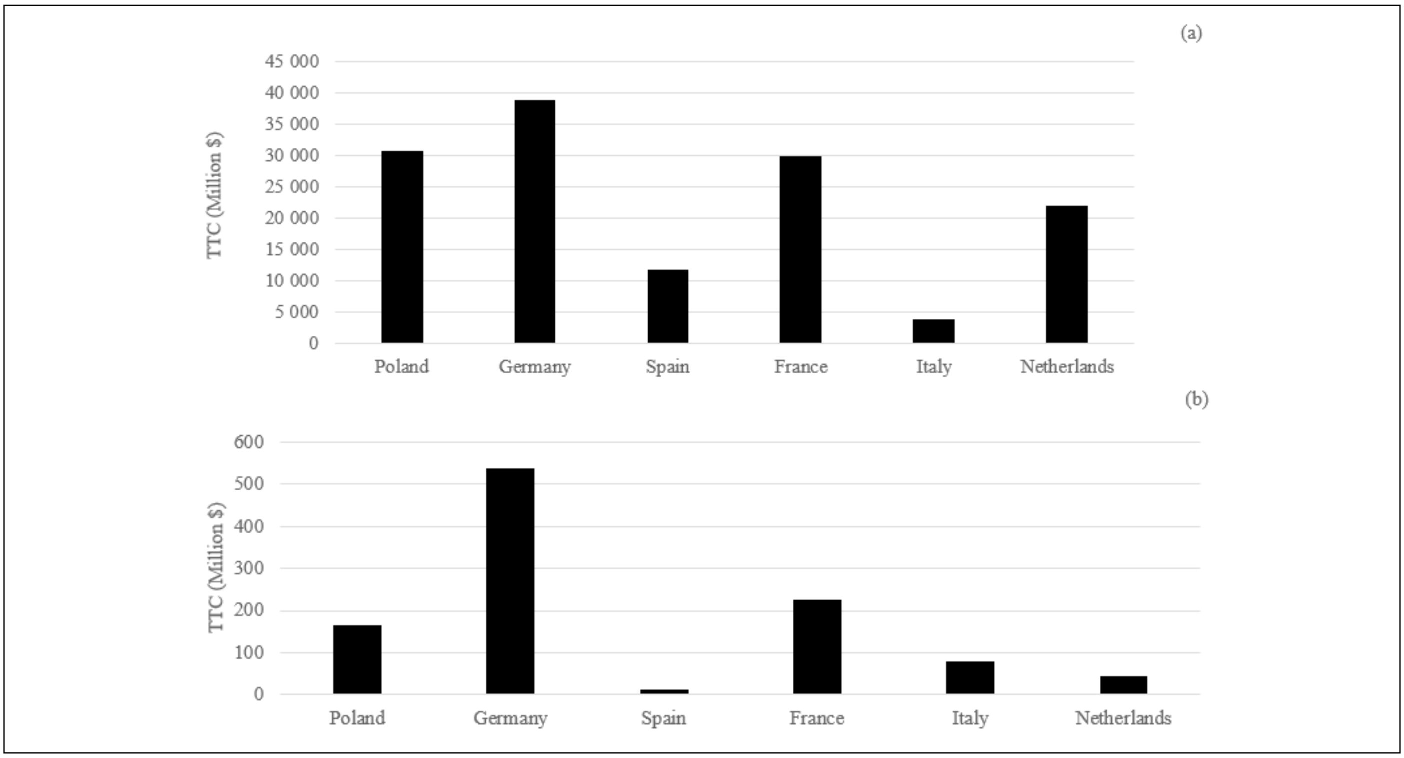

Figure 3. Total transportation cost (TTC) for the six countries with higher CO_2 emissions through (a) road (b) rail

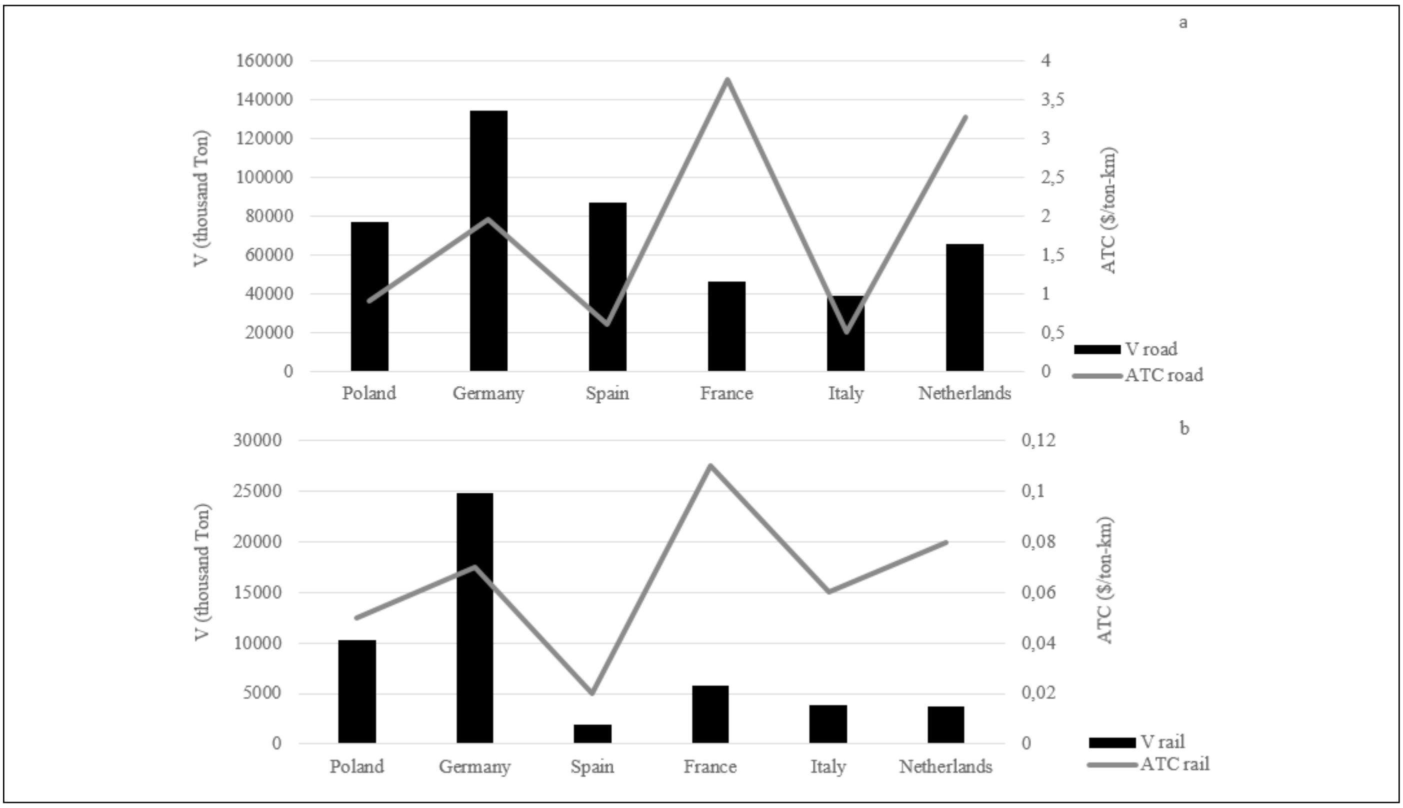

Figure 4. The volume of the transported goods (V) vs. Average transport cost (ATC) for the countries with higher CO_2 emissions by (a) road (b) rail

For a more precise assessment of transportation costs, Figure 4 and Table 4 show the transported volume of chemical goods (V) versus the average transport cost (ATC) for road and rail transportation. According to the findings, France and the Netherlands have significantly higher road ATC than the other countries. Furthermore, France has the highest rail ATC. Spain, Italy, and Poland all have the lowest road ATC rates of the six countries, with almost identical rates. Despite the low cost of rail, Spain has the lowest transport volume (V) of these countries, and this could be an excellent opportunity for this country to transition from road to rail for chemical goods transportation. Nonetheless, ATC varies by country, but it may also vary significantly within each country's various regions, but addressing this specific issue is beyond the scope of this article. However, as illustrated in Figure 5, transport cost functions for each country vary according to shipment distance.

Although road transportation is more expensive than rail in all EU27 countries, road transportation must be replaced by reliable rail transportation, mainly due to environmental concerns. However, as mentioned previously, because most transit destinations are not located on rail networks, it is impractical to switch entirely to rail; as a result, intermodal railroad transportation can significantly reduce transportation costs. By optimizing this shipping strategy, rail transportation's potential cost savings can be maximized. Thus, intermodality enhances a logistics system's economic performance by combining rail and road transportation modes. Figure 6 and Table 5 compare the cost of unimodal road and rail transport to the four intermodal scenarios which are obtained by Equation (4). According to the findings, intermodal transportation offers significant cost savings compared to road-only transportation. It should be highlighted that by increasing rail's share in intermodal scenarios, financial benefits also increased.

3.3. Availability

Figure 7 depicts the total number of intermodal terminals (N_{it}) in the EU27 countries. Appendix D contains information on intermodal terminals in the EU27 countries, including the availability of each type (seaports, inland ports, and freight villages). In some countries (for example, Bulgaria), the total number of intermodal terminals does not equal the total number of intermodal terminals of the three types; this is because the terminal does not consider only one type. According to the results, only Germany, Belgium, France, Italy, and the Netherlands have more than ten intermodal terminals, and Germany leads the EU27 with 78 intermodal terminals.

However, to assess the intermodal terminal availability in a country, intermodal terminal density (ITD) determined by Equation (5) is taken into account. Belgium, Luxembourg, the Netherlands, and Germany have a high ITD, as illustrated in Figure 8. For a more precise assessment of intermodal system availability for transporting LDHV goods, Figure 9 shows the intermodal terminal density (ITD) vs. the volume of the transported goods (V) (detailed data can be found in Appendix D). Based on the figure, it can be concluded that only Luxembourg and Belgium, which are located above the boundary line, provide acceptable intermodal terminals in terms of the volume of LDHV goods. In comparison, Germany, Spain, Poland, France, Italy, and Lithuania lack adequate intermodal terminals for the transportation of chemical goods, and this low density of intermodal terminals would be a significant impediment to these countries' transportation services.

Due to the small volume of chemical goods transported in the remaining countries (Bulgaria, Czechia, Denmark, Estonia, Ireland, Greece, Croatia, Latvia, Hungary, Austria, Portugal, Romania, Slovenia, Slovakia, Finland, and Sweden), low intermodal terminal density does not pose significant issues in terms of intermodal transport availability.

The following phase will see the development of new intermodal terminals in the required area. Cargo shippers will gravitate toward a well-connected terminal, so when constructing a multimodal freight terminal, the availability of the multimodal transportation network should be considered (Kumar & Anbanandam, 2019). As previously stated, the quantity and geographic distribution of intermodal terminals are frequently referred to as the space accessibility of the intermodal network (SA). The geographical distribution of intermodal terminals along the EU27 rail freight corridors (Rine-Alpine, North Sea-Med, ScanMed, Atlantic, Baltic-Adriatic, Mediterranean, Orient/East-Med, North Sea-Baltic, Amber) is depicted in Figure 10. As can be seen, the majority of intermodal terminals are located along specific rail freight corridors, such as the Rine-Alpine corridor, or in urban areas such as Frankfurt, which corresponds to the SPECTRUM project's study (Zunder, 2012). According to the map, despite the construction of numerous transportation infrastructures across Europe, there has been no significant increase in the number of intermodal terminals over the last decade. In this regard, the issue of location selection of an intermodal freight terminal has to be considered. According to Kumar and Anbanandam (2019) study, technical sustainability is the most important consideration for terminals location selection, followed by economic factors.

Country	**$V{*}D_{road}$**	**$V{*}D_{rail}$**	**V_{road}**	**V_{rail}**	**ATC_{road}**	**ATC_{rail}**	**TTC_{road}**	**TTC_{rail}**
Poland	34,266	3,299	76923	10,317	0.9	0.05	30,839	165
Germany	19,887	7,659	134194	24,824	1.96	0.07	38,979	536
Spain	19,854	597	87139	1916	0.6	0.02	11,912	12
France	8,015	2,041	46540	5,817	3.75	0.11	30,056	225
Italy	7,706	1,311	38674	3,872	0.51	0.06	3,930	79
Netherlands	6,745	540	65250	3679	3.28	0.08	22,124	43

Table 4. Cost breakdown for countries with higher CO_2 emissions

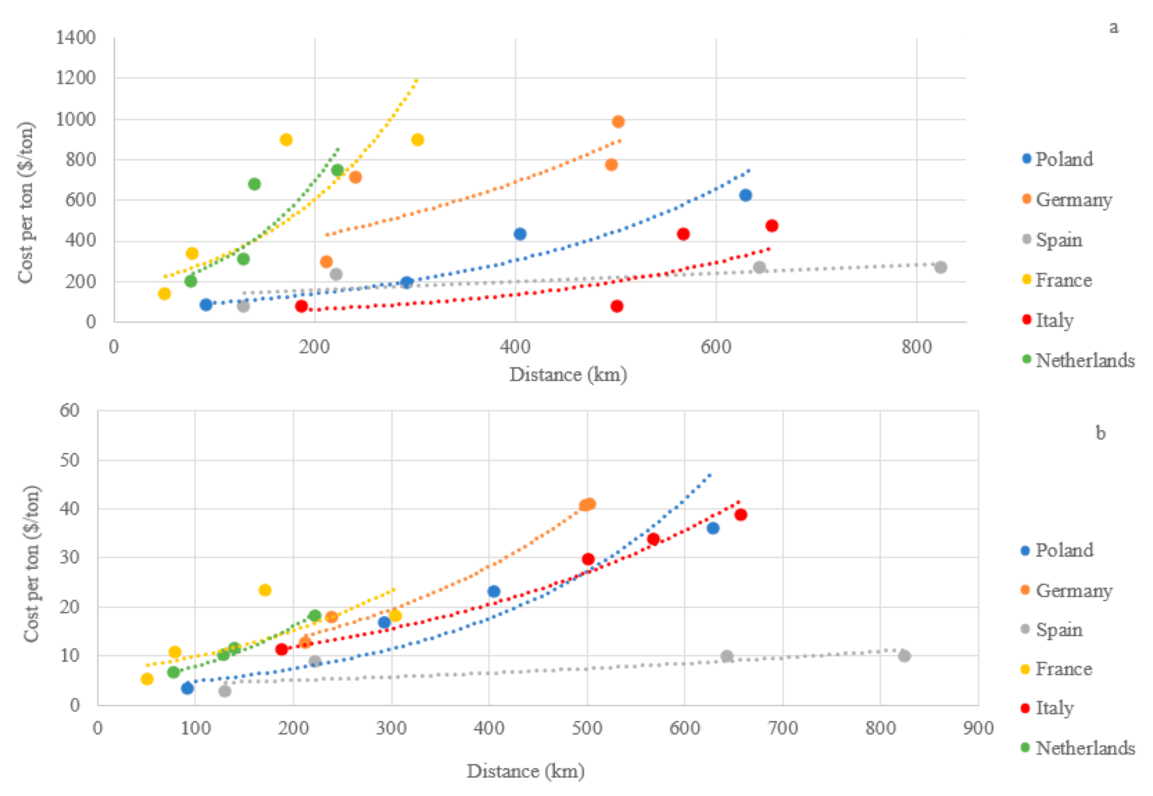

Figure 5. (a) Road and (b) Rail transport cost function (In print, this figure should be colored)

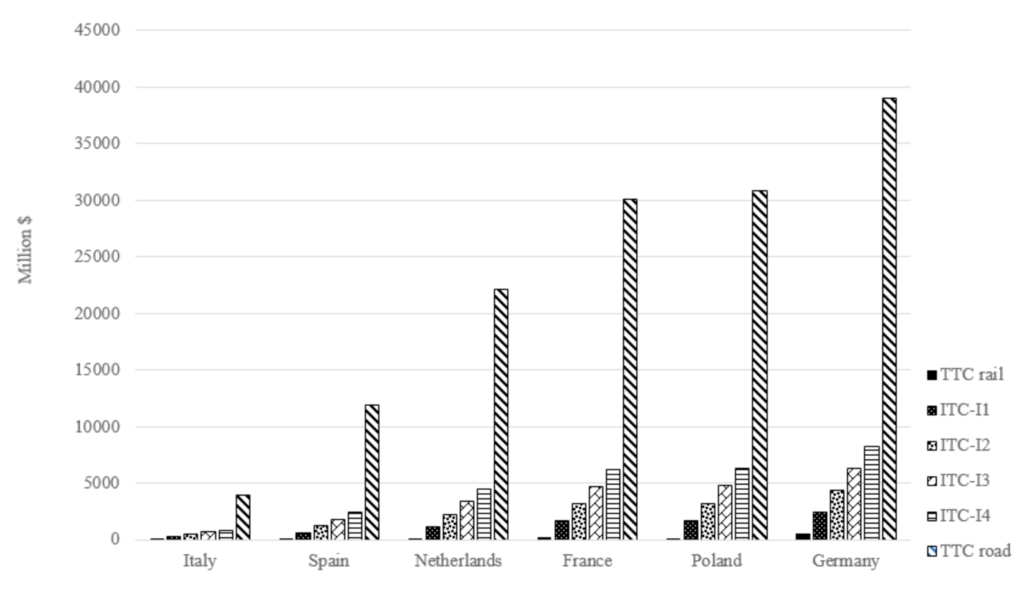

Figure 6. Comparison between intermodal scenarios and unimodal transportation cost

Contribution (C_{road}/C_{rail})	**(100/0) TTC $_{road}$**	**(0/100) TTC $_{rail}$**	**(5/95) ITC-I1**	**(10/90) ITC-I2**	**(15/85) ITC-I3**	**(20/80) ITC-I4**
Italy	3930.06	78.66	271.23	463.8	656.37	848.94
Spain	11912.4	11.94	606.963	1201.986	1797.009	2392.032
Netherlands	22123.6	43.2	1147.22	2251.24	3355.26	4459.28
France	30056.25	224.51	1716.097	3207.684	4699.271	6190.858
Poland	30839.4	164.95	1698.6725	3232.395	4766.1175	6299.84
Germany	38978.52	536.13	2458.2495	4380.369	6302.4885	8224.608

Table 5. Unimodal and Intermodal scenarios cost breakdown

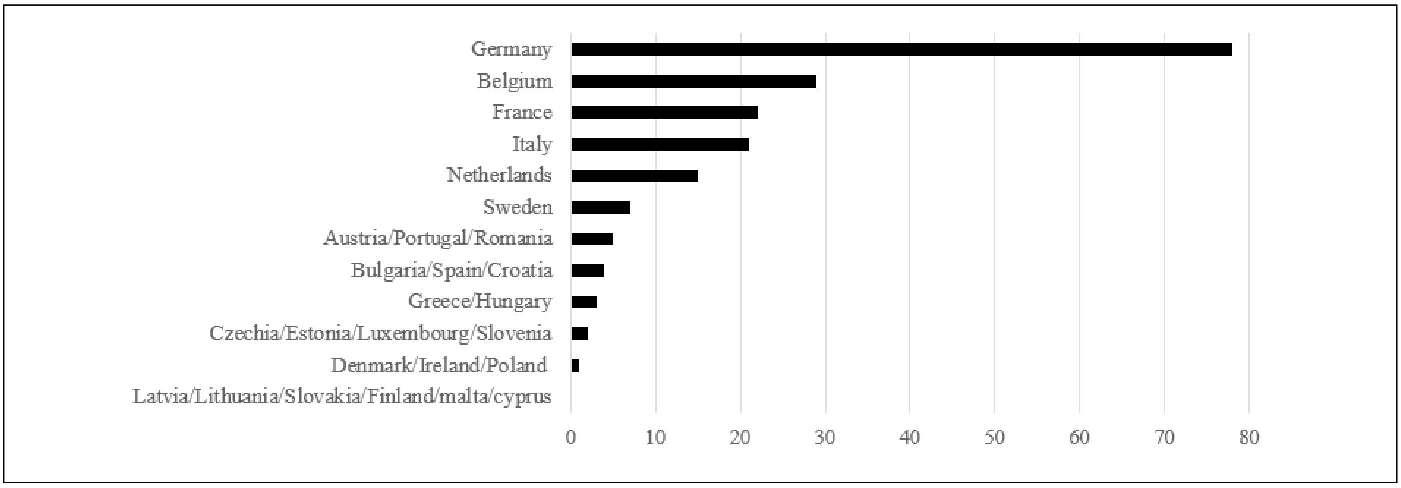

Figure 7. Total number of intermodal terminals (N_{it})

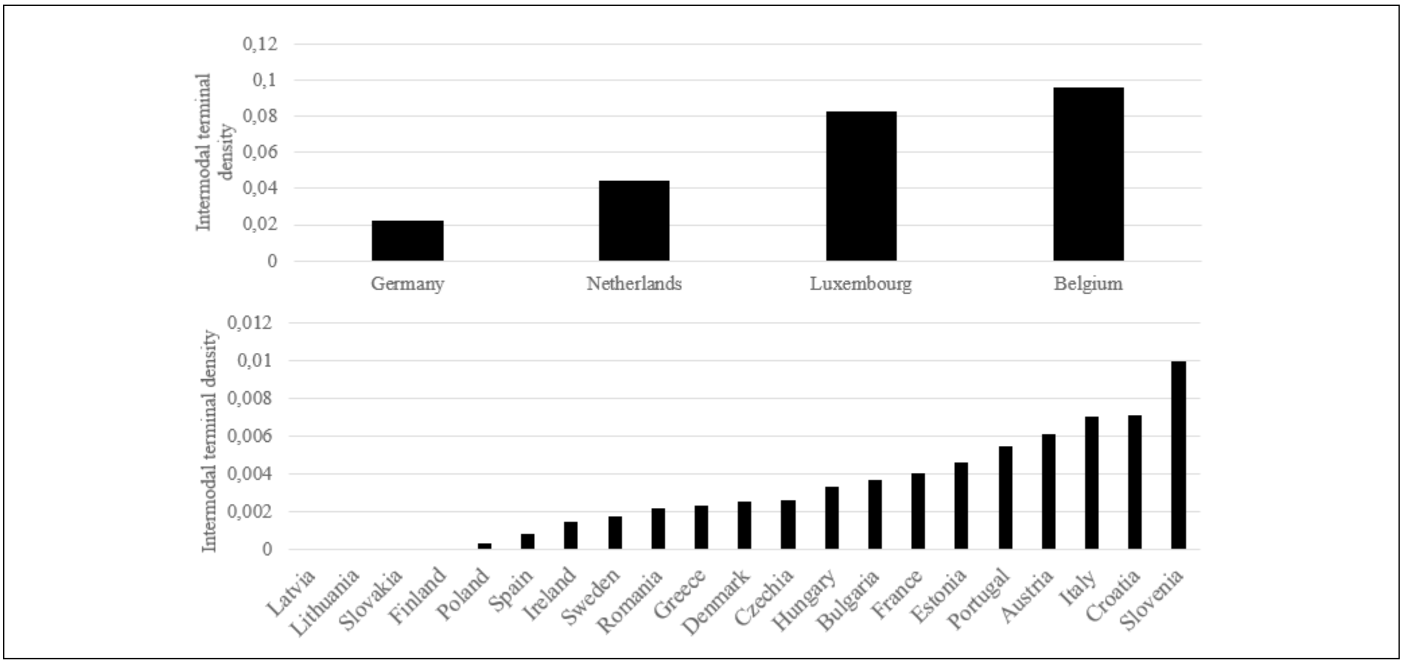

Figure 8. Intermodal terminal density in EU27 countries

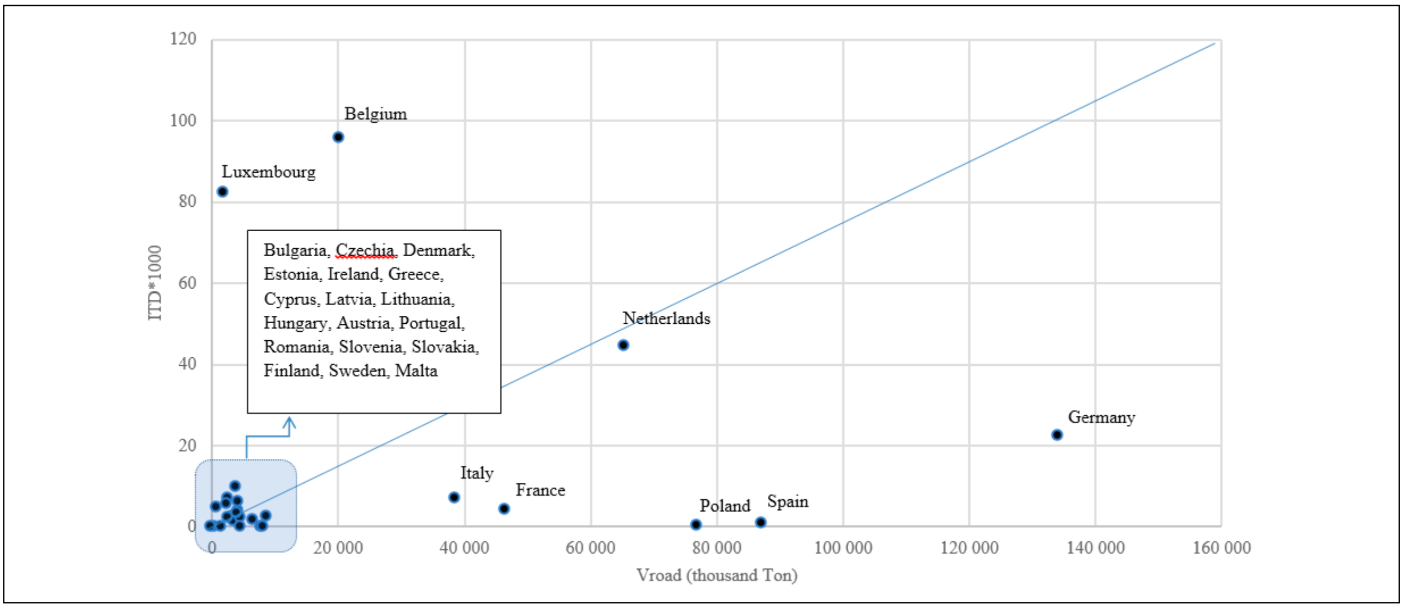

Figure 9. Intermodal terminal density (ITD) vs. Transported goods volume (V)

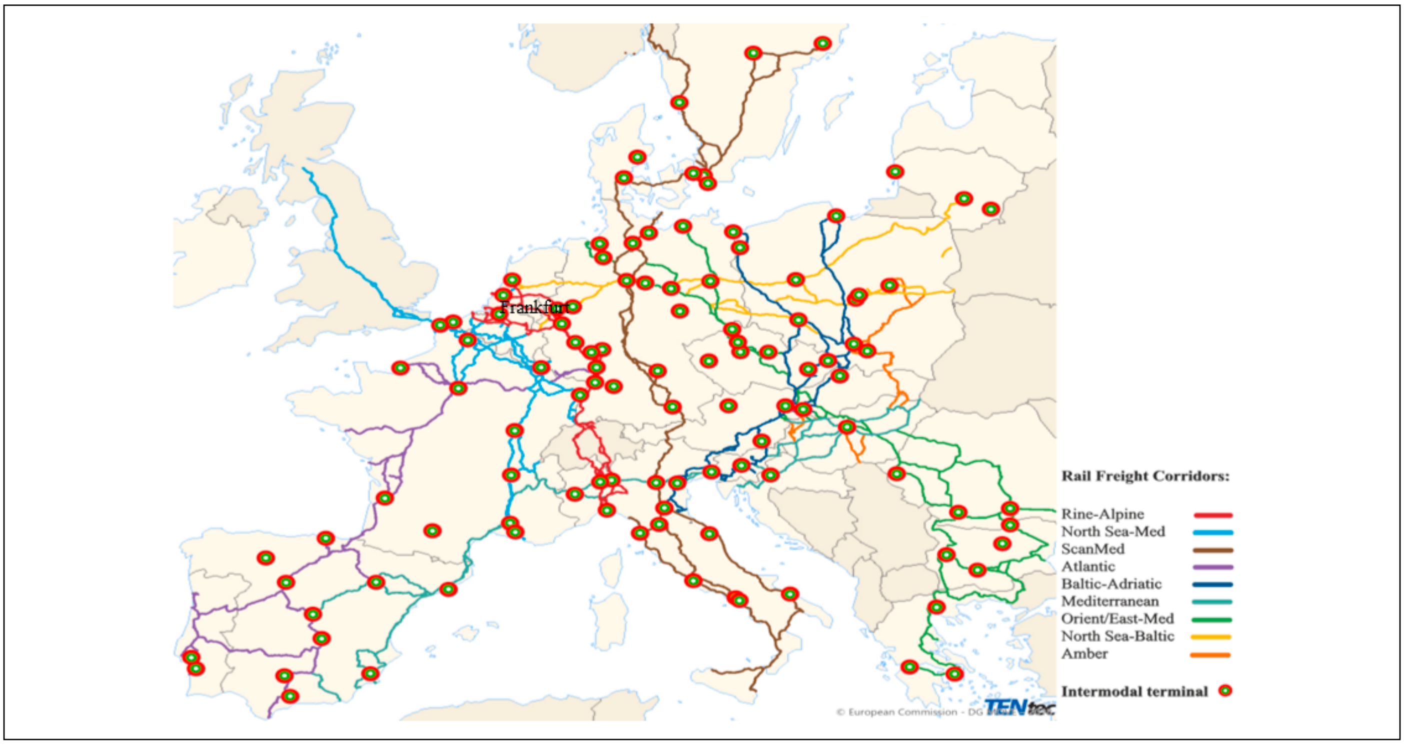

Figure 10. Intermodal network's space accessibility within EU27 (In print, this figure should be colored)

4. DISCUSSION

As stated in the literature review, some studies might be comparable to this study. To this end, Jackson et al. (2013) focused on the constraints in rail freight transportation for LDHV commodities in Europe, such as rail infrastructure capacity; extra handling cost, time, and reliability risks at terminals; opening hours; and densely situated terminals and networks. The current study focuses on the benefits of rail transportation for this type of commodity and based on the positive outcomes obtained through our strategy, it can be argued that the benefits significantly outweigh the constraints, which is perfectly consistent with Jackson et al.'s assertions; the new rail freight service, despite existing constraints, can provide a more competitive service in terms of reliability, affordability, flexibility, and timeliness, compared to road transport. Moreover, Zunder and Islam (2018) identified terminals as a significant impediment or facilitator to developing a competitive intermodal rail service in their study. The research indicates that by utilizing a rail terminal as an enabler, it is possible to transport LDHV commodities via intermodal rail at a cost-effective rate, which matches the results of our cost analysis. Furthermore, Islam and Zunder (2018) highlighted several technological innovations in their article that, if adopted by the rail industry, could result in a profitable modal shift away from the road to rail for LDHV goods shipment. Their findings suggest that these innovations have the potential to promote mode shift by directly increasing rail freight service. Additionally, these advancements can benefit the intermodality scenarios discussed in our research. Boehm et al. (2021) evaluated the cost, emissions, and time savings associated with a fully electrified, large-scale, high-speed rail freight transport system for LDHV shipment across Europe. According to their findings, switching to a fully electrified, high-speed rail freight system can result in up to an 80% reduction in CO_2 emissions. This is 20% more than the maximum CO_2 reduction achieved in our research (intermodal scenario I1), but the high-speed rail's electrical nature explains the difference. On the other hand, their strategy is not economically successful, as their cost analysis indicates that high-speed rail freight is approximately 70% more expensive than conventional truck freight. By contrast, our research indicates that traditional rail is affordable, at least in the six countries that generate the most CO_2 emissions (Poland, Germany, Spain, France, Italy, and the Netherlands).

This study has the potential to make several significant contributions to the literature. By 2030, the global population is expected to reach 8.5 billion. This will significantly impact global consumption and freight transportation, including LDHV goods. This research will help reduce the cost of transportation for LDHV items, which are expected to experience substantial growth in supply and demand globally in the near future. On the other hand, by emitting pollutants from the combustion of fossil-derived fuels, road transportation contributes to deteriorating air quality and climate change. Moreover, it contributes to noise and water pollution and affects ecosystems through various direct and indirect interactions. This article proposes intermodal scenarios to assist transportation planners in developing a more environmentally friendly transportation network. Additionally, the proposed framework is well-suited for terminal location selection, trying to maximize the multimodal network's availability for LDHV goods transportation. Consequently, offer financial benefits to infrastructure investors.

5. CONCLUSION

Road transportation contributes to poor air quality and climate change by emitting greenhouse gases from the burning of fossil fuels. Furthermore, it contributes to noise and water pollution and has an adverse effect on ecosystems via various direct and indirect interactions. According to the data analysis, the majority of chemical goods (which is a good example of LDHV commodities) were transported by road in the EU27 countries in 2020, and according to the environmental analysis, CO_2 emissions in Poland, Germany, Spain, France, Italy, and the Netherlands are higher than in the rest of the EU27. On the other hand, rail generates the most CO_2 emissions in Germany, Lithuania, Poland, and France, but they are still significantly less than the CO_2 emitted by road in these countries. This paper proposes intermodal scenarios to aid transportation planners in developing a more environmentally friendly transportation network. According to the results, transporting LDHV items via the proposed railroad intermodal network will emit less CO_2 than unimodal road transportation.

By focusing on the six countries that generate the most CO_2, it was found that transport cost functions for each country vary based on shipment distance. However, primary cost analysis of the intermodal scenarios revealed that they have the potential to reduce shipping costs compared to unimodal road transportation. Indeed, by increasing rail's share of intermodal transport, financial benefits accrue from lower transportation costs for LDHV items, which will undoubtedly experience significant growth in supply and demand in the near future.

On the other hand, maximizing the availability of the proposed intermodal network (for transporting LDHV goods) benefits infrastructure investors financially. According to the availability analysis, only Luxembourg and Belgium have an adequate intermodal terminal density when the total volume of chemical goods transported in these countries is considered. Furthermore, by analyzing space accessibility in the EU27 countries, it was discovered that the majority of intermodal terminals are located along specific rail freight corridors or in close proximity to a metropolitan area, which corroborates a study conducted by the SPECTRUM project (Zunder, 2012), which found that despite extensive transportation infrastructure construction throughout Europe over the last decade, there has been no significant change in the locations of intermodal terminals. As a result, it requires special attention from European countries.

In conclusion, road-rail intermodality improves a logistics system's economic and environmental performance by combining rail and road transportation modes to transport not only chemical goods but also other types of LDHV goods. Moreover, the proposed model is adaptable enough to incorporate new criteria or eliminate specific criteria from other countries' policies and laws, making it suitable for use in emerging and developed countries.

5.1. Limitations of the study

- Limited access to data relating to the shipment of LDHV goods in all countries worldwide to conduct a global analysis.
- Limited access to data on all types of LDHV goods to conduct a thorough analysis.
- No access to data on LDHV goods shipment by air and water to conduct a comparative analysis of all modes of transportation.
- No access to a standardized freight pricing system in most European countries to estimate precise freight shipping costs.
- Shortage of academic research on LDHV goods transportation.

5.2. Suggestions for further research

- Conduct research into the environmental, economic, and logistical implications of transporting LDHV goods by sea and air.
- Conduct a study that includes detailed data on all types of LDHV goods throughout Europe, including their weight, shipment distance, and emission factors.

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APPENDIX

Appendix A: Transported goods volume and Average transport distance for the EU27 in 2020 (Eurosat-statistic, 2020a, 2020b)

Country	$V*D_{road}$ (Million Ton-Km)	$V*D_{rail}$ (Million Ton-Km)	V_{Road} (Thousand ton)	V_{Rail} (Thousand ton)
Belgium	3,918	NA	601	NA
Bulgaria	1,711	1,116	742	4,682
Czechia	2,685	945	1,367	4,674
Denmark	300	75	352	252
Germany	19,887	7,659	21,119	24,824
Estonia	250	857	104	7,802
Ireland	429	0	543	0
Greece	1,137	NA	1,804	NA
Spain	19,854	597	7,337	1,916
France	8,015	2,041	7,791	5,817
Croatia	711	198	979	712
Italy	7,706	1,311	1,970	3,872
Cyprus	24	NA	325	NA
Latvia	747	1,273	93	3,948
Lithuania	2,949	6,441	321	17,180
Luxembourg	366	1	737	33
Hungary	1,415	802	331	3,506
Netherlands	6,745	540	12,265	3,679
Austria	576	1,078	1,012	4,472
Poland	34,266	3,299	9,783	10,317
Portugal	1,000	NA	187	NA
Romania	1,094	1,044	1,098	2,663
Slovenia	1,713	34	161	143
Slovakia	2,312	308	1,905	2,139
Finland	1,359	1,631	1,239	7,128
Sweden	1,473	686	510	1,297
Malta	NA	NA	NA	NA

Appendix B: Road transportation cost detail

Country	Route	Distance (km)	Transport Cost per ton ($/ton)	Transport cost per ton kilometer ($/ton-km)	Average transport cost (ATC) ($/ton-km)
Poland	Warsaw-Rybnik	292.42	197	0.67	0.9
	Koszalin-Krosno	631.08	619	0.98	
	Warsaw-Radom	92.42	83	0.90	
	Slupca-Chelm	406.06	431	1.06	
Germany	Berlin-Munich	504.41	984	1.95	1.96
	Berlin-Frankfurt	497.93	766	1.54	
	Düsseldorf-Hannover	240.15	710	2.96	
	Ulm-Frankfurt	212.42	296	1.39	
Spain	Valensiya-Teruel	130.29	77	0.59	0.6
	Madrid-Albacete	223.45	237	1.06	
	León-Sabadell	644.03	264	0.41	
	Barcelona-Badajoz	825.3	264	0.32	
France	Nemours-Calais	304.46	897	2.95	3.75
	Paris-Hirson	172.33	895	5.19	
	Amiens-Senlis	79.36	333	4.20	
	Noyon-Senlis	51.5	138	2.68	

Country	Route	Distance (km)	Transport Cost per ton ($/ton)	Transport cost per ton kilometer ($/ton-km)	Average transport cost (ATC) ($/ton-km)
Italy	Rome-Crotone	501.67	77	0.15	0.51
	Rome-Napoli	188.44	77	0.41	
	Milan-Napoli	657.52	470	0.71	
	Verona-Benevento	568.79	429	0.75	
Netherlands	Delfzijl-Venlo	223.92	742	3.31	3.28
	Amsterdam-Venlo	141.04	682	4.84	
	Dokkum-Amsterdam	129.46	305	2.36	
	Dokkum-Urk	78.41	204	2.60	

Appendix C: Rail transportation cost detail

Country	Route	Distance (km)	Transport Cost per wagon ($/wagon)	Transport cost per ton ($/ton)	Transport cost per ton kilometer ($/ton-km)	Average transport cost (ATC) ($/ton-km)
Poland	Warsaw-Rybnik	292.42	444	16.63	0.06	0.05
	Koszalin-Krosno	631.08	962	36.03	0.06	
	Warsaw-Radom	92.42	88	3.30	0.04	
	Slupca-Chelm	406.06	616	23.07	0.06	
Germany	Berlin-Munich	504.41	1098	41.12	0.08	0.07
	Berlin-Frankfurt	497.93	1085	40.64	0.08	
	Düsseldorf-Hannover	240.15	478	17.90	0.07	
	Ulm-Frankfurt	212.42	335	12.55	0.06	
Spain	Valensiya-Teruel	130.29	77	2.88	0.02	0.02
	Madrid-Albacete	223.45	237	8.88	0.04	
	León-Sabadell	644.03	264	9.89	0.02	
	Barcelona-Badajoz	825.3	264	9.89	0.01	
France	Nemours-Calais	304.46	480	17.98	0.06	0.11
	Paris-Hirson	172.33	627	23.48	0.14	
	Amiens-Senlis	79.36	289	10.82	0.14	
	Noyon-Senlis	51.5	138	5.17	0.10	
Italy	Rome-Crotone	501.67	789	29.55	0.06	0.06
	Rome-Napoli	188.44	297	11.12	0.06	
	Milan-Napoli	657.52	1033	38.69	0.06	
	Verona-Benevento	568.79	895	33.52	0.06	
Netherlands	Delfzijl-Venlo	223.92	487	18.24	0.08	0.08
	Amsterdam-Venlo	141.04	306	11.46	0.08	
	Dokkum-Amsterdam	129.46	269	10.07	0.08	
	Dokkum-Urk	78.41	172	6.44	0.08	

Appendix D: Intermodal terminal detail

EU27 Countries	Terminal Area type			Total number of intermodal terminals (N_{IT})	Countries area (A) (km^2)	Intermodal terminal Density (ITD)	V_{road} (thousand Ton)
	Seaport	Inland port	Freight village				
Belgium	21	15	0	29	30280	0.09577	20,171
Bulgaria	3	1	1	4	108560	0.00368	4,153
Czechia	0	2	0	2	77200	0.00259	8,673
Denmark	1	1	1	1	40000	0.0025	3,311
Germany	8	43	33	78	349380	0.02233	134,194
Estonia	2	0	0	2	43470	0.0046	703
Ireland	1	0	0	1	68890	0.00145	3,501
Greece	3	0	0	3	128900	0.00233	4,570

EU27 Countries	Terminal Area type			Total number of intermodal terminals (N_{IT})	Countries area (A) (km²)	Intermodal terminal Density (ITD)	V_{road} (thousand Ton)
	Seaport	Inland port	Freight village				
Spain	1	0	3	4	499603.479	0.0008	87,139
France	3	19	0	22	547557	0.00402	46,540
Croatia	4	0	0	4	56590	0.00707	2,639
Italy	4	5	12	21	297730	0.00705	38,674
Cyprus	NA	NA	NA	NA	9240	NA	422
Latvia	0	0	0	0	62090	0	1,393
Lithuania	0	0	0	0	62630	0	4,591
Luxembourg	0	2	1	2	2430	0.0823	1,810
Hungary	0	2	1	3	91260	0.00329	4,039
Netherlands	10	9	1	15	33670	0.04455	65,250
Austria	0	4	1	5	82520	0.00606	4,240
Poland	0	1	0	1	306170	0.00033	76,923
Portugal	3	1	1	5	91605.6	0.00546	2,405
Romania	3	2	0	5	230080	0.00217	2,728
Slovenia	2	0	0	2	20136.4	0.00993	3,848
Slovakia	0	0	0	0	48080	0	7,883
Finland	0	0	0	0	303920	0	8,024
Sweden	7	0	0	7	407310	0.00172	6,447
Malta	NA	NA	NA	NA	320	NA	NA