Dependence of Transport and External Cost Variables on Transportation Route Length

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Abstract: External transport costs are becoming an increasingly important factor in the choice of transport routes. According to sustainability principles, the first choice criterion should be the route with the least harmful impact on the environment and health. Sometimes the criteria for transportation costs are in conflict with environmental ones. There is a need to optimize them to maintain the trend of sustainable transport development. Cost and external cost behaviors of intermodal maritime–rail container transport from China over different European ports to central European destinations were examined. The aim was to determine the differences in dependency on transport route length of these two variables that are able to partly explain their different features. The complete functional dependency of external cost in maritime transport and transport cost in rail transport on route length is determined. External cost dependence on the transport route length in the railway segment was strong but incomplete. Maritime external cost share in the total external cost of combined transport was at least 83%. The weak negative dependence of maritime transport cost on route length probably reflects efforts to maintain the competitiveness of consolidated longer routes. This article contributes to the ongoing discussion of seaport competitiveness within Europe.

Keywords: transport costs; external costs; transport route; length; dependence; maritime and rail transport

1. Introduction

It has been ten years since the European Union (EU) announced strong support for the sustainable development of transport, emphasizing the need for reducing the harmful effects of transportation on the environment and human health [1]. To this end, it advocates green logistics, which means the mode and route of transport that has the least possible harmful impact. The valorization of that damage is expressed through external cost calculation based on handbooks periodically published by reputable, competent institutions [2]. The same policy advocates external cost internalization aiming to add the external cost to the transport cost, and collect it from those who cause the damage.

The principal sources of external costs in transport are environmental costs, traffic accidents, and traffic congestion. Several other sources are of secondary importance. Generally, except for the current influence of the COVID-19 pandemic, which caused market disruption in 2021, there are no frequent accidents or congestion in maritime and rail transportation, such that environmental costs predominate. According to the pointed characteristics and transport capacities, maritime–rail transportation is considered the intermodal freight transport with the lowest externalities [3]. Among environmental costs, emissions and climate change impacts make up the majority of the total costs and are the most significant indicators of external costs in these two modes of transport [2]. An
environmental cost is also the easiest to measure and can be systematically monitored and controlled in this context.

Emissions are the products of the released energy of fuel. Emissions external costs will be proportional to the quantity of energy invested in fuel production and the energy consumed (fuel consumed) on the transport route (up- and downstream processes). Thus, external costs will be proportional to the length of the transport route, and the green criteria in the choice of it will advocate the shortest way between the starting point and destination.

Transportation costs also have many components, and among them, the most important are fuel, labor, and maintenance costs. By choosing the shortest transport route, one could generally assume the transport costs will be lower due to the lower amount of fuel consumed and the smaller number of working hours of the machine and crew. Current sustainability trends should support this choice. However, the criteria for selecting a transport route from the point of view of transport cost are so complex that they can result in a completely different outcome. In maritime transport, the size of vessels considered and the possibility of entering the port of call can be crucial. In rail transport, the number, frequency, and duration of individual connections between seaports and hinterland destinations, as well as the reliability of these services, are decisive factors for transport route choice.

This paper aims to objectify the dependence of unit freight transport costs (TEU) and external costs on the route length in maritime and rail transport, consider it in both modal segments, and show whether the costs follow the current sustainable transport policy.

2. Literature Review

In the process of interpreting research results related to transport cost, the environmental dimension has seldom been a significant valorization factor. According to [4], literature citations on distance as a competitiveness factor in intermodal transport are rare. In [5], the author considered transport length to be a good indicator of transport costs, which increase slightly with the route length. The authors in [6] concluded that distance was not a good indicator of transport costs. Rather, it is primarily the efficiency and quality of service, especially in maritime transport. Exploring the dependence of transport cost on distance (including external costs), the authors in [7] showed that the costs of intermodal road–rail transport fall below the costs of unimodal road transport only after a certain distance and frequency of departures. Since the inclusion of ecological criteria in the transport route choice, the linkage of external costs and transport distance has been clear. In [8], the authors claimed that no source had been found in the literature not linking external costs to transport distance. Simultaneously, tools are being developed to help calculate which directions and transport alternatives are able to reduce external costs [9]. In [10], the authors emphasized that calculation is not simple. Moving cargo from the road to the ship does not automatically lead to a drop in external costs. It depends on several parameters, including the choice of transport route. In [11], the authors claimed the need to valorize every traffic route for every form of transport. There have also been efforts to challenge the direct link between external costs and distance by introducing the travel purpose criterion [12]. The impression remains that these are exceptions. An effort to optimize fuel consumption by choosing fixed traffic routes and economical speed in all traffic modalities to establish green traffic routes is more frequent [13]. Optimization of fuel consumption has also been attempted by internalizing external costs with proposals to introduce a mileage tax in the tax system added to the fuel consumption tax, making external costs even more important in the function of journey length [14].

3. Materials and Methods

This study monitors intermodal, maritime rail transport of the TEU (twenty-foot equivalent unit) weighing 10 t from China to Europe. Intermodal transport means the transportation of the cargo unit using two or more transport modalities without goods manipulation between individual modalities [15]. The calculation was performed on 32 traffic routes. The starting point of the maritime segment was the port of Shenzhen-
Shekou. The type of ship was a CC Transatlantic Trade with a capacity of 2–4, 7k TEU, speed 33%, and LF (load factor) 70%. The route passes through the Suez Canal to the port of Alexandria in Egypt and then continues in different directions either to the ports of the northern Mediterranean (Genoa, Thessaloniki), the Adriatic Sea (Trieste, Koper, Rijeka), the Black Sea (Constanta), or alternatively through Gibraltar and the Atlantic Ocean to North-Western European ports (Rotterdam, Hamburg). The transport routes then continue from those ports by rail to Central European destinations (Budapest, Vienna, Prague, and Munich). The calculation was performed according to a container train with a capacity of 1000 t, LF (load factor) 49.8% and ETF (empty trip factor) 20%. Transportation costs were calculated using software from the Sea Rates [16] and World Freight Rates [17] companies. Emission, climate change impact, energy consumption, and transport route length were measured using EcoTransIT® World software [18], which also suggests the type of vehicle choice. The emission unit prices from the latest handbook of external transport costs used in the valorization procedure for pollutants measured in the research are shown in Table 1.

Table 1. Emission unit prices used in maritime and rail transportation.

| Emission Category | 2016 * €/kg | Reevaluation + 6.1% (2019) |
|-------------------|-------------|---------------------------|
| **Air Emission Excl.** |             |                           |
| Maritime Transport |             |                           |
| CO₂               | 0.10        | 0.1122                    |
| SOx               | 10.9        | 11.57                     |
| NOx rural         | 12.6        | 13.37                     |
| PM₂₅ rural        | 70.00       | 74.27                     |
| PM₁₀ average      | 22.30       | 23.66                     |
| NMVOC             | 1.20        | 1.27                      |
| **Maritime transport Mediterranean** |             |                           |
| CO₂               | 0.10        | 0.1122                    |
| SOx               | 9.20        | 9.76                      |
| NOx               | 3.00        | 3.18                      |
| PM₂₅              | 24.60       | 29.28                     |
| PM₁₀ average      | 14.00       | 14.85                     |
| NMVOC             | 0.50        | 0.53                      |

* data retrieved from [2].

Values were re-evaluated at a rate of 6.1% for 2019 [19]. For the maritime transport route, the unit emission values for the Mediterranean were used as averages for the whole line. This exception was performed as a compromise between higher rates indicated in the handbook for the Atlantic Ocean and North and Baltic Seas and absent but objectively lower rates in the Indian Ocean and Red and South China Seas, equally for all examined routes. The calculation includes the external costs of emissions, climate change, and up and down-streaming processes and covers most of the total external costs in maritime and rail transport [20,21]. The cost of the intermodal hub, insurance, discounts, and the intermodal hub external costs were omitted due to the specific purpose of this research. The selected conditions did not influence the corresponding settings of each traffic route in the model. The transport and external cost dependence in EUR (y) on the length of the voyage in km (x) was examined by the linear regression method determining the coefficient of determination \( R^2 \) as

\[
R^2 = \left( \frac{1}{N} \right) \left( \frac{1}{\sigma_x \cdot \sigma_y} \right) \sum \frac{(x_i - \bar{x}) \cdot (y_i - \bar{y})}{\sigma_x \cdot \sigma_y}^2 ,
\]  

(1)
where \( N \) is the number of observations used to fit the model, \( \Sigma \) is the summation symbol, \( x_i \) is the \( x \) value for observation \( i \), \( \bar{x} \) is the mean \( x \) value, \( y_i \) is the \( y \) value for observation \( i \), \( \bar{y} \) is the mean \( y \) value, \( s_x \) is the standard deviation of \( x \), and \( s_y \) is the standard deviation of \( y \) [22], and the correlation test determining correlation coefficient \( (r) \) as

\[
r = \left[ \frac{1}{(n - 1)} \right] \sum \left\{ \left[ \frac{(x_i - \bar{x})}{s_x} \right] \cdot \left[ \frac{(y_i - \bar{y})}{s_y} \right] \right\},
\]

where \( n \) is the number of observations in the sample, \( \Sigma \) is the summation symbol, \( x_i \) is the \( x \) value for observation \( i \), \( \bar{x} \) is the sample mean of \( x \), \( y_i \) is the \( y \) value for observation \( i \), \( \bar{y} \) is the sample mean of \( y \), \( s_x \) is the sample standard deviation of \( x \), and \( s_y \) is the sample standard deviation of \( y \) [23].

The results are interpreted based on the Chaddock scale (referent values \( 0 \leq R^2 \leq 1 \) and Spearman’s correlation coefficient scale (referent values \(-1 \leq r \leq 1\)). Two methods control each other.

Valid data on transport and external costs in 2019 and distances were prepared using listed software for each transport route (Tables 2 and 3).

**Table 2.** Maritime transport costs per TEU (MTC), external costs per TEU (MEC), and route length (\( s_m \)).

| Shenzhen-Alexandria- | MTC (€) | MEC (€) | \( s_m \) (km) |
|----------------------|---------|---------|----------------|
| Constanta           | 1464.45 | 380.30  | 14,056.30      |
| Thessaloniki        | 1756.00 | 364.05  | 13,555.81      |
| Rijeka              | 1788.81 | 392.38  | 14,246.71      |
| Koper               | 1772.40 | 394.82  | 14,503.46      |
| Trieste             | 1772.40 | 395.02  | 14,507.67      |
| Genoa               | 1165.05 | 402.06  | 14,724.57      |
| Rotterdam           | 1378.26 | 502.33  | 18,134.07      |
| Hamburg             | 1391.65 | 511.48  | 18,624.82      |

**Table 3.** Rail transport costs per TEU (RTC), external costs per TEU (REC), and route length (\( s_r \)).

| Budapest Via         | RTC (€) | REC (€) | \( s_r \) (km) | Vienna Via         | RTC (€) | REC (€) | \( s_r \) (km) |
|----------------------|---------|---------|----------------|--------------------|---------|---------|----------------|
| Constanta            | 1619.83 | 36.00   | 1052.50        | Constanta          | 2010.24 | 42.59   | 1306.48        |
| Thessaloniki         | 1351.21 | 57.56   | 1006.64        | Thessaloniki       | 1684.95 | 63.36   | 1253.61        |
| Rijeka               | 853.27  | 15.16   | 562.46         | Rijeka             | 1001.20 | 10.72   | 569.78         |
| Koper                | 981.66  | 17.32   | 649.92         | Koper              | 992.25  | 11.20   | 586.53         |
| Trieste              | 976.78  | 17.00   | 633.56         | Trieste            | 982.48  | 9.88    | 562.47         |
| Genoa                | 2081.36 | 32.72   | 1134.84        | Genoa              | 2003.21 | 22.82   | 977.79         |
| Rotterdam            | 2652.77 | 39.91   | 1426.26        | Rotterdam          | 2278.34 | 33.80   | 1176.03        |
| Hamburg              | 2059.38 | 43.81   | 1210.16        | Hamburg            | 1654.83 | 38.71   | 1015.42        |

| Prague via           | RTC (€) | REC (€) | \( s_r \) (km) | Munich via          | RTC (€) | REC (€) | \( s_r \) (km) |
|----------------------|---------|---------|----------------|--------------------|---------|---------|----------------|
| Constanta            | 2539.63 | 57.26   | 1638.64        | Constanta          | 2702.42 | 51.25   | 1764.33        |
| Thessaloniki         | 2132.64 | 77.95   | 1585.77        | Thessaloniki       | 2726.84 | 68.07   | 1638.26        |
| Rijeka               | 1460.29 | 20.14   | 828.72         | Rijeka             | 912.48  | 12.63   | 562.03         |
| Koper                | 1435.05 | 20.30   | 845.55         | Koper              | 946.66  | 13.13   | 578.86         |
| Trieste              | 1413.07 | 20.30   | 792.22         | Trieste            | 905.15  | 12.89   | 525.53         |
| Genoa                | 1608.43 | 33.73   | 1153.06        | Genoa              | 1079.34 | 21.05   | 701.39         |
| Rotterdam            | 1580.76 | 34.83   | 984.02         | Rotterdam          | 1474.94 | 28.53   | 837.76         |
| Hamburg              | 1309.19 | 25.10   | 655.69         | Hamburg            | 1624.71 | 27.60   | 779.00         |

The data were processed by MS Excel [24].

4. Results

For easier understanding and interpretation, the results are presented separately for the maritime and rail segments of intermodal transport.

The dependence of MTC on \( s_m \) is shown in Figure 1. The representativeness coefficient \( R^2 = 0.24 \) belongs to the category of weak connection (Chaddock scale 0.00–0.25), and the
correlation coefficient $r = -0.49$ confirms that the link is weak and negative (Spearman’s scale $-0.5 \leq r < 0$).

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The dependence of RTC on $s_r$ is shown in Figure 2. The graph suggests a conclusion about the high representativeness of the regression model (Chaddock scale $0.64 < R^2 < 1$) and the strong, almost complete dependence of transport costs on distance in rail transport (Spearman’s scale $0.8 < r < 1$).

The dependence of MEC on $s_m$ is shown in Figure 3. The values $R^2$ and $r$ point out the complete dependency of external costs on distance in maritime transport.

![Figure 1](image1.png)  
**Figure 1.** Analysis of the dependence of maritime transport costs (MTC) on route length ($s_m$) by linear regression and correlation test.

![Figure 2](image2.png)  
**Figure 2.** Analysis of the dependence of rail transport costs (RTC) on route length ($s_r$) by linear regression and correlation test.

![Figure 3](image3.png)  
**Figure 3.** Analysis of the dependence of external costs (MEC) on route length ($s_m$) by linear regression and correlation test.
The dependence of MEC on sm is shown in Figure 3. The values $R^2$ point out the complete dependency of external costs on distance in maritime transport.

Figure 3. Analysis of the dependence of maritime external costs (MEC) on route length (sm) by linear regression and correlation test.

The dependence of REC on sr is shown in Figure 4. There is a strong dependence of external costs on distance in the railway segment of intermodal transport at the examined traffic routes (Chaddock scale $0.64 < R^2 < 1$; Spearman’s scale $0.8 < r < 1$), but weaker concerning the maritime transport segment.

Figure 4. Analysis of the dependence of rail external costs (REC) on route length (sr) by linear regression and correlation test.

The share of the rail external costs in the total external costs of intermodal unit transport modality for the examined transport routes was 2.44–17.64%.

5. Discussion

The external costs behavior examined by the linear regression method indicates a positive dependence of external costs on the route length in intermodal, maritime–rail transport on the chosen traffic routes. It is complete and functional (maximal) in maritime transport, while in rail transport, the stated dependence is high but not total. The reason for this
lies in the energy consumption structure, which in electric rail transport is predominantly WTT (well to tank), so it mainly comes from external cost sources that do not depend on the length of the distance traveled (upstream processes). In maritime transport, energy consumed is predominantly TTW (tank to wheel), where the damage originates mainly from the means of transport, i.e., the ship. The external costs analysis on the examined routes also established that at least 83%, and most often more than 90%, come from the maritime transport segment (Tables 2 and 3). This conclusion indicates that marine transport is the most significant external cost indicator for maritime–rail transportation on the chosen traffic routes. At the same time, it confirms that the route length in maritime transport is directly proportional to the size of the external costs. It marks marine transportation with a severe polluter stigma and breaks down prejudices about it as an eco-friendly transport modality.

The dependence of transport costs on route length in the railway segment is almost complete, considering distance-based pricing in rail transport. In maritime transport, contract pricing is ordinary, and the dependence on route length is weak and negative. It means that transport costs fall with a unit of distance, i.e., the longer the transport route length, the lower the costs. When there are relatively lower costs per unit of length route, it could fall under the rules of economies of scale [25]. However, this is about absolute values. Such a result was already noticeable in Table 2, where the transport route to Rotterdam and Hamburg was about 400 EUR/TEU cheaper than the 4000–5000 km shorter transport route to ports in the northern Mediterranean and surrounding seas. Despite the same route length, the voyage to the Italian port of Genoa is 600 EUR/TEU cheaper than the one to the Italian port of Trieste.

The reasons for such a state of the market are complex and, for sure, have their historical component. Arguments about the different levels of service quality in individual ports can only partially explain it. The disparity between the shortest and longest transport time on the examined traffic routes towards identical Central European destinations was about seven days. These data indicate significant differences in the quality of transport services provided in the time component of transport. Transport time is the variable in the transport route length function and indirectly indicates the magnitude of external costs. In [26], the author considers it as a competitive factor in transportation. It is also a qualitative factor in the freight flow formation that can be easily measured. The shorter the transport time, the lower the external costs and, consequently, the better the transport service. In intermodal, maritime–rail transport, the transport time mostly depends on the length of the maritime segment. When the marine transport segment is shorter, the total transport time is typically lower. Due to comparatively low speeds in marine traffic, the differences in time on different traffic routes are significant. In the context of the freight flows formation, the time component, obviously qualitatively unfavorable for northern European ports, points out the strength of consolidated cargo flows to Western and Northern Europe that cannot be disturbed by such a clear and significant time difference in the transport service delivery. Moreover, transportation is an activity in which the time and financial components have an almost essential meaning. Unlike the transport costs, the length of the voyage on the examined traffic routes was not significant in the choice of maritime transport routes.

The authors in [9] exhaustively list the factors that affect transportation costs, assuming their equal individual impact. In [27], the authors point out that distance is one of the decisive factors in the transport price. They also find that features more sensitive to competition include the freight quantity, quality transport services, and company strategy. Trends in modern transport development policy emphasize environmental criteria as being decisive in the choice of the transport route. According to the socio-ecological approach, the first choice of transport is that with the minimum of harmful impacts on the environment and health. Therefore, within freight transport, maritime–rail freight transport (by electric railway) is the optimal transport mode, and the route of first choice is also the shortest. The elaboration of these principles is always welcome, provided that the direction of current
trends is maintained. Thus, in the work of [28], the authors state that the influence of external costs on the choice of transport route is, among others, in the function of traffic density and include external cost as a decision-making factor in well-connected transport networks. The results of this study are also one form of such elaboration. They show that the shortest transport route in the maritime segment of intermodal transport is a condition and guarantee of the lowest external costs. Reducing the marine transport route length could be a strategic measure for reducing external costs and implementing a sustainability policy in global container transport. From a business point of view, it would be important that the maritime segment of intermodal transportation is as long as possible and that the rail segment is shorter. Choosing the shortest maritime transport route as the ecological route of choice can increase transport costs. An example of this is the Emission Control Areas, defined by the IMO. To reduce emissions, especially SOx, more expensive low-sulfur fuel must be used when navigating these areas. For this reason, carriers need to optimize the routes and speeds of especially smaller ships in every single voyage [29]. Some shippers decide to bypass ECAs and prolong voyages or navigate at higher speeds outside and lower speeds inside ECAs. The result is higher fuel consumption and higher total emissions, especially CO₂ emissions [30,31]. Various multicriteria models of maritime transport optimization have been developed, including occasional or continuous monitoring, e.g., within the EU project SuperGreen [32]. Emission-proportional fuel consumption depends on many fluctuating factors such as speed, fuel costs, fixed time costs, cargo inventory costs, type of goods, and CO₂ emission costs [33–35]. By optimizing the speed of navigation and choosing appropriate voyage routes and ports of call, the models enable reducing the fuel consumption and total cost of navigation [34,36].

Although there are technical possibilities for a successful global reduction of CO₂ emissions by 50% by 2050 [37], the degree of internalization based on CO₂ emissions assessment can be pretty low (23–28%), suggesting that a single measure is not suitable or sufficient for all transport segments [38]. Monitoring, reporting, and verification of CO₂ emissions within the so-called “MRV Regulation” have proved unsuccessful [39]. With the aim of reducing transport costs and ensuring the sustainable development of supply chains, much better cooperation between port terminals and shipping liners is recommended [40].

Low transport cost is a significant competitive factor along the transport route. On a significantly longer transport route, it is an excuse for delaying sustainable transport policy implementation. Due to its large capacity, there are no alternatives to maritime transport for now. In environmental terms, an alternative to marine transportation should be marine transport of the least possible damage. Following these principles, measures taken to reduce the negative transport impact on the environment and health should also influence the transport cost category. The sanction policy makes no sense without comprehensive measures that would disable polluters from continuing to perform harmful actions.

This research topic has a direct link to the ongoing European discussion about port competitiveness. For many years the North-Western European Ports (the so-called north-range between Le Havre and Hamburg) have dominated container handling statistics. However, additional infrastructure investments (e.g., in Valencia or Algeciras in Spain), dedicated terminals to specific shipping lines with strategic shareholdings (e.g., in Piraeus in Greece), or the development of new ports and terminals (e.g., in Gdansk and Swinoujscie in Poland) have changed the market situation. Together with climate change-based rethinking of transport patterns, this is leading to a more segmented industry with faster and more likely changes in transport patterns.

6. Conclusions

The external costs of maritime and rail segments and the transport costs of the railway part of intermodal sea–rail freight transport show a complete or high degree dependence on route length. External costs of the maritime transport segment make up the majority of the total external costs and are directly proportional to the route length. On the other hand, transport costs in the marine part show a weak and negative dependence on route length.
for the examined traffic routes. Such a result indicates that the maritime transport pricing policy does not directly reflect the environmental trends of transport development. This finding is the main contribution of the research, revealing targets for future implementation of transport sustainability measures. The dependence of costs on route length, singled out from among other factors on which costs depend on the transport route (speed, load, energy costs, market conditions, quality of various transport services, etc.), is the main limitation of this research and should always keep in mind. It does not reduce the significance of the conclusions, but suggests the dynamic, simultaneous influence of all factors. Multivariable dependence of the costs in transportation should be a design of future research.

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References

1. European Commission. White Paper, Roadmap to a Single European Transport Area—Towards a Competitive and Resource Efficient Transport System; Publications Office of the European Union: Brussels, Belgium, 2011.
2. Van Essen, H.; Van Wijngaarden, L.; Schroten, A.; De Bruyn, S.; Sutter, D.; Bieler, C.; Maffii, S.; Brambilla, M.; Fiorello, D.; Fermi, F.; et al. Handbook on the External Costs of Transport; CE Delft: Delft, The Netherlands, 2019.
3. Mostert, M.; Limboug, S. External costs as competitiveness factors for freight transport—A state of the art. Transp. Rev. 2016, 36, 692–712. [CrossRef]
4. Reis, V. Analysis of mode choice variables in short-distance intermodal freight transport using an agent-based model. Transp. Res. Part A Policy Pract. 2014, 61, 100–120. [CrossRef]
5. Tanaka, T. Transport costs, distance, and time: Evidence from the Japanese Census of Logistics. IDE Discuss. Pap. 2010, 241, 1–32.
6. Martínez-Zarzoso, I.; Nowak-Lehmann, F.D. Is distance a good proxy for transport costs? The case of competing transport modes. J. Int. Trade. Econ. Dev. 2007, 16, 411–434. [CrossRef]
7. Janic, M. Modelling the full costs of an intermodal and road freight transport network. Transp. Res. D Transp. Environ. 2007, 12, 33–44. [CrossRef]
8. Braekers, K.; Janssens, G.K.; Caris, A. Review on the comparison of external costs of intermodal transport and unimodal road transport. In Proceedings of the BIVEC-GIBET Transport Research Day, Brussels, Belgium, 27 May 2009.
9. Fridell, E.; Jerksjö, M.; Wolf, C.; Belhaj, M. A Tool for Calculating External Costs Associated with Transportation of Goods. 2009. Available online: https://www.lifecyclecenter.se/wp-content/uploads/2009_4-A-tool-for-calculating-external-costs-associated-with-transportation-of-goods.pdf (accessed on 15 July 2021).
10. Lee, P.T.W.; Hu, K.C.; Chen, T. External Costs of Domestic Container Transportation: Short-Sea Shipping versus Trucking in Taiwan. Transp. Rev. 2010, 30, 315–335. [CrossRef]
11. Vukić, L.; Poletan Jugović, T. Planning and valorization of the branch Xa of Corridor X from the aspects of external costs. Pomorstvo 2016, 30, 151–159. [CrossRef]
12. Hagedorn, T.; Sieg, G. Emissions and External Environmental Costs from the Perspective of Differing Travel Purposes. Sustainability 2019, 11, 7233. [CrossRef]
13. Bekaš, T.; Ehmke, J.F.; Psaraftis, H.; Puchinger, J. The Role of Operational Research in Green Freight Transportation. Eur. J. Oper. Res. 2019, 274, 807–823. [CrossRef]
14. Schleiniger, R. Road Transport: Externalities and Efficient Pricing. 2020. Available online: https://www.odyssee-mure.eu/publications/policy-brief/road-transport-externalities-efficient-pricing-odyssee-mure.pdf (accessed on 25 July 2021).
15. United Nations Economic Commission for Europe (UN/ECE). Terminology on Combined Transport. 2001. Available online: https://unece.org/transport/publications/terminology-combined-transport (accessed on 5 August 2021).
16. SeaRates. Transportation Costs. 2019. Available online: https://www.searates.com/ (accessed on 15 August 2021).
17. World Freight Rates. Transportation Costs. 2019. Available online: http://worldfreightrates.com/en/freight (accessed on 15 August 2021).
18. EcoTransIT World. 2019. Available online: https://www.ecotransit.org/index.en.html (accessed on 15 August 2021).
19. Eurostat. Real GDP Growth Rate—Volume. 2020. Available online: https://ec.europa.eu/eurostat/databrowser/view/tec00115/default/table?lang=en (accessed on 20 August 2021).

20. Van Essen, H.P.; Boon, B.H.; Schrotten, A.; Otten, M.; Maibach, M.; Schreyer, C.; Doll, C.; Jochem, P.; Bak, M.; Pawlowska, B. Internalisation Measures and Policies for All External Cost of Transport (IMPACT); CE Delft: Delft, The Netherlands, 2008.

21. International Union of Railways (UIC). External Costs. 2021. Available online: https://uic.org/support-activities/economics/external-costs (accessed on 25 August 2021).

22. StatTrek Com. 2021. Available online: https://stattrek.com/statistics/dictionary.aspx?definition=coefficient_of_determination (accessed on 24 September 2021).

23. StatTrek Com. 2021. Available online: https://stattrek.com/statistics/correlation.aspx (accessed on 24 September 2021).

24. MS Excel. Microsoft Office 2007. Available online: https://www.microsoft.com (accessed on 10 July 2021).

25. Zgonc, B.; Tekavčič, M.; Jakšič, M. The impact of distance on mode choice in freight transport. Eur. Transp. Res. Rev. 2019, 11, 1–18. [CrossRef]

26. Kreutzberger, E.D. Distance and time in intermodal goods transport networks in Europe: A generic approach. Transp. Res. Part A Policy Pract. 2008, 42, 973–993. [CrossRef]

27. Camisón-Haba, S.; Clemente-Almendros, J.A. A global model for the estimation of transport costs. Econ. Res. Ekon. Istraz. 2020, 33, 2075–2100. [CrossRef]

28. Ambrosino, D.; Sciomachen, A.; Surace, C. Evaluation of flow dependent external costs in freight logistics networks. Networks 2019, 74, 111–123. [CrossRef]

29. Ma, D.; Ma, W.; Jin, S.; Ma, X. Method for simultaneously optimizing ship route and speed with emission control areas. Ocean Eng. 2020, 3, 107170. [CrossRef]

30. Chen, L.; Yip, T.L.; Mou, J. Provision of Emission Control Area and the impact on shipping route choice and ship emissions. Transp. Res. Part D Transp. Environ. 2018, 58, 280–291. [CrossRef]

31. Fagerholt, K.; Gausel, N.T.; Rakke, J.G.; Psaraftis, H.N. Maritime routing and speed optimization with emission control areas. Transp. Res. Part C Emerg. Technol. 2015, 52, 57–73. [CrossRef]

32. Panagakos, G.; Psaraftis, H.N. Model-based corridor performance analysis – An application to a European case. Eur. J. Transp. Infrastruct. Res. 2017, 17, 2. [CrossRef]

33. Ma, W.; Ma, D.; Ma, Y.; Zhang, J.; Wang, D. Green maritime: A routing and speed multi-objective optimization strategy. J. Clean. Prod. 2021, 305, 127179. [CrossRef]

34. Ma, W.; Hao, S.; Ma, D.; Wang, D.; Jin, S.; Qu, F. Scheduling decision model of liner shipping considering emission control areas regulations. Appl. Ocean Res. 2021, 106, 102416. [CrossRef]

35. Zhang, X.; Lam, J.S.L.; Çağatay, I. Cold chain shipping mode choice with environmental and financial perspectives. Transp. Res. Part D Transp. Environ. 2020, 87, 102537. [CrossRef]

36. Zhen, L.; Li, M.; Hua, Z.; Lv, W.; Zhao, X. The effects of emission control area regulations on cruise shipping. Transp. Res. Part D Transp. Environ. 2018, 62, 47–63. [CrossRef]

37. Halim, R.A.; Kirstein, L.; Merk, O.; Martinez, L.M. Decarbonization Pathways for International Maritime Transport: A Model-Based Policy Impact Assessment. Sustainability 2018, 10, 2243. [CrossRef]

38. Vierth, I.; Axel Merke, A. Internalization of external and infrastructure costs related to maritime transport in Sweden. Res. Transp. Bus. Manag. 2020, 100580. [CrossRef]

39. Panagakos, G.; Pessôa, T.D.S.; Dessypris, N.; Barford, M.B.; Psaraftis, H.N. Monitoring the Carbon Footprint of Dry Bulk Shipping in the EU: An Early Assessment of the MRV Regulation. Sustainability 2019, 11, 5133. [CrossRef]

40. Venturini, G.; Cagatay, I.; Kontovas, C.A.; Larsen, A. The multi-port berth allocation problem with speed optimization and emission considerations. Transp. Res. Part D Transp. Environ. 2017, 54, 142–159. [CrossRef]