Project in Railway Technology
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Report

Intermodal Freight Transport on the ScanMed Corridor: Rail-Road-Sea Integration, Efficiency, and System Optimization

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Executive summary

With freight transportation being the backbone of economies and preventing a looming climate crisis, a closer look into the modes of freight transportation is needed. To address the economic viability and the environmental impact of a transportation mode, this report compares the transportation costs, the transportation time, and the carbon dioxide emissions of road, rail, and maritime transportation.

Policies by the European Union to strengthen the single market incentivize a modal shift of freight transportation from the road to more sustainable modes, including rail transport. Therefore, the European Union has introduced the Trans-European Transport Network (TEN-T). This network consists of essential freight corridors across Europe that shall be strengthened. One of these corridors is the Scandinavian-Mediterranean corridor spanning from Finland across the Scandinavian countries, down to Malta. On this corridor lie Gothenburg and Hamburg with the unique situation of being able to transport freight between these two places by truck, train, or feeder ship. Thus, a comparison between unimodal and intermodal transportation on this stretch is conducted. To take first and last mile logistics into account, transporting a container completely by truck is compared to transporting a container by feeder ship or by train for the main leg and by truck for the first and last mile. Furthermore, a comparison of electric freight systems is undertaken and a proposal to enhance rail freight attractiveness through higher reloading efficiency is explored.

The report finds that the best suited mode of intermodal transportation, including first and last mile logistics, is road–rail. It achieves the lowest cost and fastest transportation time for the given route. The most environmentally friendly mode of transportation is the feeder ship, but it has the highest costs and longest transportation time. Furthermore, electrified trains consume approximately 78 % less energy than electrified trucks at this distance. Lastly, an improvement of the reloading efficiency of rail freight could drastically improve its competitiveness.

Abbreviations

CEF Connecting Europe Facility

CO_2 carbon dioxide

CO_2e carbon dioxide equivalent

EU European Union

GHG greenhouse gas

HCT High-Capacity Transport

KPI key performance indicator

ScanMed Scandinavian-Mediterranean

TEN-T Trans-European Transport Network

TEU twenty-foot equivalent unit

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Chapter 1

Introduction

1.1 Background

Freight transport in Europe plays a critical role in supporting economic activity and supply chains. However, the sector is also a major contributor to environmental impacts, accounting for approximately one quarter of total greenhouse gas (GHG) emissions in the European Union (EU), with road transport being the dominant source (European Commission, 2021b). Despite ongoing policy efforts to shift freight toward more sustainable modes, road transport continues to dominate due to its high flexibility, reliability, and door-to-door service capability.

In contrast, rail and feeder-ship freight transport offer significant advantages in terms of energy efficiency and therefore lower emissions, particularly for long-distance and high-volume transport. Studies indicate that rail transport can reduce emissions by up to 62% when compared to road transport (Bilgili, 2023), especially when electrified rail systems are used (European Environment Agency, 2022). However, rail freight faces structural and operational challenges, including limited network capacity, infrastructure constraints, and reduced flexibility compared to road transport (Bontekoning et al., 2004).

In addition, shipping plays a huge role in intra European trade as 40% of this trade within Europe is done by means of short sea shipping (Xavier et al., 2005). When it comes to the Nordic region, and Sweden in particular, maritime corridors are essential for connecting domestic markets to major European hubs like Hamburg in Germany, facilitating the movement of high-volume exports and imports through specialized container terminals.

To address these challenges, intermodal transport systems have been promoted as a key solution. Intermodal transport integrates different transport modes typically combining rail or ship for long-distance haulage with road transport for first and last mile delivery to improve overall system efficiency and sustainability (Crainic and Kim, 2007). The EU has actively supported this transition through strategic initiatives such as the Trans-European Transport Network (TEN-T), which aims to enhance connectivity, remove bottlenecks, and facilitate seamless cross-border freight movement (European Commission, 2020).

Additionally, the growing pressure to reduce GHG-emissions and meet climate targets has increased the importance of shifting freight transport toward more sustainable alternatives. Governments and regulatory bodies across Europe are introducing stricter environmental policies and incentives to encourage the use of intermodal transport in the form of rail and maritime transport alternatives. These measures not only aim to reduce the environmental impact of freight movement but also promote a more balanced and resilient transport system. As a result, intermodal transport is increasingly viewed as a key approach to achieving both economic efficiency and environmental sustainability in the European logistics sector.

There is a significant need for a systematic analysis of different types of intermodal transport systems and their comparison with unimodal transport. Such an analysis should consider key performance indicators (KPIs), including cost per ton-kilometer, energy efficiency, emissions, and operational practicality. In addition, the evaluation should account for the influence of policy frameworks within the EU.

The following research provides a comparative analysis within the field of logistics. To establish a clear framework, the study first distinguishes between the two primary transport categories in Europe: unimodal transport (typically road freight) and intermodal transport (cf. Section 2.1).

1.2 Project description

This research focuses on the comparability of intermodal transport systems. This specific mode was selected because, unlike multimodal transport, intermodal operations utilize standardized loading units (cf. Section 2.1).

In the defined geographical scope of the Gothenburg–Hamburg TEN-T corridor, this standardization facilitates a more robust comparison of KPIs. The study evaluates the operational efficiency of road–rail and road–short sea intermodal chains relative to unimodal road transport. Furthermore, the scope extends to analyzing the influence of subsidy frameworks on individual transport modes and their subsequent impact on the competitiveness of intermodal transport solutions.

1.3 Research questions

1. How do road–rail and road–short sea transports compare to unimodal road transport between Hamburg and Gothenburg regarding cost, transport time, and carbon dioxide equivalent (CO_2e) emissions?
2. How do current and future EU and local policy frameworks and infrastructure projects influence the modal split on this corridor?

1.4 Aim

The objectives of the project are as follows:

- To define the differences between intermodal and unimodal transport.
- To gather and analyze data from ports, railway undertakings, logistic companies, governments, and European reports on intermodal and unimodal transport, with special focus on voyage time, costs, and environmental impact.
- To evaluate challenges of intermodal transport on the route Gothenburg–Hamburg.
- To examine EU and local policies, subsidies, and the impact of these on international freight transport.
- To reach a fair comparison between intermodal and unimodal transport.

1.5 Limitations

This report is limited to the analysis of the transportation of standard 20-foot freight containers measured in twenty-foot equivalent units (TEUs) between Gothenburg and Hamburg. The analysis of the different modes of transportation is subject to the availability of data. Furthermore, only rail, road, and sea transportation with namely electric trains, combustion engine trucks, and feeder ships will be considered. An extra section will compare electric trucks to electric trains. This report focuses on voyage time, transportation costs, and environmental impact of the different modes of transportation as well as EU and local policies and subsidies.
AI was used to find sources, translate self-written texts into English, and find systematic errors in the report.

Chapter 2

Definitions and methodology

2.1 Definitions

Unimodal transport refers to direct transport or door-to-door transport, where freight is transported directly from a point A to a point B. A single means of transport (e.g., only a truck, train, or ship) is used exclusively for the entire journey. Since the transport mode is not changed, there is no transfer of goods to other transport modes along the route (Ballis and Golias, 2002; Dolge et al., 2023).

Multimodal transport describes the carriage of freight by at least two different modes of transport. This system requires a transfer of goods at specific interfaces (terminals or hubs), to switch from one carrier to another. Historically, multimodal systems often consist of a sequence of independent, non-integrated transport services where the cargo itself may be handled during the transfer (European Commission, 2026).

Intermodal transport is a specialized form of multimodal transport where goods are moved in a single loading unit, such as a standardized container or semi-trailer across two or more modes. Its defining characteristic is that the cargo itself is never handled during transshipment. Instead, only the standardized unit is moved between trucks, trains, or ships. This ensures that the freight remains untouched within the same unit from the starting to the end destination (Ballis and Golias, 2002).

Intermodal terminals are critical infrastructure facilities utilized for the transshipment of freight. Their primary objective is to facilitate the transfer of standardized loading units between different modes of transport. Generally, these facilities are categorized into two distinct types: bimodal terminals, which handle transfers between two modes (e.g., road–rail or road–sea), and trimodal terminals, which integrate three modes, typically rail, road, and waterborne transport (URRI, 2017).

Twenty-foot equivalent unit (TEU) is "a unit of cargo capacity, especially for container ships. These ships carry cargo in standard metal boxes, called containers, which can be transferred easily to trains or trucks. TEU is an abbreviation for 'twenty-foot equivalent unit.' One TEU represents the cargo capacity of a standard container 20 feet long, [...], or half the capacity of a similar container 40 feet long." (Rowlett, 2018).

2.2 Methodology

This report compares unimodal and intermodal transportation between Gothenburg and Hamburg based on one TEU, a standardized unit representing one 20-foot ISO-container (Eurostat, n.d.). For comparability, the average weight of one TEU is defined as 12.5 t for this report, as suggested in Schönknecht (2009).

Two systems will be compared: port-to-port transportation as unimodal transport and door-to-door transportation as intermodal transport including a first and last mile road transportation leg and rail or maritime transportation for the main leg.

Furthermore, the metrics to compare the transportation modes are the average transportation time in hours, the CO_2e emissions in $\frac{g}{TEU \times km}$, and the cost in $\frac{€}{TEU \times km}$. All metrics are calculated for the full distance and normalized per TEU-km based on the assumed average weight of a TEU.

As the Gothenburg–Hamburg route is part of an EU TEN-T corridor, EU subsidies are researched to show their impact of the modal split and shift of freight transportation in Europe. The comparison focuses on the implementation of regulations by Sweden and Germany and the TEN-T regulations.

To compare the transportation modes, first the unimodal modes, road, rail, and ship between the ports of Gothenburg and Hamburg are compared with the just introduced metrics. Then, the comparison is expanded to take intermodal transportation from and to a location about 100 km (Comité National Routier (CNR), 2021) from the respective sea or rail hub into account. 100 km is the average length of a first and last mile in Germany according to Comité National Routier (CNR) (2021). This makes it possible to consider door-to-door logistics. The transportation time is defined as the time it takes for one TEU to be transported from the port of Gothenburg to the port of Hamburg for the unimodal comparison. The transportation time for the intermodal transportation includes the first and last mile. The chosen factors show both the environmental impact of the respective transportation mode, as well as the economic viability.

Lastly, to show future potential, electrified intermodal transport with electrified trains and trucks is compared to unimodal transport with electrified trucks and reloading efficiency is suggested as a key factor for enhancing rail freight competitiveness.

Chapter 3

Transportation modes

3.1 Transportation corridor Gothenburg–Hamburg

To ensure the comparability of various transport modes, particularly with respect to short-sea feeder operations, few European corridors offer a similar degree of parity. The Hamburg–Gothenburg (Scandinavia) relation was specifically selected due to its role within the TEN-T initiative, specifically as a critical segment of the Scandinavian-Mediterranean (ScanMed) core network corridor.

The strategic significance of this corridor is further highlighted by the construction of the Fehmarn Belt fixed link, one of the most ambitious infrastructure projects in recent history (Federal Ministry for Digital and Transport, 2024). This development underscores the corridor's essential function in advancing sustainable intermodal transport across northern Europe. Consequently, this corridor provides an ideal empirical framework to evaluate the performance of individual transport modes and intermodal chains, ensuring the highest possible level of comparability for this research.

3.2 Road freight

Road freight transport is a key component of logistics and is the dominant mode of inland freight in the EU, playing a central role in supply chains due to its flexibility and accessibility. According to Eurostat (2024b), Germany and Sweden recorded approximately 280 billion and 63 billion tonne-kilometres of road freight, respectively, in 2024. Road transport dominates transportation flows, accounting for over 75% of inland freight activity in the EU — a share that has increased by 6.8% in the previous decade according to the European Environment Agency (2024). This modal dominance is driven by road freight's operational advantages i.e. door-to-door service capability, high frequency, and operational flexibility essential for modern just-in-time logistics systems.

3.3 Sea freight

The sea freight market plays a significant role in global trade and goods transportation. Around 80% of all international trade volume is, at some point, transported on a ship (Hassellöv et al., 2025). As a result, this market is also one of the main causes of GHG emissions. It accounts for approximately 2-3% of all global carbon emissions (Bartulović et al., 2025).

When it comes to short sea shipping, specifically within Europe, sea freight was responsible for around 67.8% of all freight transport performance in 2022, handling approximately 3.4 billion tonnes of cargo in 2023 (Koritarov and Dimitrakiev, 2025). Moreover, the Port of Hamburg states that throughout the year of 2025, it exported 77 614 TEU to the south of Sweden and received 95 241 TEU from there (Port of Hamburg 2025).

The main role of the sea freight transport is the long-haul leg in multimodal chains, connecting European markets and distributing goods to inland destinations via inland waterways (Koritarov and Dimitrakiev, 2025).

3.4 Rail freight

Freight transport by rail is used to transport goods on the main leg of the journey. In 2024, 16.6% of all inland freight in the EU was transported by rail, with both Sweden and Germany having a higher split with 30.0% and 20.3%, respectively (Eurostat, 2024a).

On the ScanMed TEN-T corridor, one of the main rail traffic lines is between Malmö, Sweden and Maschen, Germany (ScanMed Rail Freight Corridor, 2023) which lies directly between Hamburg and Gothenburg. Furthermore, this stretch is being serviced with over-length trains of up to 835 m allowing for freight trains of up to 2300 t (DB Cargo, 2025). In comparison, the standard length of a freight train in the EU is 740 m (Kemmeter, 2022).

In 2020, $3,150,000$ t of goods were transported by rail from Sweden to Germany and $1,279,000$ t from Germany to Sweden (Eurostat, 2020).

Chapter 4

Subsidies in the EU

4.1 Subsidies in Sweden vs. Germany

While Germany and Sweden both operate within the same strict regulatory framework of the EU state aid policy, they pursue different methods in how subsidies are applied. Both countries aim to promote sustainable transport and regional connectivity through two different approaches of subsidies.

Germany's strategy is characterized primarily by passive subsidies, which focuses on reducing the financial burden on market participants through tax relief and fee exemptions rather than direct liquidity injections. This approach aims to create a favorable market environment that incentivizes specific behaviors.
A key instrument is the exemption from road tolls for heavy goods vehicles equipped with low-emission or carbon-neutral engine. Furthermore, trucks engaged in intermodal logistics are frequently exempt from motor vehicle tax (German: 'Kraftfahrzeugsteuer'). Rather than subsidizing individual transport companies, the German state focuses on massive investment in infrastructure, particularly the rail network. The objective is to lower the baseline operating costs for all users of the system (Bundesamt für Logistik und Mobilität (BALM), 2024; Bundesministerium der Finanzen, 2024; Generalzolldirektion, 2024; DB InfraGO AG, 2024).

In contrast, Sweden utilizes a more active subsidy model. In this framework, the state directly assumes costs that would otherwise be borne by transport operators, thereby ensuring the attractiveness of specific transport modes or the economic viability of certain regions. A standout example of this active approach is the state's coverage of over 90% of track access charges for rail freight. By covering most of the track access fees, they create a competitive environment for rail and road transport (European Commission, 2021a). This measure expired with the 2025/2026 timetable change and will be replaced by a new subsidy program starting in 2028, which was approved in May 2026. Under this program, the Swedish state guarantees to cover 20% of the track access fees (Trafikverket, 2026). Furthermore, the Swedish government permits High-Capacity Transport (HCT) vehicles reaching up to 34.5 meters in length and 74 tonnes in weight on designated road networks (Danish Ministry of Transport and Swedish Ministry of Rural Affairs and Infrastructure, 2025).

4.2 Trans-European Transport Network Regulation

The TEN-T framework aims to integrate EU transport by eliminating bottlenecks and standardizing rail across key corridors (European Commission, 2020; European Union, 2024). It is funded primarily by the Connecting Europe Facility (CEF) and CEF2, dedicating 25.81 billion € to derisk crossborder infrastructure projects (European Union, 2021; Trafikverket, 2025). A critical CEF project for this study is the Fehmarn Belt fixed link (ScanMed corridor), which will heavily influence the modal split on the Hamburg–Gothenburg route.

4.3 Fehmarn Belt fixed link

Planned to open in 2031 and supported by up to 1.3 billion € in EU funding, the 18 km Fehmarn Belt fixed link is critical for the Hamburg–Gothenburg corridor (Femern A/S, 2024; Federal Ministry for Digital and Transport, 2024; European Commission, 2022). It will reduce rail distance by 160 kilometers and cut crossing time to seven minutes, fundamentally boosting intermodal competitiveness in this corridor (Federal Ministry for Digital and Transport, 2024). However, achieving a lasting modal shift towards rail will still require complementary policies, such as competitive track access fees and technical harmonization, to fully capitalize on these structural time savings (TENTacle Project Consortium, 2019).

Chapter 5

Comparison of unimodal and intermodal transportation

5.1 Unimodal transport

5.1.1 Transportation time and distances

Firstly, when evaluating transportation time and distance, the *SeaRates* voyage simulator and analytical calculations were utilized, as illustrated in Figure 5.1. The estimated voyage distance for the road mode is 740 km (SeaRates by DP World, 2026e), sea and rail freights would travel 579 km (SeaRates by DP World, 2026c) and 601 km (SeaRates by DP World, 2026d), respectively. However, the rail route shown benefited from a rail ferry which no longer operates, thus, a distance of 843.6 km was established based on the EcoTransIT methodology (EcoTransIT, 2026).

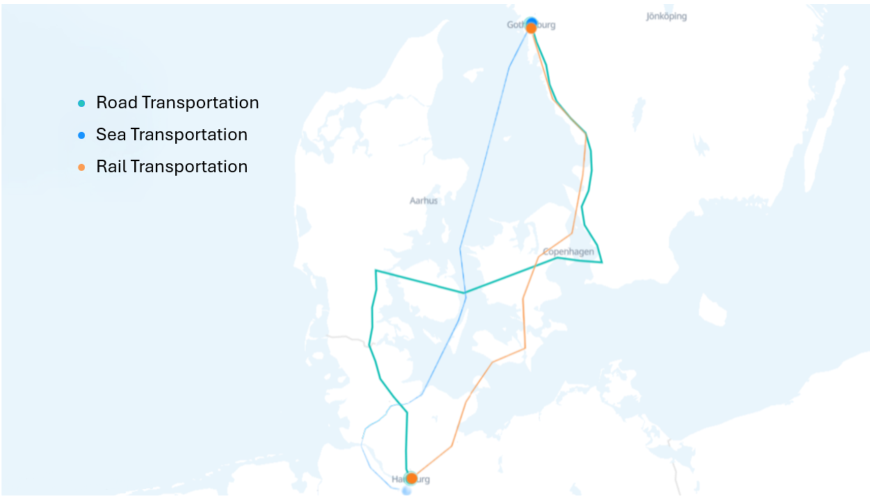


Figure 5.1: Map of unimodal voyages (Green: road transport; blue: sea transport, orange: rail transport) (SeaRates by DP World, 2026a).

In terms of voyage time, *SeaRates* showed that, for road transport (trucks), it would take 18 hours (SeaRates by DP World, 2026e), while *Routescanner* determined the ship travel time between the Gothenburg and Hamburg ports would be around 48 hours (RouteScanner, 2026). When it comes to the rail voyage, the following analytical calculation was done: assuming the distance of 843.6 km and dividing it by the average train velocity of 60 km/h (56 km/h for Göteborg–Malmö and 63 km/h for Malmö–Maschen (ScanMed Rail Freight

Corridor, 2023)), the result is a 14 hour rail voyage. This also demonstrates how the voyage time can be highly influenced by track availability.

5.1.2 Carbon dioxide (CO_2) emissions

Secondly, as far as carbon dioxide (CO_2) emissions are concerned, road freight produces around 139.85 $CO_2 \frac{g}{t \times km}$ while sea and rail freights emit 18.89 $CO_2 \frac{g}{t \times km}$ and 52.92 $CO_2 \frac{g}{t \times km}$, respectively, (Bilgili, 2023). When converting these values into $CO_2 \frac{g}{TEU \times km}$ as explained in Chapter 2, the results can be compared in Table 5.1.

Table 5.1: CO_2 emissions per transportation mode per km.

	$CO_2 \frac{g}{t \times km}$	$CO_2 \frac{g}{TEU \times km}$
Road	139.85	1748.13
Sea	18.89	236.13
Rail	52.92	661.50

This clearly demonstrates that sea shipping is the most environmentally friendly transportation method followed by rail. The road transportation mode results clearly show that this method would not be suitable for long voyages as it produces more than twice the amount of CO_2 than rail and sea freights.

However, it is important to note that the results seen in Table 5.1 are purely general values within the EU and are not specified to the case study of this report (Gothenburg–Hamburg corridor) as each transportation method takes different routes which result in different voyage distances. For this specific route the values showed in Table 5.1 have to be multiplied by the distances explained in Chapter 5.1.1 resulting in 1294 $CO_2 \frac{kg}{TEU}$ for road mode while sea and rail shipping would emit 137 $CO_2 \frac{kg}{TEU}$ and 558 $CO_2 \frac{kg}{TEU}$ respectively.

Furthermore, some studies say that a 720 m train could replace 52 trucks. This number could be increased to 58 trucks in the case of the train having 835 m length (Kemmeter, 2022). This, once again, shows that CO_2 emissions can vary a lot depending on transport configurations. Thus, a good overall conclusion might not be as clear as hoped.

5.1.3 Transportation costs

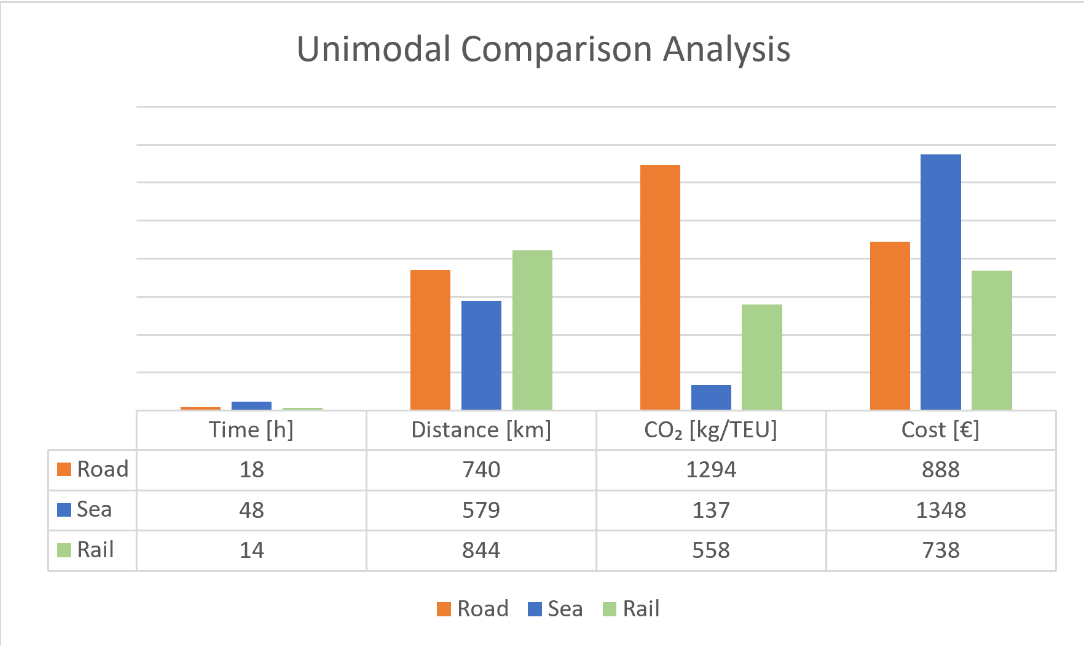
Finally, for the price comparison, it is of extreme importance to understand that this type of information tends to be hard to obtain due to private market competitiveness and internal values and strategies of companies.

This being said, the methods used to obtain a general idea for the transportation costs for each mode can vary. For instance, for the road transportation method, the average price of 1.2 $\frac{€}{km}$ was used (De Smedt and De Wispelaere, 2020; Meulen et al., 2022; Kienzler et al., 2020). Now, by multiplying by the distance explained in Section 5.1.1 (740 km), it is possible to obtain an approximation of 888 € to transport one TEU on this route by road.

On the other hand, the price to transport a TEU by ship could be either 1740.32 € (SeaRates by DP World, 2026b) or 955.58 € (Hapag-Lloyd, 2026). To address this divergence the mean price of 1347.95 € is the one to be taken into consideration.

When it comes to the transport price of one TEU from Gothenburg to Hamburg by train, some studies say that the price per ton-kilometre ($\frac{€}{t \times km}$) would be 0.07 (Forschungsinformationssystem, 2026). Therefore, multiplying it by 12.5 (average weight of a TEU) and by the distance stated in Section 5.1.1 (843.6 km) results in 738.15 € for the whole voyage.

To sum, all of the final results obtained can be seen in Figure 5.2.



	Time [h]	Distance [km]	CO_2 [kg/TEU]	Cost [€]
Road	18	740	1294	888
Sea	48	579	137	1348
Rail	14	844	558	738

Figure 5.2: Unimodal comparison analysis.

5.2 Intermodal transport

The intermodal transport configuration for the Hamburg–Gothenburg corridor is structured into three segments: first mile, main haul, and last mile. The first and last mile are both performed by road transport, each covering approximately 100 km, while the main haul is carried out either by train or ship. To keep the analysis comparable, the 200 km of the first and last mile is also added to the unimodal road transportation that is taken as comparison to road–rail and road–sea.

5.2.1 CO_2 emission modeling approach

The CO_2 emission assessment for the intermodal transport chains is based on the emission factors previously introduced in Section 5.1.2. Total emissions were calculated by multiplying the transport distance of each segment (first mile, main haul, and last mile) by the corresponding emission factor and subsequently aggregating the results to obtain total emissions per TEU and distance. These are presented in Figure 5.3. The first and last mile segments were to be performed by road transport, while the main haul was carried out either by rail or short-sea shipping. These results are compared to unimodal road transportation including the first and last mile. This distance-based methodology is commonly applied in European freight transport studies and enables a consistent comparison between unimodal and intermodal transport systems (European Environment Agency, 2022; EcoTransIT, 2026).

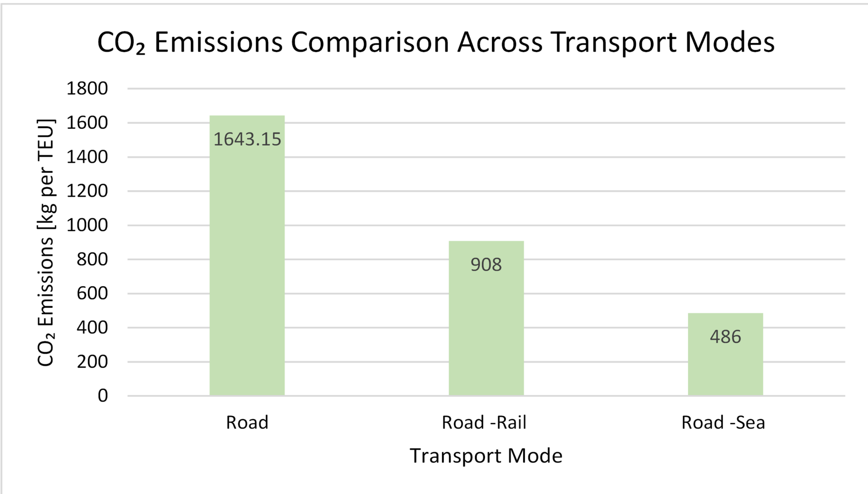


Figure 5.3: CO_2 emission comparison analysis.

5.2.2 Transit time analysis

The transit time assessment in this study is based on total door-to-door transport duration, incorporating both the main haul and the additional first and last mile segments required in intermodal transport. Unimodal transport times were introduced in Section 5.1.1, while the total intermodal transportation times are presented in Figure 5.4 and Table 5.2. For intermodal configurations, additional time is included to account for first and last mile transportations, each covering approximately 100 km and estimated at 1.5 hours based on average truck speeds of 60–70 km/h. The total intermodal transport time is therefore calculated as the sum of the first mile, main haul, and last mile durations. This approach reflects standard logistics modeling practices, where total transit time includes both line-haul transport. (SeaRates by DP World, 2026d; European Commission, 2021b). Additionally, separate terminal handling and reloading times were not explicitly modelled due to limited operational data available.

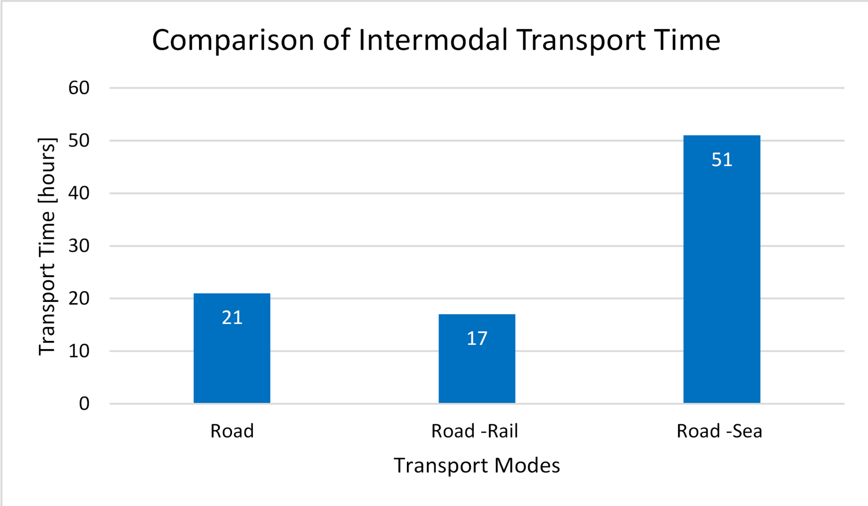


Figure 5.4: Time comparison analysis.

5.2.3 Cost assessment

The cost analysis of the transport modes is based on total transport cost per TEU, combining both unimodal and intermodal transport components to ensure methodological comparability. To ensure a methodologically consistent comparison, the 200 km distance representing the intermodal first and last mile was added to the baseline of the unimodal road transport. For the intermodal road segments the value of 1.08 €/km were provided by an international car manufacturer internally and used for this section, while the costs for the road and rail segments were taken from Section 5.1.3. For intermodal transport, total costs were calculated by combining proportional first and last mile road transport costs with the corresponding main haul transport costs of rail or sea transport. Based on these calculations, the estimated total transport cost was approximately 954 € per TEU for road–rail transport and 1564 € per TEU for road–sea transport presented in Figure 5.5 and Table 5.2. The results indicate that while intermodal transport alternatives may provide environmental advantages, they remain partially less economically competitive than unimodal road transport for medium-distance corridors such as Hamburg–Gothenburg.

This approach reflects standard logistics cost modelling practices, where transport costs include distance-based operational expenditures as well as indirect handling and transfer effects associated with intermodal freight systems. However, separate terminal handling and reloading costs were not explicitly considered due to limited publicly available operational data and are therefore assumed to be partially reflected in the freight rate estimates used in this study (SeaRates by DP World, 2026a; Comité National Routier (CNR), 2021; European Commission, 2021b; European Court of Auditors, 2023).

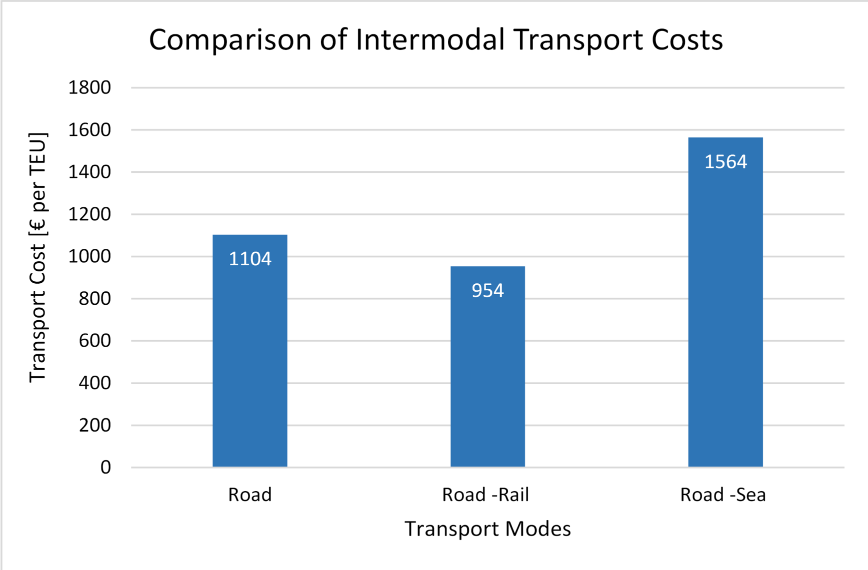


Figure 5.5: Cost comparison analysis.

5.2.4 Comparative analysis

When comparing uni and intermodal solutions, the latter demonstrate significant environmental benefits. Road–sea transport achieves the lowest emissions, providing a 70 % reduction compared to unimodal road transport, while road–rail provides a 45 % reduction, confirming the lower carbon intensity of maritime and rail transport. Nevertheless, these environmental gains are offset by operational and economic drawbacks: road–sea transport incurs the highest cost (1564 € per TEU), reflecting port handling, longer routes, and operational complexities. Road–rail transport, on the other hand, positions itself as a highly competitive alternative with a theoretical transit time of 17 hours. However, this estimation does not fully account for real-world operational delays associated with terminal handling, strict train scheduling, and intermodal coordination, which reduce its practical flexibility.

The overview in Figure. 5.6 further reinforces this imbalance, illustrating that no single transport mode dominates across all criteria, but rather that each represents a different optimization strategy.

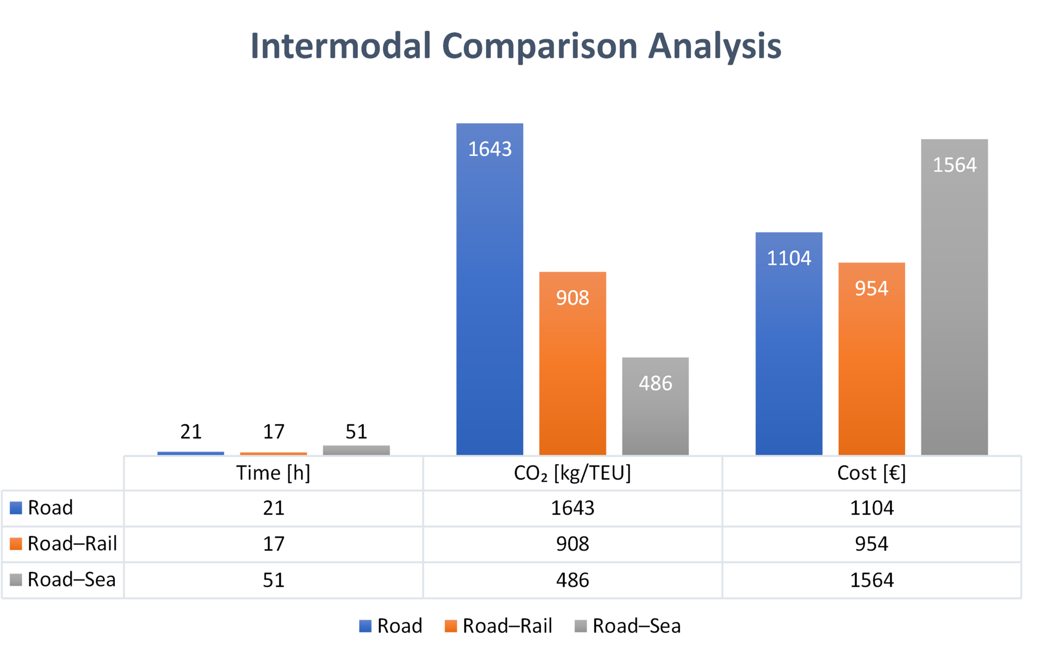


Figure 5.6: Intermodal transport comparison analysis.

Importantly, the Hamburg–Gothenburg corridor ($\sim$ 700 km) falls within the medium- to long-distance range typically considered suitable for intermodal freight transport in Europe. Nevertheless, the environmental advantages of intermodal transport are accompanied by additional operational requirements, including terminal handling, modal transfers, and coordination delays, which contribute to increased transport costs and practical transit durations (European Rail Freight Association, 2021; European Union Agency for Railways, 2021).

5.2.5 Energy consumption comparison of electrified freight transport systems

The energy consumption of battery-electric trucks and electric rail freight was compared using representative energy intensity (EI) values. For battery-electric trucks, energy consumption (E) is calculated based on distance (D) as:

$$E = D \times EI \tag{5.1}$$

Applying an average EI of 1.3 kWh/km (Li et al., 2020) over the 740 km road distance, the estimated consumption is:

$$E_{truck} = 740 \text{ km} \times 1.3 \text{ kWh/km} = 962 \text{ kWh per TEU} \tag{5.2}$$

For electric rail, energy consumption factors in cargo weight (W), calculated as:

$$E = D \times W \times EI \tag{5.3}$$

Assuming 12.5 t per TEU, a representative EI of 0.02 kWh/t-km (International Union of Railways (UIC), 2012; Topsector Logistiek, 2018), and a 844 km rail distance, the estimated consumption is:

$$E_{rail} = 844\ \text{km} \times 12.5\ \text{t} \times 0.02\ \text{kWh/t-km} \approx 211\ \text{kWh per TEU} \quad (5.4)$$

This represents an energy reduction of approximately 78% for electric rail compared to battery-electric trucks visualized in Figure 5.7, demonstrating the significantly higher energy efficiency of rail-based systems for medium- and long-distance freight operations (Li et al., 2020; International Union of Railways (UIC), 2012; Topsector Logistiek, 2018).

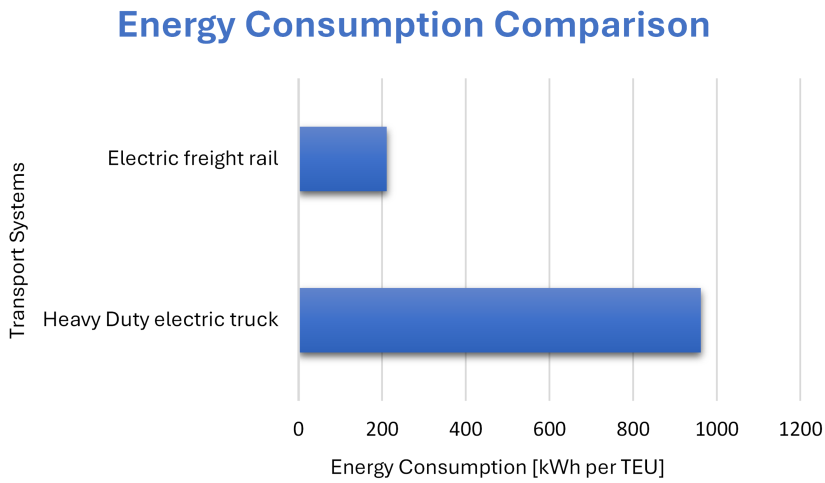


Figure 5.7: Energy consumption comparison of electrified freight transport systems.

5.3 Improving the loading and reloading efficiency for rail freight transportation

One way to make rail transport more attractive would be to increase its loading and reloading efficiency. Not only would this reduce the CO_2 emissions per TEU but also the transportation time and possibly the costs. One way to achieve a higher efficiency would be train planning. This refers to the spatial allocation of containers onto specific intermodal rail—cars. This configuration directly affects operational efficiency, as the specific arrangement of containers significantly influences both the energy consumed and the time required for terminal handling. Furthermore, optimized train planning is essential for maximizing the utilization of available wagon carrying capacity (Corry and Kozan, 2008).

Another benefit from a good spatial allocation of containers is an increase of the aerodynamic efficiency which can reduce operation costs, as well as improving the energy efficiency. A good way to improve the aerodynamic drag of a train is by minimizing the gaps between loads. For a better perspective, changing the operational strategy from a 100% slot utilization to a 100% slot efficiency can reduce the fuel consumption by up to 2.3 litres per km (Rickett, 2014).

5.4 Summary of results

The comparison of analysis for different transportation modes has shown that each transportation mode has its advantages and disadvantages. Most notable are the highest CO_2 emissions for unimodal road transportation together with the lower energy efficiency of trucks in comparison to trains. Furthermore, the intermodal transportation using rail–road theoretically is the fastest and shows the best balance between cost and CO_2 emissions. Therefore, the intermodal transportation of rail–road shows the best trade-off between time, cost, and emissions. Lastly, road–sea transportation is the most environmentally friendly, but far exceeds the cost and transportation time of the other two modes. These results are presented in Table 5.2.

Table 5.2: Comparative analysis of transport modes for the Hamburg-Gothenburg corridor (based on 1 TEU of 12.5 t).

Transport Mode	**CO_2 [kg]**	**Time [h]**	**Cost [€]**	**Energy [kWh]**	**Pros & Cons**
Unimodal Road (Truck)	1,643	21	1,104	962	**Pros:** Fast and cheap option due to direct door-to-door delivery. **Cons:** Highest environmental impact.
Intermodal (Road-Rail)	908	17	954	211	**Pros:** Cheapest and (theoretically) fastest, 45% less CO_2 than trucks, 78% less energy consumption than electric trucks. **Cons:** Not flexible, chained to the train timetable (transfer time not included, therefore longer in reality).
Intermodal (Road-Sea)	486	51	1,564	N/A	**Pros:** Most environmentally friendly option with a 70% CO_2 reduction in comparison to trucks. **Cons:** By far the most expensive due to high port fees and complex logistics chains and the slowest.

Chapter 6

Concluding remarks

6.1 Conclusion

This report compared unimodal and intermodal transportation along the ScanMed TEN-T corridor between Gothenburg and Hamburg. The focus was on comparing intermodal transportation using rail or maritime transportation for the main leg and road transportation for the first and last mile to unimodal transportation using road transportation for the full journey. The comparison was based on the transportation time, the overall costs, and the CO_2 emissions.

The overall conclusion is that the intermodal transportation using rail–road leads to the most benefits, having the theoretically shortest transportation time and the lowest cost while also significantly reducing CO_2 emissions in comparison to unimodal road transportation.

For the comparison of unimodal port-to-port transportation, in terms of transport time, the road was faster than the sea, but had the highest CO_2 emissions. The maritime transportation has the lowest CO_2 emissions, but the highest transportation costs and time. The rail transportation is the shortest in terms of transportation time and has the lowest costs while having 407 % of the emissions of ships but only 57 % of the CO_2 emissions of trucks.

Taking intermodal transportation into account leads to a similar spread of results. The intermodal transportation mode using road–rail remains the fastest, while the combination using ships with road–sea stays the slowest. The CO2 emissions for the road–sea combination stay the lowest, while only using the road stays the highest and the cost for intermodal road–rail transportation stays the lowest, while the cost for using the sea stays the highest.

When comparing electric trucks to electric trains based on energy consumption, electric trains are significantly more efficient and thus will produce lower CO_2 emissions.

Finally, a way to cut transportation time of trains is to improve the efficiency of reloading through train planning. Furthermore, by improving spatial allocation of the containers the operation costs can be reduced due to aerodynamic efficiency. On an EU level a combined framework has been established with the TEN-T to focus on shifting transportation to more sustainable modes.

6.2 Outlook

The infrastructural and regulatory developments in the Gothenburg–Hamburg corridor described in this report will have a massive impact on future logistics behavior within this region. The Fehmarnbelt Fixed Link stands out as the most significant milestone and a flagship project. The tunnel's projected opening in 2031 could trigger a massive shift toward rail freight. As discussed in Chapter 4, the opening of the Fehmarnbelt Fixed Link will heavily impact the modal shift in freight haulage.

Adjustments to pricing strategies are also necessary. While current approaches in Sweden and Germany are a good start, they still lean too heavily in favor of road transport. In the future, the external costs of individual transport modes should be more strictly accounted for.

This report provides only a high level overview of the Gothenburg–Hamburg corridor. For further research in this field, an effort should be made to develop a model that more accurately depicts how various transport modes and regulations affect transport in this corridor.

Future work could focus on the following aspects:

- Incorporating detailed terminal handling, container reloading, and transshipment costs to improve the economic representation of intermodal transport systems.
- Analysing advanced operational time modelling which considers terminal dwell times, rail scheduling constraints, congestion effects, and customs procedures.
- Incorporating real-time logistics and freight tracking data to improve the accuracy of transport time and route estimations.
- Conducting sensitivity analyses on fuel prices, carbon taxation, infrastructure charges, and energy costs to evaluate the robustness of transport competitiveness under changing economic conditions.
- Evaluating the impact of varying container weights, cargo volumes, and loading efficiencies on transport emissions and transport costs.

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