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Eliminating Barriers for Sustainable Transport Systems on Maritime Silk Road and Baltic–Adriatic Corridor under BRI

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Abstract: Infrastructure elements are a crucial factor in accommodating larger ships, organizing longer trains, and ensuring the higher flow of goods in intermodal hubs. The Belt and Road Initiative (BRI) supports the development of infrastructure on the defined transport routes—the Maritime Silk Road (MSR), which includes the European southern transport route through the northern Adriatic. The research emphasizes the importance of the port, and railway infrastructure development on the Baltic–Adriatic Corridor (BAC) by analyzing the pollution level produced from transport means currently employed. The results of SO_2, NO_x, PM10, and the energy efficiency of intermodal transport chains prove that the current transport route to the northern leg of the BAC via the port of Gdansk is more environmentally friendly, even if it is about 3000 NM longer. The article provides a scientific contribution by pollution data elaboration for demonstrating the need and justification for high investment in BAC in order to establish sustainable transport chains. The study shows that pollution values from supply chains on the Asia–Central Europe axis could be reduced by up to 30% by eliminating infrastructural barriers in the port of Koper and on the railway network at BAC, which is one of the primary goals of BRI.

Keywords: sustainable transport systems; Belt and Road Initiative; Baltic–Adriatic Corridor; container terminal; railway network; intermodal transport

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1. Introduction

Sustainable transport is part of a wider vision of sustainable development [1] and lies on three pillars of sustainability: environmental, social, and economic [2]. Loo and Tsoi [3] expose five elements that are crucial for sustainable transport development: vehicle transformation, modal-split transformation, city transformation, economic, and lifestyle transformation. Sustainable transport systems play an important role in linking these elements, as they ensure the movement of goods and people, a lower level of environmental usurpation, economic development, and the balanced development of cities and hinterlands.

The One Belt and One Road (OBOR) and Belt and Road Initiative (BRI) are China's recent initiatives to develop the global economy, provide infrastructure development, and the development of new goods and, thus, transportation routes [4]. The strategy of recognition and eliminating bottlenecks on crucial transport routes includes the modernization and construction of the necessary transport infrastructure of all transport sectors to achieve optimal and sustainable operation of transport systems. The Organisation for Economic Co-operation and Development (OECD) [5] emphasizes that the need for the development of transport infrastructure at the global level in the future will be higher than the financial resources provided for investments, so it will be necessary to focus on critical projects. The

BRI provides planned development and investment by focusing on key transport corridors, which will also have significant geo-economic impacts on the EU (European Union) and ongoing transport systems [6].

BRI pursues a faster and more comprehensive development of transport systems on vital connections between Asia, Europe, and Africa. The development of transport chains lies in the development of the Maritime Silk Road (MSR), which is based on the historically known Silk road [7] and is significantly related to the construction and modernization of port infrastructure [8]. At the same time, BRI supports more environmentally friendly transport corridors and follows the reduction of environmental pollution from transport activities [9]. The focus on high-speed rail is essential [10] to achieve a faster modal shift from the road to rail [11]. The intermodal transport route through the Mediterranean to the Adriatic Sea is particularly emphasized, which can dramatically shift the weight of transport chains from northern European ports and intermodal terminals to ports in the Mediterranean region [12].

The study aims to expose the infrastructural barriers on the southern part of BAC, as presently, this transport route does not use sustainable transport systems compared to the northern leg of BAC. The research includes an analysis of the existing operation of intermodal transport chains from Asia for Central European markets, such as Slovakia, the Czech Republic, and Poland, along existing transport routes through northern Europe (NTR) and along the southern transport route (STR) through the Mediterranean Sea. In 2015, China signed a BRI cooperation agreement with three central European countries (Slovakia, the Czech Republic, and Poland) located on the European Baltic–Adriatic Corridor (BAC). An essential link between the MSR and the BAC is formed for an optimal connection to the Central European market. The BAC is one of the most important transport links between the northern and southern parts of Europe, which can effectively connect Central Europe. It is the shortest transport route connecting the Baltic region with the Mediterranean and runs through the territory of six European countries [13]. Europe has determined various infrastructure projects on this corridor, including maritime nodes—the ports of the northern Adriatic and the Polish ports of Gdynia and Gdansk [14]. For land connections, projects aim to improve railway infrastructure, increasing rail and road throughput, especially in the vicinity of European cities and significant multimodal terminals, such as Vienna, Bratislava, Katowice, Warsaw, and Žilina [15]. The focus of the study is on providing a critical look at the current infrastructural and suprastructural elements of the transport route and presenting impacts on pollution levels generated by ongoing intermodal chains.

The study bases on the H1 hypothesis stating that infrastructure constraints on the STR through the northern Adriatic do not currently provide competitive and sustainable supply chains starting in Asia to Central Europe, compared to the transport route on the north of BAC; consequently, BRI activities are useful in developing environmentally friendly and lean intermodal transport chains in Europe.

On this basis, transport chains through the ports of Gdansk and Koper are analyzed. Elements of economic aspects and level of pollution from transport activities through both ports are compared. With this, the comparative advantages of the transport corridor development and the critical elements of bottlenecks for the effective implementation of MSR and BAC are highlighted. The scientific contribution of the study is in scientific data presentation and the promotion of such research, which highlights the sustainable development of transport systems and supports the targeted adaptation of transport infrastructure in less developed regions. The results of the study emphasize the importance and need for targeted infrastructural elements modernization in the port of Koper and on the southern part of the BAC to accelerate the creation of sustainable and energy-efficient transport chains in Europe. Their development can also be encouraged and supported through an active BRI approach and by the promotion of common synergies between Europe and China.

2. Theoretical Background

Intermodal transport chains are based on efficient transport processes and increasingly on sustainable transport systems [16] in order to ensure the shortest possible transport process with as little transshipment of goods [17]. At the same time, the overall costs of the intermodal transport chain should be as low as possible and environmentally neutral [18,19]. Intermodal networks and related transport logistics processes need to be also energy efficient and result in the lowest possible GHG (greenhouse gasses) emissions [20], with the carbon footprint being the most exposed [21].

Qian et al. [22] emphasize the importance of research about sustainable transport systems from a strategic and implementation point of view. The strategic approach must include guidelines for long-term development [23] and model elaboration [24], while the operational approach should be focused on the implementation basis. Such an approach has been carried out by Sislian et al. [25] by analyzing interrelated theoretical concepts of port sustainability and practical ones of ocean carrier network problem in order to develop a wider conceptual framework for sustainability in the maritime industry. Cariou et al. [26] expose other elements directly connected to implementation decisions influencing sustainable maritime transport, such as carrier decisions about larger ships, feet composition, and operational characteristics, that significantly influence CO_2 pollution levels. Pizzol [27] confirms that the use of more modern ships and shortening transport routes is a necessity in the operation of sustainable transport chains. These ships provide economies of scale and, at slightly reduced sailing speeds, lower CO_2 emissions [28]. Besides larger and newer ships, Acciaro et al. [29] expose the use of innovative technologies in the port for sustainable transport chains, which, however, require high investments.

The land part of intermodal chains should be organized by rail transport, while just last-mile delivery should use road transport [30]. The results of a study by Wiegmans and Janic [31] show that the use of long-distance rail transport is more environmentally sustainable than the use of maritime connections between Asia and Europe, so it is advisable to shorten the sea route as much as possible. Li and Zhang [32] state that modal shift to rail is highly dependent on pricing policy, where Islam and Mortimer [33] see that the price can be decreased by forming longer trains and with higher transport speed that shortens the wagon turnaround time.

Within the European Union intermodal network, there are infrastructural bottlenecks that currently limit the rapid movement of large quantities of goods from other already operating transport chains [15], and especially in Central and Eastern Europe [34]. The port infrastructure and superstructure in the Adriatic Sea currently does not allow the accommodation of the largest container ships used in northern European ports [35]. The berth subsystem at container terminals does not provide the infrastructural elements and operating conditions for work on ULCV (Ultra Large Container Vessels). The same is true for the container storage and dispatch subsystems, as with a rapid increase in container throughput, the entire port or container terminal system would become congested [36]. By infrastructural and suprastructural improvements, ports must follow sustainable development, where Ignaccolo et al. [37] propose the use of a sustainability matrix for efficient port development. Hinterland connections are also a bottleneck. The identification of transport sections that limit flow and eliminating them is undoubtedly an essential element of BRI development. Thus, research must identify and highlight infrastructural bottlenecks that inhibit the operation of sustainable supply chains on MSR and BAC.

3. Materials and Methods

The research consists of seven steps forming a conceptual research framework (Figure 1). The first step includes the problem definition of understanding the efficiency of transport systems on the southern part of BAC from a sustainable point of view. The second step defines the transport route model, three elements of intermodal transport chain performance and their data collection, and special tool use. Transport cost, pollution level, and transit time analysis on both transport routes (NTR and STR) are performed according to the present situation in the third step. Moreover, the fourth step consists of data collection and analysis of actual infrastructural and suprastructural bottlenecks on STR that are limiting the use of larger ships, longer trains, and higher train speed. Simulations of pollution levels by using improved transport systems and larger vessels on STR form the fifth step, followed by the analysis of needed investments to enhance transport systems on STR. Finally, a cost–benefit from an environmental point of view is exposed as the first step in a cost–benefit analysis that will be further elaborated under the ongoing project.

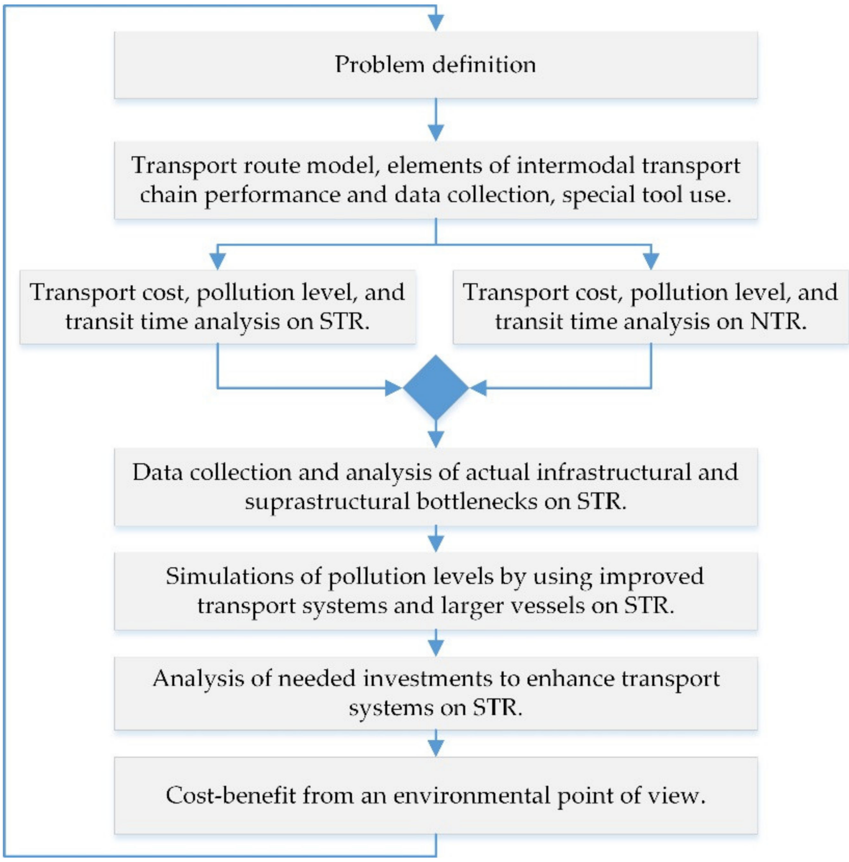

Figure 1. Research framework. Source: Prepared by authors.

The model of the intermodal transport route consists of three legs connecting intermodal nodes: port of loading (POL), discharging port (POD), and final destination (Figure 2). As case loading ports, three representative ports with more than 20 million TEU (Twenty-foot Equivalent Unit) throughput per year are used. They cover the northern part of the Chinese coast (POL Qingdao), the central region (POL Shanghai), and the southern part of the Chinese coast (POL Shenzen). The second group of nodes consists of discharging ports from the northern and southern parts of the BAC. These are the most important ports at BAC from a container throughput perspective, Gdansk (Poland) with 2.07 million TEU throughput in 2019, and Koper (Slovenia) with a throughput of 0.96 million TEU in 2019. The analysis includes maritime lines with direct service from the Asian ports, offered by the two major alliances, 2M and Ocean Alliance. Both have established direct maritime services to POD Gdansk [38] and also POD Koper [39].

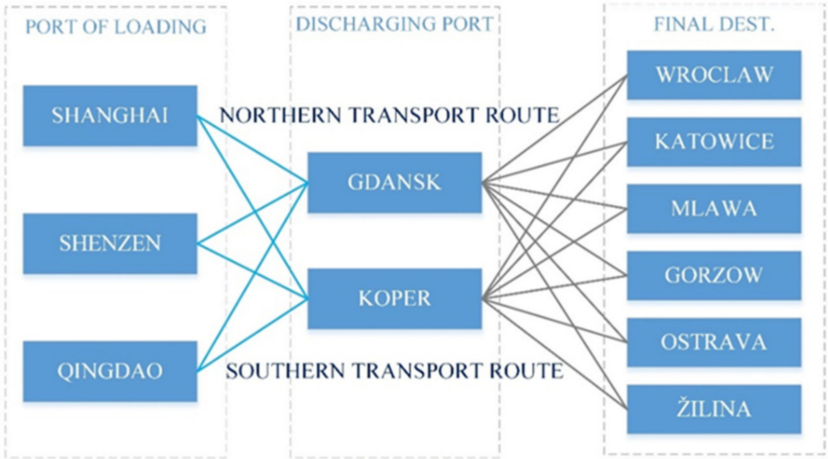

Figure 2. Transport route model. Source: Prepared by authors.

The third leg, the route to the intermodal hubs, is represented by two groups of final destinations on the BAC. The first group consists of destinations with similar distance from both ports (Ostrava–Czech Republic, Žilina–Slovakia), while in the second group are destinations closer to POD Gdansk. Nonetheless, due to the shorter sea transport route to POD Koper, it is advisable to check the impact on sustainable intermodal transport chains. The final destinations on the BAC, which are less than 600 km away from POD Koper, are not included, because the significantly shorter transport route is economically and environmentally more efficient.

Three crucial elements of intermodal transport chain performance are analyzed: total transport costs, time component, and pollution level by taking into account also the energy efficiency of the entire transport chain. The pollution and energy efficiency components are analyzed by using the EcoTrasIT tool developed by IVE mbH and partners. The tool is used by different logistics companies, as the methodology for calculating emissions from various means of transport is following standard EN 16258. A version from 27.9.2019 is used [40]. The following input variables are used for calculations: container weight 14 tons (with container tare included), the size of the ship on the NTR is ULCV (Ultra Large Container Vessel), and on the STR Suezmax, there are ships with a capacity of over 7000 TEU to 15,000, TEU because the container terminal at Koper does not allow the accommodation of larger vessels presently.

On both transport routes, the same ship occupancy (85%) and reduced ship travel speed (20%) are used, even though some container lines sail with even lower slow-steaming values [41]. The calculator does not allow direct calculation of emissions from Asian ports to POD Gdansk, so the values to POD Hamburg and the average values of the extended voyage from POD Hamburg to POD Gdansk are calculated. For the land route of intermodal transport chain from POD to final destinations following values are used: diesel engine of a truck (EUR 5 engine) with truck loading factor 53%, while for rail transport electrified line classification EU UIC 2 is selected and occupancy factor 64%. The loading factor is calculated according to container weight and maximum allowed carrying weight per transport mean.

The cost element analysis includes a separate cost overview of transport prices on the STR and NTR, using existing maritime container services and the size and volume of ships to the ports of the northern Adriatic and via the Polish port of Gdansk. The total costs also include the costs of container transshipment in ports (THC), port security (ISPS), and on-carriage costs by truck and rail to selected destinations. Prices were valid for the 3rd quarter (3Q) and 4th quarter (4Q) 2019. Rates were obtained by direct demand from freight forwarders and intermodal operators organizing supply chains on a defined transport model.

The time component includes average transport times performed by existing container services from three Asian ports to the ports of Koper and Gdansk, with on-carriage transport time. The service timeline basis on schedules valid in the 3rd and 4th quarter 2019 published on web sites, before the impact of the COVID 19 epidemic on the global economy and supply chains, and were checked with forwarders directly.

The research includes an analysis of the operation of the intermodal transport chain from Asia through the northern Adriatic and the northern European port of Gdansk to the markets at BAC. The research basis on two auxiliary hypotheses (H1.1 and H1.2), which enable the testing of the primary research hypothesis H1 (infrastructural restrictions on the STR through the port of Koper do not allow competitive and sustainable supply chains, compared to the northern transport route (NTR) via the port of Gdansk). These hypotheses are:

Hypothesis 1.1 (H1.1). *Current transport connections and maritime services through the northern Adriatic do not ensure the optimal implementation of supply chains in terms of elements of pollution, time and cost.*

Hypothesis 1.2 (H1.2). *Targeted upgrading of transport infrastructure is needed to enable the use of more modern transport technologies for cost optimization and reduction of environmental usurpation on STR, and to represent a valid transport alternative to the northern part of BAC.*

4. Results and Data Analysis

4.1. Pollution Analysis on BCA via Southern and Northern Transport Route

The environmental analysis contains data from the first leg of maritime transport on port–port route and the second part of the land transport by road and rail. Comparisons of environmental data include energy consumption, carbon footprint, NO_x, and SO_2 emissions, NMHC (Nonmethane hydrocarbon) emissions, and PM10 emissions, which have had the most significant impact on air pollution and climate change [42]. The analysis of the maritime transport of container shows that the values of emissions and energy consumption on both PODs are very similar, even though the sea transport route to POD Gdansk is about 3000 NM longer. Energy consumption from the three Asian ports to Gdansk is only 1 to 5% higher than to Koper, and the difference in the carbon footprint of just maritime container transport is similar. There are even smaller differences in NO_x and NMHC emissions, up to 3%. For SO_2 emissions, the maritime transport to POD Gdansk produces even 4 to 6% fewer emissions than to Koper presently. The reason is the use of larger ships, which can be accepted at the container terminal in Gdansk, as they produce lower emissions per on-board container, thus compensating the 25% longer transport route.

Different distances to the final destinations of Wroclaw, Katowice, Mlawa, Gorzow, Ostrava, and Žilina via both legs of the BAC increase the differences in emissions and energy efficiency, especially with the comparability of road and rail transport. The road transport route via POD Koper to Wroclaw is 426 km longer, to Katowice 346 km, to Mlawa 1030 km, to Gorzow 464 km, to Ostrava 164 km, and to Žilina 73 km. The differences in the length of the transport route by rail are even more considerable, namely 589 km to Wroclaw, 366 km to Katowice, 1165 km to Mlawa, 466 km to Gorzow, 204 km to Ostrava, and 108 km to Žilina.

Differences in energy consumption on the entire transport route from POL to the final destination are significantly higher when using road transport on POD Koper. Still, competitiveness is increased considerably to destinations in northern Slovakia and the Czech Republic, where the STR is more energy efficient (Table 1).

Table 1. Comparison of energy efficiency from selected port of loading (POL) to the final destination via discharging port (POD) Gdansk vs. POD Koper (% of value via POD Koper).

	Maritime Transport & Trucking					
POL	**Wroclaw**	**Katowice**	**Mlawa**	**Gorzow**	**Ostrava**	**Žilina**
Shanghai	78.66	82.81	55.64	77.28	91.90	97.18
Shenzen	79.13	83.50	55.06	77.68	93.12	98.71
Qingdao	78.41	82.46	55.89	77.07	91.30	96.44
	Maritime Transport & Rail					
	Wroclaw	**Katowice**	**Mlawa**	**Gorzow**	**Ostrava**	**Žilina**
Shanghai	89.03	94.94	75.57	92.32	99.60	102.49
Shenzen	90.45	96.85	75.98	94.00	101.93	105.06
Qingdao	88.34	94.03	75.35	91.52	98.51	101.30

The carbon footprint values of the whole intermodal transport chain are the lowest when using the STR and the organization of land transport by rail, except for transportation to Mlawa, which is significantly closer to POD Gdansk. The carbon footprint of such an intermodal transport chain to the cities of Wroclaw, Katowice, and Gorzow is 1 to 10% lower than through POD Gdansk (Figure 3).

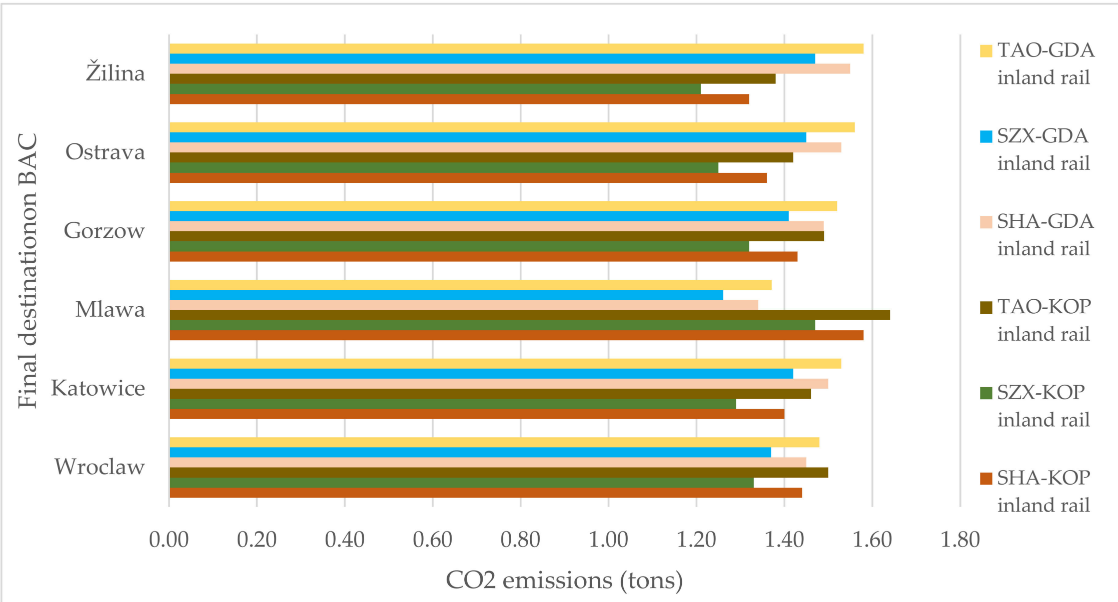

Figure 3. CO_2 emissions from POL to the final destination on Baltic–Adriatic Corridor (BAC) through POD Koper and POD Gdansk with rail transport to the final destination.

When using the STR by road to Wroclaw, Katowice, and Gorzow, the carbon footprint is 20% higher than via northern Europe. The differences are smaller in transport to Ostrava and Žilina and amount to 3–8% (Figure 4).

The analysis of NO_x and SO_2 values of the entire intermodal transport chain shows the dominant role of maritime transport, as it produces 98 to 99% of NO_x and SO_2 emissions in the whole transport leg from Asia to the markets of Central Europe. A greener intermodal transport chain in terms of NO_x and SO_2 emissions depends on the nautical route and the size and age of the ships. Besides, a reduction in sailing speed also has an impact.

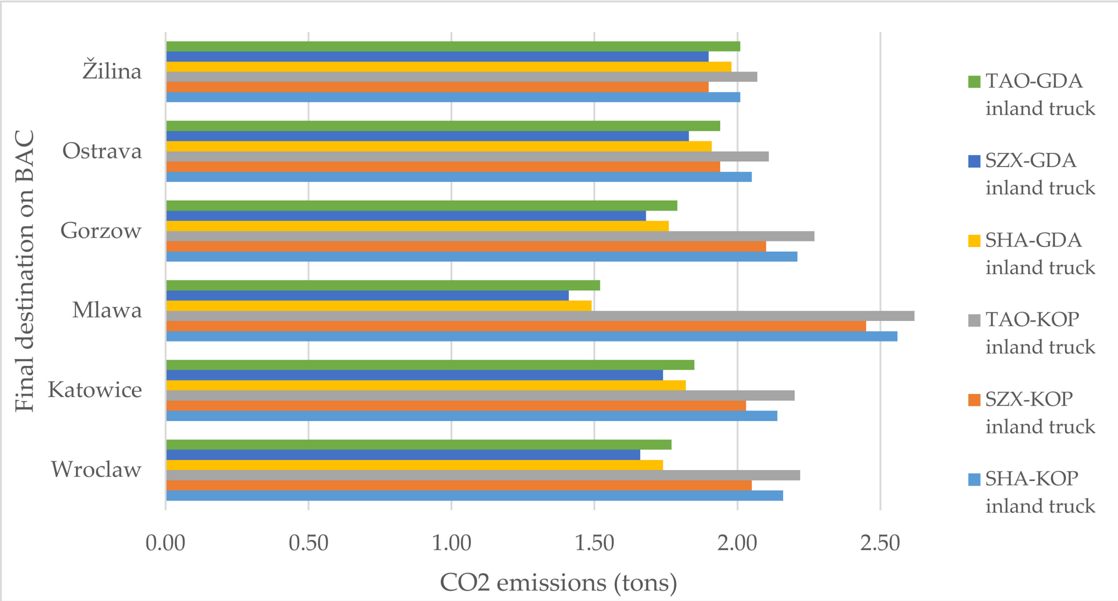

Figure 4. CO_2 emissions from POL to the final destination on BAC through POD Koper and POD Gdansk with truck transport to the final destination.

Taking into account the same sailing speeds of ships and the occupancy of cargo space and lower capacity ships at POD Koper, the STR by using the railway is greener in most cases from the NO_x emissions perspective. Such an intermodal transport chain produces up to 10% fewer NO_x emissions compared to road transport. For SO_2 emissions, the transport route is greener via the NTR when using road transport to final destinations (Table 2). The transport chain from POL Qingdao to the final destination on the BAC via POD Gdansk produces up to 8% fewer SO_2 emissions. The differences are reduced by shortening the maritime transport route; consequently, the difference in the Shenzhen transport chain is just under 2%, which confirms the fact that SO_2 emissions mainly depend on the size of the ship and the share of the maritime transport route in the entire transport chain.

Table 2. NO_x and SO_2 emissions on the entire intermodal transport route.

	NO_x Value in kg											
	Wroclaw		**Katowice**		**Mlawa**		**Gorzow**		**Ostrava**		**Žilina**	
Sea route	Truck	Rail	Truck	Rail	Truck	Rail	Truck	Rail	Truck	Rail	Truck	Rail
SHA-KOP	31.6	29.3	31.6	29.2	32.7	29.6	31.8	29.3	31.3	29.2	31.2	29.1
SHA-GDA	30.6	29.6	30.7	29.7	29.9	29.3	30.6	29.7	31.0	29.7	31.2	29.8
SZX-KOP	29.6	27.3	29.6	27.2	30.7	27.6	29.8	27.3	29.3	27.2	29.2	27.1
SZX-GDA	28.6	27.6	28.7	27.7	27.9	27.3	28.6	27.7	29.0	27.7	29.2	27.8
TAO-KOP	32.6	30.3	32.6	30.2	33.7	30.6	32.8	30.3	32.3	30.2	32.2	30.1
TAO-GDA	30.5	29.5	30.7	29.7	29.8	29.3	30.5	29.6	31.0	29.7	31.2	29.7
	SO_2 Value in kg											
SHA-KOP	18.4	18.6	18.3	18.5	18.5	19.0	18.4	18.6	18.3	18.4	18.3	18.2
SHA-GDA	17.9	18.3	17.9	18.4	17.8	18.0	17.9	18.4	17.9	18.5	18.0	18.6
SZX-KOP	17.4	17.6	17.3	17.5	17.5	18.0	17.4	17.6	17.3	17.4	17.3	17.2
SZX-GDA	16.9	17.3	16.9	17.5	16.8	17.0	16.9	17.4	17.0	17.5	17.0	17.6
TAO-KOP	19.4	19.6	19.3	19.5	19.5	20.0	19.4	19.6	19.3	19.4	19.3	19.2
TAO-GDA	17.9	18.3	17.9	18.4	17.8	18.0	17.9	18.4	17.9	18.5	18.0	18.6

NMHC emission values are the lowest when using the maritime service at POD Koper and rail transport for on-carriage transport mode. Compared to rail transport via POD Gdansk, the values are 4% lower for supply chains to Katowice and Gorzow and up to 21% for supply chains to closer Žilina. Compared to the NMHC values via the NTR, the use of sea and rail transport via the STR is 10% greener, mainly due to the shorter sea route.

Emissions of PM10 particulate matter behave slightly differently. The lowest values are generated from maritime transport to POD Gdansk with trucking of container to the final destination. Emissions from sea transport per TEU are lower when using larger and newer ships, which has a significant impact on total PM10 emissions, as maritime transport contributes 98% of these emissions along the entire transport route. PM10 emissions via the NTR to BAC are up to 5% lower compared to the route via the northern Adriatic.

The results of the pollution of intermodal transport chains show different values of the most favorable transport route, depending on the maritime service and kind of land transport. A transport chain across NTR by using rail for land transports is the most energy efficient. The least SO_2 and PM10 emissions are generated using the NTR with road transport for container delivery to the final destination. The STR with rail transport is greener in terms of carbon footprint, $NO_{x,}$ and NMHC emissions, except for transport northern of Wroclaw and Gorzow.

4.2. Time Comparison

The analysis of the total transport time from POL to the final destination on BAC includes data of container lines and services with direct connections from Asia to POD Gdansk and Koper and the time of land transport by land. The direct services of the two largest alliances, namely 2M and Ocean Alliance, operate in both PODs. These two alliances consist of six container lines: MSC, Maersk, COSCO, CMA-CGM, Evergreen, and OOCL. Other container lines also use the service by individual agreements, even if they are not in the mentioned alliances, such as Hapag and HMM.

A comparison of maritime service times shows a 5 to 10% difference in transport time between services to the same POD. The differences are due to different intra-Asia connections, such as the Qingdao port connection, which is connected directly with POD Gdansk, meanwhile, with POD Koper, an additional feeder service via hubs, such as Busan, Ningbo, or Shanghai, is used. The best transport times to POD Koper and POD Gdansk differ in favor of the STR, where the time to Koper is 24% shorter from POL Qingdao, 17% shorter from POL Shanghai, and 24% shorter from POL Shenzen (Figure 5). On the land transport leg, there are no significant differences in time that would significantly affect the total transport time. Road transport is organized within two days from unloading from the vessel to complete the formalities for the release of the container, the trip organization, and the necessary customs formalities. For rail transport, the whole transport time is extended by an additional day.

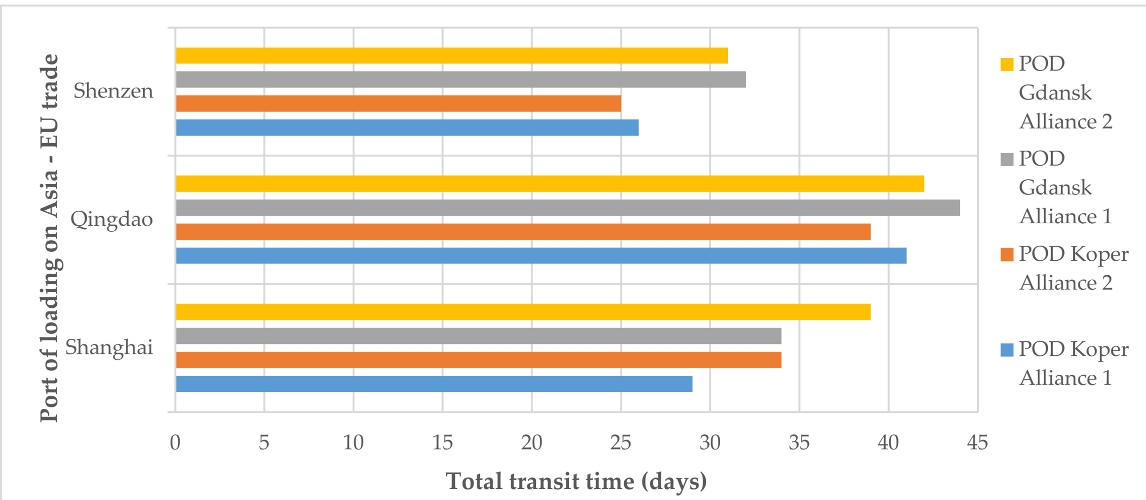

Figure 5. Total transport time from POL to final destinations on BAC with road transport delivery from POD Koper and Gdansk.

The research confirms that from a time point of view, the use of maritime services via POD Koper is more profitable, as supply chains from certain POLs are shortened by up to 6 days. Shippers and consignees have fewer goods in the supply chain (for an entire week of production) or in the inventories, which enables the reduction of supply costs and the provision of the company's liquidity.

4.3. Cost Perspective

A comparison of the prices of the entire transport from POL to POD and land transport by truck, including manipulation costs at POD, ISPS costs, and delivery order cost, shows equal prices to Ostrava and Žilina through both ports. As the distance from POD Koper increases, the price difference increases due to road transport. The cost of maritime transport in 4Q 2019 to both PODs was almost the same, with a slight difference (5 and 7%) in favor of the route via POD Koper. For transport to the farther destinations on the BAC from POD Koper, the total transport costs are up to 37% higher compared to those via POD Gdansk (Figure 6).

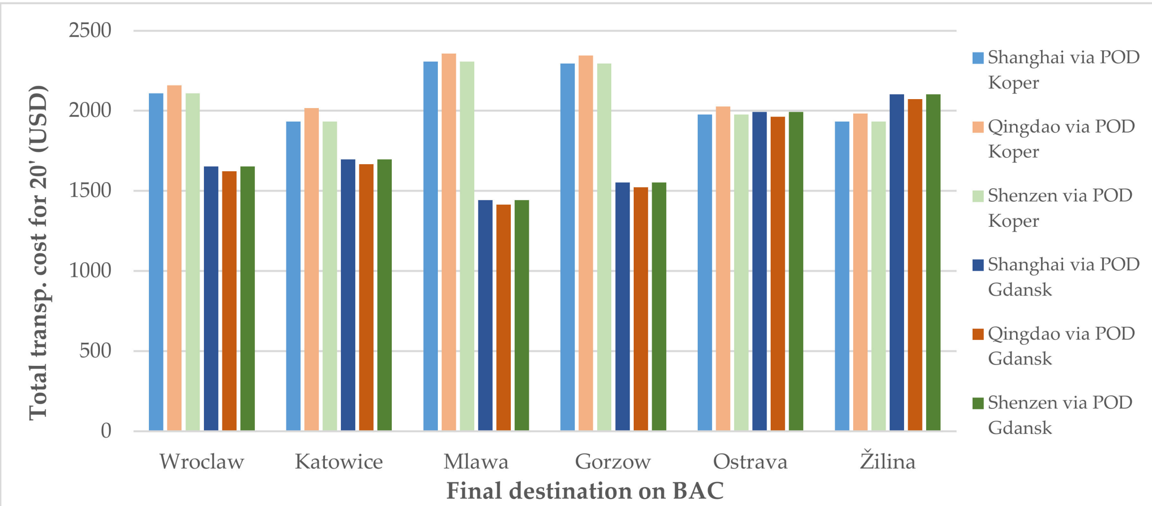

Figure 6. Comparison of total maritime transport cost from POL via Koper and Gdansk with trucking cost to the final destination on BAC.

The analysis of the total transport costs between Chinese ports and final destinations on the BAC via POD Koper and POD Gdansk, using land rail transport from POD, shows a similar relationship. Transport via POD Koper using the railway is more competitive to Ostrava and Žilina. In contrast, the costs to the northern destinations on BAC are significantly higher via the STR. Transport costs using the railway to Wroclaw and Katowice via Gdansk are 20% lower than via POD Koper (Figure 7).

The comparison of the most cost-effective intermodal transport chains from POL to destinations on the BAC shows the competitiveness of the STR using rail transport to Ostrava and Žilina. NTR is the cheapest when using truck transport to destinations. Via the STR, the use of road transport is most favorable only by transport to Mlawa and Gorozow, meanwhile to other destinations, the transport chain is cheaper by rail. A comparison of the most cost-effective transport solutions via the southern and northern parts of the BAC demonstrates the justification for using the NTR for destinations more than 800 km away from the northern Adriatic ports. However, the entire intermodal transport route from Asia is significantly longer (Table 3).

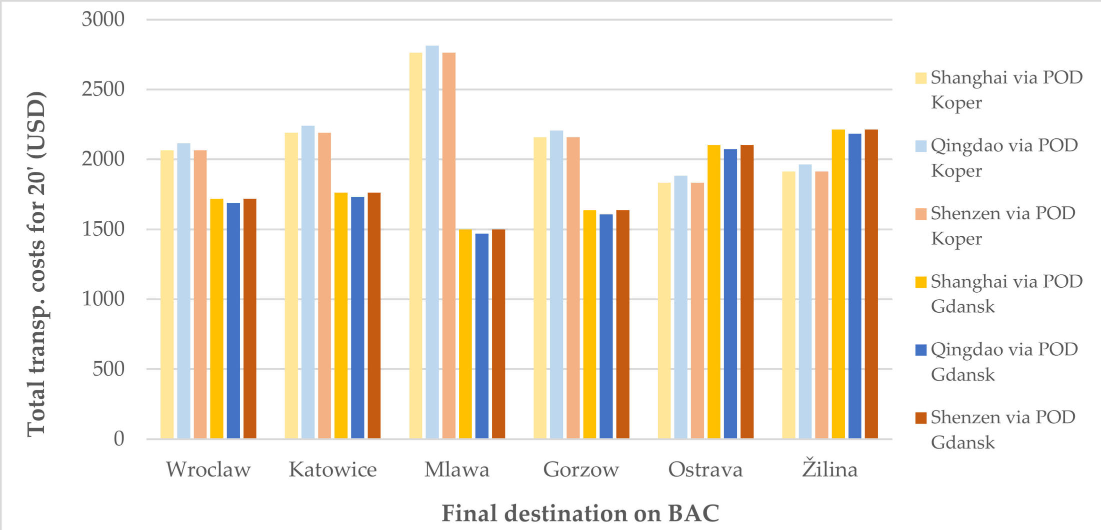

Figure 7. Comparison of total maritime transport cost from POL via Koper and Gdansk with rail cost to the final destination on BAC.

Table 3. Price comparison of best total transport price via POD Gdansk and POD Koper (% of price via southern transport route (STR) through POD Koper).

POL	Wroclaw	Katowice	Mlawa	Gorzow	Ostrava	Žilina
Shanghai	80%	88%	63%	72%	109%	110%
Qingdao	77%	83%	60%	69%	104%	106%
Shenzen	80%	88%	63%	72%	109%	110%
Best option from Gdansk	Truck	Truck	Truck	Truck	Truck	Truck
Best option from Koper	Rail	Rail	Truck	Truck	Rail	Rail

Source: Prepared by authors.

5. Discussion

5.1. Port and Inland Infrastructure Modernization for Greener and Reliable Intermodal Transport Chains

The existing STR from Asia via the northern Adriatic with the land connection to the BAC is less competitive compared to NTR, in terms of energy consumption and from an environmental perspective. Besides, it is more than 20% more expensive to distant destinations compared to NTR. To ensure the competitiveness of the STR, it is necessary to upgrade and modernize the port infrastructure and hinterland connections on the BAC. By this, larger ships could call the port, and the port infrastructure could handle higher quantities of containers.

The results of the study where larger container ships are used in simulation calculations show that ships with a carrying capacity of over 15,000 to 20,000 TEU would reduce energy consumption by 23% compared to the existing maritime connections at POD Koper. To a similar extent, the carbon footprint and other emissions would be reduced as well. Lower GHG emissions from maritime transport would significantly affect the environmental acceptability of the entire intermodal transport chain on the Asia-Central Europe axis.

The entire intermodal transport chain via POD Koper would be 7% more energy efficient using the railway (to Wroclaw), and even up to 25% to Žilina. Results show an exception in the case of the transport chain to Mlawa, which would still be 10% more efficient via POD Gdansk (Figure 8). However, if the consignee or the buyer would request the organization of land transport by road to Wroclaw, Katowice, and Gorzow, the energy-savings on the transport route via POD Gdansk would be between 5 and 12%. On the contrary, transport by road to Žilina and Ostrava would be 5 to 13% more energy efficient via the STR.

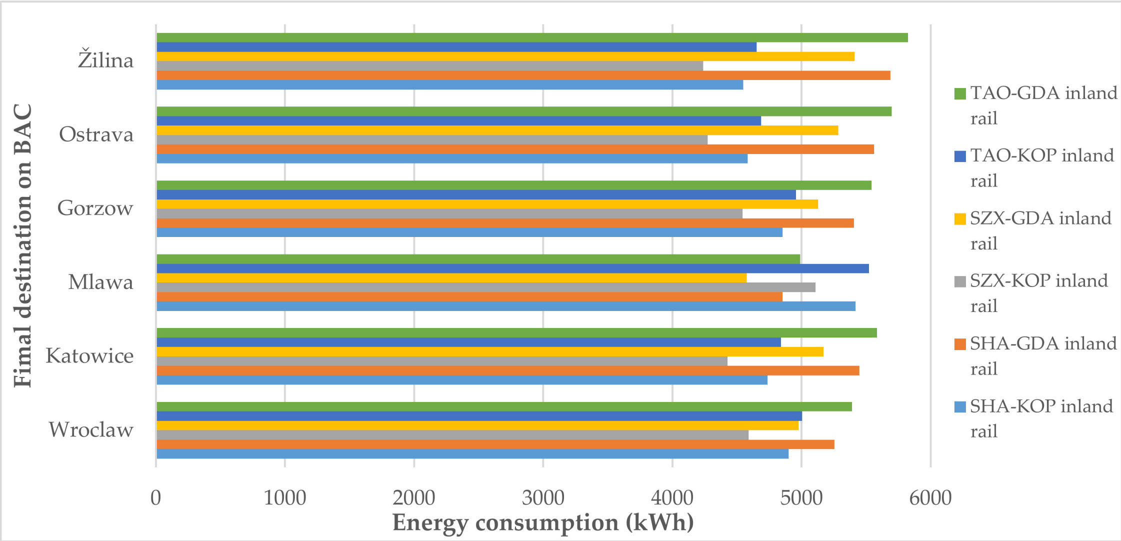

Figure 8. Energy consumption of intermodal transport chain to POD Gdansk and with eventually bigger ships to POD Koper.

The carbon footprint on the STR using rail to selected destinations on the BAC would be 20 to 30% lower compared to the transport chain via NTR with railing. In the case of the particular requirement to use road transport for on-carriage transport, the carbon footprint via POD Gdansk to the cities of Wroclaw, Katowice, Mlawa, and Gorzow would be still lower (Table 4).

Table 4. CO_2 emissions on northern and southern European transport routes with larger vessels to POD Koper.

Sea Route	CO_2 Value in Tons											
	Wroclaw		Katowice		Mlawa		Gorzow		Ostrava		Žilina	
	Truck	Rail	Truck	Rail	Truck	Rail	Truck	Rail	Truck	Rail	Truck	Rail
SHA-KOP	1.89	1.17	1.87	1.13	2.29	1.31	1.94	1.16	1.78	1.09	1.74	1.05
SHA-GDA	1.74	1.45	1.82	1.50	1.49	1.34	1.76	1.49	1.91	1.53	1.98	1.55
SZX-KOP	1.80	1.08	1.78	1.04	2.20	1.22	1.85	1.07	1.69	1.00	1.65	0.96
SZX-GDA	1.66	1.37	1.74	1.42	1.41	1.26	1.68	1.41	1.83	1.45	1.90	1.47
TAO-KOP	1.91	1.19	1.89	1.15	2.31	1.33	1.96	1.18	1.80	1.11	1.76	1.07
TAO-GDA	1.77	1.48	1.85	1.53	1.52	1.37	1.79	1.52	1.94	1.56	2.01	1.58

Source: Prepared by authors.

The values of other NO_x, SO_2, NMHC, and PM10 emissions would be significantly lower on the STR. The transport chain to more distant destinations, such as Wroclaw, Katowice, and Gorzow, would produce 20 to 36% fewer NO_x emissions and 16 to 30% fewer SO_2 emissions (Table 5). Similar reductions would be for PM10 and NMHC emissions.

Table 5. Pollution emissions via POD Gdansk to final destinations vs. emissions via POD Koper by using larger container vessels (% of STR value).

POL	Wroclaw		Katowice		Mlawa		Gorzow		Ostrava		Žilina	
	Truck	Rail	Truck	Rail	Truck	Rail	Truck	Rail	Truck	Rail	Truck	Rail
NO_x Emission Difference												
Shanghai	124.1	132.4	125.2	133.4	116.0	129.7	123.5	132.9	127.6	134.1	129.0	134.5
Shenzen	126.2	135.6	127.4	136.8	117.3	132.6	125.5	136.2	130.1	137.5	131.7	137.9
Qingdao	119.1	126.6	120.2	127.6	111.6	124.1	118.6	127.1	122.5	128.2	123.8	128.5
SO_2 Emission Difference												
Shanghai	124.6	125.3	124.9	127.5	122.8	119.8	124.5	126.4	125.5	129.0	125.8	130.4
Shenzen	126.5	127.2	126.9	129.7	124.5	121.3	126.4	128.4	127.5	131.3	127.8	132.8
Qingdao	116.4	117.2	116.7	119.2	114.8	112.2	116.3	118.2	117.2	120.5	117.4	121.8
NMHC Emission Difference												
Shanghai	115.0	130.4	117.2	130.7	100.5	129.5	113.5	130.6	121.7	131.0	124.0	131.1
Shenzen	116.2	133.5	118.6	133.9	100.5	132.5	114.5	133.7	123.5	134.1	126.0	134.3
Qingdao	114.7	129.6	116.8	130.0	100.5	128.7	113.2	129.8	121.3	130.2	123.5	130.3
PM10 Emission Difference												
Shanghai	122.4	123.9	122.6	125.9	120.4	119.0	122.2	125.0	123.2	127.4	123.5	127.8
Shenzen	124.6	126.2	124.8	128.4	122.4	120.7	124.4	127.4	125.4	130.0	125.8	130.5
Qingdao	121.8	123.3	122.0	125.2	119.9	118.5	121.6	124.3	122.5	126.6	122.9	127.0

Source: Prepared by authors.

5.2. Terminal Infrastructure and Suprastructure Maintenance and Improvement with BRI

According to the analysis, it will be necessary to upgrade and modernize infrastructural elements of the container terminal and handling equipment in the Port of Koper to accommodate ULCV with a capacity of over 18,000 TEU. The berth will need to be extended, as the current length does not provide enough space for contemporary work on two ships with a carrying capacity of over 12,000 TEU. The length of the berth is only 596 m (POD Gdansk 1300 m). By extending the berth by 100 m, it will still be challenging to work simultaneously on two ships with a carrying capacity of over 12,000 TEU, as the safety distance between the vessel must be taken into account. The limit is also the maximum draft of the ship, which is 14.5 m (POD Gdansk 16.5 m). If the Port of Koper would like to accept a fully loaded ship with a carrying capacity of over 18,000 TEU, it will be necessary to deepen the navigable channel and the berth depth by an additional 1.5 m.

According to official data presented by the Port of Koper [43], the current static capacity of the terminal for full containers is 19,130 TEU, while 9547 TEU positions are used for empty containers (total capacity at POD Gdansk 64,000 TEU). With the arrival of larger ships, which justify their arrival with a larger quantity of full boxes, it will be necessary to increase the static storage capacity by arranging additional storage areas in the hinterland of the extended berth, which should additionally be extended by 150 m. Before this, it will be necessary to consolidate further the old part of the berth enabling the installation of Super Post-Panamax gantry cranes. The extension of the berth to the sea will result in the acquisition of 24,830 m^2 of the new storage area. By this, the total static storage capacity will increase by 15%. The cost for the berth extension by 100 m and the arrangement of the equipped storage area is estimated at EUR 46 million [44]. The cost value for an additional extension of 150 m depends on whether the expansion would be done into the sea or the existing land. The construction price is estimated at EUR 60 to 70 million.

Simultaneous work on mother ships limits works on smaller feeder ships. Thus, the Port of Koper plans to build two new berths on the north part of the terminal, 341 m long. By this, an additional storage area measuring 53,185 m^2 would be provided [44]. The price of such an investment is around EUR 150 million.

Investments in the superstructure of the terminal will also be required, as the terminal uses two Super Post-Panamax cranes, four Post-Panamax, and three Panamax cranes, while POD Gdansk uses in total 17 Ship-to-Shore (STS) cranes. For simultaneous work on the ULCV and a ship with a capacity of 15,000 TEU, and by taking into account the load capacity of the berth and the distance between STS cranes, 10 STS cranes could be installed on the southern berth. Consequently, four more Super Post-Panamax cranes would be needed. With the construction of the berth in the northern part, two additional STS cranes could be operational. The total investment in STS cranes is estimated at EUR 65 million. Electric RTGs (Rubber Tyred Gantry cranes) are planned for work at the storage area, which will require an investment of EUR 20 million.

The built new capacities of the operational berth and storage space will also require investments in railway tracks and new RMGs (Rail Mounted Gantry cranes). The construction of an additional three manipulative rail tracks and the installation of two RMGs would increase the ratio of dispatched containers by rail, which supports the green mode of intermodal transport and is in line with the European Union environmental policy. The investment is estimated at EUR 13 million [39]. A rough assessment of the development and maintenance of a container terminal for receiving ships with over 18,000 TEU capacity, while providing equal support to other container lines providing feeder services in the north of the Adriatic Sea requires financial investments of EUR 350 to 400 million. Only by this, POD Koper could offer similar services already offered by POD Gdansk, and according to projections from Port of Koper management, such development would allow an annual throughput of over 1.25 Mio TEU by 2025 and 1.75 Mio TEU, where improvements on the railway network should be made simultaneously [45].

5.3. Main Rail Infrastructural Bottlenecks Elimination on the Southern Part of BAC with BRI

In addition to the modernization of the port infrastructure and superstructure, it will also be necessary to improve the railway infrastructure at the BAC in order to achieve a higher train speed (100 km/h), train length (740 m), and axle load of 22.5 tons. This will ensure lower emissions per ton of freight transported or per freight unit (TEU) in rail transport and allow a transport price reduction. By analyzing the Work Plan for the Baltic–Adriatic corridor [15], different infrastructural bottlenecks must be eliminated on the railway connection from the Port of Koper to Austria, Hungary, Slovakia, Czech Republic, and southern Poland.

According to the Work Plan, about 7% of the railway infrastructure on the BAC does not meet the axle capacity requirement of 22.5 t, and 28% of the infrastructure does not provide a transport speed of 100 km/h. Poland and Slovenia have the highest deviation in both requirements, whose network is directly connected to the ports of Gdansk and Koper. Most of the railway network on the BAC (71%) does not provide a train length of 740 m. The average length of the BAC is about 600 m [15].

The infrastructure on the Slovenian BAC course does not allow 22.5 tons of axle load on 15% of the corridor route and, at the same time, does not provide a speed of 100 km/h on 75% of the national part of BAC. Even greater is the deviation in train length that should be 740 m long as 79% of the national railway corridor does not allow it. The sections Koper–Divača and Maribor–Šentilj (towards Graz) are exposed as critical and financially expensive. Investments are needed in the construction of the second track at Koper–Divača, the value of which is estimated at EUR 1 billion [46]. In the section of the railway connection Maribor–Šentilj, it is necessary to complete the modernization of the existing line and build a second track to achieve the planned flow of trains on the BAC. The total investment is estimated at EUR 350 million.

The Austrian railway network course on the BAC reaches a load condition of 22.5 tons per axle. The problem is the length of trains, which should be eliminated by 2030 with the modernization of lines. The most important and financially substantial project is the electrification of the Marchegg (AT)–Devínska Nová Ves (SK) line, where it is planned to double the flow of trains and build a terminal. The estimated investment is EUR 550 million [15].

For the further development of freight traffic from Koper to Slovakia to BAC, it will be necessary to eliminate congestion around Žilina and Bratislava, where low transport speed generates congestions. Namely, about 14% of the Slovak network on the BAC does not reach the required speed of 100 km/h, which is mostly associated with bottlenecks around Žilina and Bratislava. The most important projects are the modernization of the Žilina station and the connections, worth EUR 234 million, and the modernization of the line between Žilina and Ostrava (Čadca–Krasno nad Kysucou) with an investment of EUR 220 million. The station and line between Devinaska Nova Vas and Bratislava also require modernization, the cost of which is estimated at EUR 926 million. The railway connection between Ostrava and Katowice requires the modernization of the connection at Ostrava, amounting to EUR 222 million, with the costs of the sections on the Polish side to Katowice estimated at a total of EUR 950 million. An additional 134 million will have to be invested in the modernization of the Katowice-Wroclaw route. Connection Ostrava–Wroclaw requires 222 million investments for the modernization of the line on the Czech side, while 200 million investments are planned from the border to Opola on the Polish side.

Undoubtedly, these are important infrastructure projects planned for construction in this decade to which investments in the modernization and maintenance of intermodal terminals need to be added. A total of 14 projects worth EUR 569 million have been recorded, including projects in Wroclaw, Ostrava Paskov, Lodz, and Warsaw, which are important for increasing the role of the STR at BAC in connecting Asia with Europe [13].

Elimination of bottlenecks in the southern course of the railway network on the BAC and modernization of the container terminal in Koper is a precondition for the development of sustainable transport routes that will lead to lower GHG emissions and ensure more energy-efficient supply chains. Infrastructure projects of upgrading and maintenance at the container terminal in the port of Koper worth EUR 360 million to establish an efficient and green MSR and more than EUR 5 billion of investments in key bottlenecks of the railway network in the gravitational area of the northern Adriatic port (from a total of 37.9 billion foreseen for the development of rail transport on the corridor) to establish sustainable green intermodal transport chains.

5.4. Environmental Benefits of Transport Systems Improvement on STR

Taking into account the Port of Koper forecast, the annual throughput of containers is expected to exceed 1.75 million TEU by 2030. In addition to the cost perspective, environmental and financial benefits need to be highlighted. Without new investments, the further development of container traffic through the Port of Koper is very limited, as the terminal already operates at the upper limit of infrastructural and suprastructural capacity. Revenues of the port and other stakeholders would not change significantly, as only a few percent growth in traffic could be achieved. In the case of upgrading the container terminal, it would enable 770,000 TEU higher annual throughput, but with the support of the construction of hinterland transport infrastructure. Taking into account the theoretical basis of the simulation, that the entire growth could be carried out using road transport only (the railway is currently congested), and all these containers would be shipped to destinations between 550 and 1100 km from Koper (average approx. 800 km), on the entire route from China (e.g., POL Shanghai) 1340 thousand tons of CO_2 would be produced. It would be consumed by about 5.15 billion kWh.

The construction of the container terminal and the hinterland railway network would allow the organization of additional railway connections. The simulations where 35% of additional containers would be transported by road and 65% by rail show that 994 thousand tons of CO_2 would be generated, and 4.08 billion kWh would be consumed. From an environmental point of view, the benefits of investments would generate new container flows of 770,000 TEU that, at the same time, could reduce CO_2 emissions by 346 thousand tons and improve the energy efficiency of transport chains by 1.07 billion kWh.

Further research will be aimed at deepening the understanding of investments in the environment, as spatial intervention also has negative consequences and not only positive as the reduction of GHG gases. The research will also focus on monitoring the development of maritime services, ships used, and terminal technology, which will enable the development of a comprehensive cost-benefit approach that can assess the projected high investment in infrastructure construction in the southern part of the BAC.

6. Conclusions

The research highlights the need for an active policy of construction and maintenance of transport systems in the STR in providing sustainably oriented intermodal transport chains from the eastern overseas markets. The long-term development of transport systems must support the creation of lean intermodal transport chains that are energy efficient and more environmentally friendly while remaining time and price-competitive. The BRI initiative supports such developments by removing bottlenecks in ports and modernizing the land network.

The STR from Asia to the northern Adriatic is specifically identified in the MSR development initiative. The development of MSR is importantly linked to the development of BAC to effectively connect the markets of Central Europe, such as Slovakia, the Czech Republic, and also the southern part of Poland, although the land transport route is significantly longer than through northern European ports. The results of the research enable the confirmation of H1.1 that the current transport connections and functioning transport systems across the northern Adriatic do not ensure the optimal implementation of intermodal transport chains from time, cost, and pollution elements point of view. Intermodal transport chains are currently less energy efficient, producing higher values of NO_x, SO_2, and PM10 emissions than chains through POD Gdansk. The carbon footprint via the STR is lower than at POD Gdansk, but it is possible to reduce the carbon footprint by 20% by upgrading and regularly maintaining the infrastructure and superstructure of the container terminal in POD Koper for accepting larger ships. NO_x and SO_2 emissions could be reduced by up to 30%.

The analysis at the container terminal in Koper shows infrastructure and superstructure unsuitability for the accommodation of ULCV with a carrying capacity of over 18,000 TEU. Investments between EUR 350 and 400 million will be needed to adjust the terminal. However, the efficient use of rail transport in intermodal transport will require high investments in BAC, with only key infrastructure adjustments exceeding EUR 5 billion. Hypothesis H1.2 can be confirmed, as targeted upgrades of infrastructure elements are needed to allow the use of more modern transport technologies as a viable alternative to NTR. By using larger ships, increasing rail travel speed, and train length, it is possible to expect a reduction in intermodal transport prices on the STR, which would also make supply chains price competitive to current supply chains to the north of BAC.

The basic research hypothesis H1 can be confirmed, as the results of the research show the current non-competitiveness of the STR via POD Koper in the formation of sustainably oriented intermodal transport chains from Asia (except carbon footprint, NMHC emissions, and shorter transport time), compared to the transport route to POD Gdansk. An infrastructurally and suprastructurally modernized transport system in STR on the MSR would enable sustainably oriented intermodal transport chains, which would also be more energy efficient. The orientation of BRI and the development of MSR in the Adriatic is expedient and necessary for the operation of sustainably oriented supply chains.

The results of the study are limited by the assumptions about container size and weight as the average values and equality of data for all analyzed transport routes are used. Furthermore, the size of ships, their age, and service rotation affect energy consumption and pollution levels, which also represent dynamic variables. Thus, obtained emission data are an approximation to the actual situation but, at the same time, represent a useful basis for evaluating environmentally acceptable modes of operation of intermodal transport chains. The same is valid for price levels that are subject to high fluctuation, especially in maritime transport. All these limitations will be used in future research to develop methodological approaches for evaluating the environmental usurpation of intermodal chains. Finally, to more comprehensively address the adequacy of the sustainable transport systems development, a cost–benefit analysis will be required, taking into account financial benefits and other external elements, such as lowering congestion and noise pollution. The latter will be the subject of further research.

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