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ANALYSIS OF THE POSSIBILITY OF REDUCING EXTERNAL COSTS OF TRANSPORT WITHIN LAND-SEA TRANSPORT CHAINS ON THE EXAMPLE OF ZACHODNIOPOMORSKIE VOIVODESHIP, POLAND

Summary. Land-sea transport chains constitute a key part of the Europe's economy, as a significant part of its trade is carried out using sea transport. Transport, storage, or delivery processes carried out within these chains are characterized by specified economic and technical efficiency, which often does not take into consideration the external costs these processes generate. Therefore, there is a need for further changes in the European land-sea transport chains, the aim of which should be a further reduction of the negative influence of transport on the society and the environment, in accordance with the assumptions adopted under the EU's sustainable development policy.

The article examines the land-sea freight transport chains in terms of the EU's sustainable development goals on the example of Zachodniopomorskie Voivodeship (ZV), Poland. The region was selected owing to two key factors. First, the transport chains across the region are typical for many European areas. Second, the region itself has experienced intensive development of the Transport, Shipping and Logistics (TSL) sector and a number of changes in freight flows for several years.

The main goal of the article was to identify the possibility of reducing external costs resulting from the use of combined transport solutions in ZV. Two case studies were analyzed for this purpose. In both of them, the assumed effect was the reduction of external costs of freight transport in ZV. The potential reduction of external costs generated by cargo transport in ZV was estimated on the basis of the European methodology in terms of the amount of external costs generated by individual modes and means of transport. The research showed that the implementation of combined transport in ZV can bring measurable benefits to the region. The analyses also allowed for the identification of technical and organizational activities that are crucial for ZV and make it possible to reduce negative transport effects.

1. INTRODUCTION

The transport system is a crucial socio-economic part of developing every region, country, and continent. Its shape and principles of operation depend on geographical location, demographic features, and position in the socio-economic system of countries and continents. In most regional transport systems, it is possible to distinguish the three following subsystems:

1. Inside subsystem – relating to movement of people and freight between locations in the region.
2. In-out subsystem – concerning movement of people and freight from locations in the region to other regions or the other way round.

3. Transit subsystem – involving movement of people and freight from drop-off locations to the pick-up points located outside the region using its transport infrastructure and the potential of the local Transport, Shipping and Logistics sector.

Transport of people or freight implemented within each of the subsystems is distinguished by particular characteristics. Some are specific only to transport in a particular subsystem, whereas some may be shared by two or three subsystems. The features of individual subsystems combined create a unique nature of a given regional transport system.

The regional transport systems constitute the subsystems of national and continental transport systems. They are shaped by typically functional features associated with satisfying transport needs [1], as well as their sustainable development, understood as minimizing the negative influence of transport on society and the environment. This approach, currently typical for the EU [2], is reflected in both scientific research and practical solutions implemented in transport systems, and its goal is to minimize the negative external effects of implemented transport processes.

When analyzing the regional transport systems in Europe, we should keep in mind that, according to data from 2013, 74% of goods imported and exported from the EU and 37% of the domestic trade is carried out through seaports [3]. Hence, seaports are key parts of numerous European transport corridors. Their importance in the EU transport system can be demonstrated by the fact that the total handling of the EU's seaports in 2017 exceeded 4 billion tons [4]. The Trans-European Transport Network (TEN-T) includes 329 seaports, most of which are part of the TEN-T Core Network Corridors and Ports [3]. A significant proportion of the European land-sea transport chains are grouped in these corridors, which run through most regions in the whole Europe and are an integral part of the regional transport systems. Zachodniopomorskie Voivodeship (ZV), Poland, is an example of such a region and serves as the research area.

The article presents the research on the freight transport system of ZV, with particular attention given to the land-sea transport chains. The literature mainly presents papers dealing with the problem of reducing external costs from a national or international perspective. This paper takes up the issue from the perspective of a given region, filling the literature gap.

The main goal of the article was to identify the possibility of reducing external costs resulting from the use of combined transport solutions in the region. For this purpose, we identified key activities that may reduce the negative effects of freight transport in the region in terms of sustainable development. Two case studies were analyzed: study I - launching the system of semitrailer rail transport from the Ferry Terminal in Świnoujście in ZV to the central and southern Poland as well as the Czech Republic and Hungary, and study II - launching the system of rail container transport from the ports of Gdynia and Gdańsk to the planned intermodal terminal in Dunikowo in ZV. In such cases, the assumed effect was the reduction of external costs of freight transport in ZV. The obtained results correspond to the assumptions of the EU's sustainable development policy.

2. RESEARCH PROCESS

The research process consisted of three main stages.

The first stage included a review of literature relevant for the subject of the study. It covered selected issues concerning transport systems; EU's policy on sustainable transport development, external transport costs, and their influence on the environment; organization of land-sea transport chains; and operation of transport systems at various levels ranging from international to regional or local levels.

The second stage involved an analysis of the freight transport system in ZV. At this stage, the characteristics of the transport system of the studied region were described taking into consideration the three sub-systems in its area, i.e. inside, in-out, and transit subsystems. At this stage, the key parts of the region's transport infrastructure used in freight transport were presented. This stage also characterized the land-sea transport chains of ZV. Statistics and the data obtained from the seaports as well as forwarding and transport companies operating in the region served to determine the specific features of the land-sea transport chains in the region, taking into consideration the freight distribution system according to load categories.

The third stage of the research process defined the technical and organizational activities, which are of crucial importance for the development of sustainable land-sea transport chains in ZV, and which may reduce the negative social and environmental effect of transport. Taking into consideration the identified activities and adopting the EU methodology in terms of the amount of external costs generated by individual modes and means of transport, we estimated a potential reduction in external costs, resulting from use of combined transport solutions in the region.

The research process was summarized by presenting conclusions.

3. SUSTAINABLE TRANSPORT DEVELOPMENT PURSUANT TO EU POLICY – LITERATURE REVIEW

Transport is currently one of the most important factors of human life and development of the society. It is essential to ensure people's mobility. It also serves as an economic development generator (it allows to conduct production activities, trade, and economic exchange, often also on a global scale). As pointed out by Saighani and Sommer [5], transport is an important basis for social participation and the prosperity of the population, which brings indisputable benefits.

However, transport that is indispensable for people is becoming a bigger threat to their health and life, as well as to the surrounding environment. The dynamic increase in demand for transport services translates into traffic congestion [6, 7], an increase in road accidents, land consumption [8, 9], as well as increase in noise and vibration [10, 11]. The growing demand for transport services also increases fuel consumption. In this respect, transport is identified as one of the most difficult sectors to decarbonize [12]. Internal Combustion Engine Vehicles (ICEV) dominate the market of transport services, thus dominating the use of fossil fuels, which puts the transport sector at the forefront of the production of harmful greenhouse gases, and the influences air pollution [13, 14]. Transport services are therefore associated with the emission of a great number of harmful substances, including NO_X, CO, CO_2, PM_{10}, and $PM_{2.5}$ [15, 16]. The external costs of transport are associated with the negative influence of transport activities on the environment and human life. They should be interpreted as costs of eliminating potential consequences of road accidents, noise, air, water, and soil pollution [17].

Climate change, attributed directly or indirectly to human activity, can be considered one of the greatest threats to the planet. According to available studies, it can be indicated that transport sector accounts for approximately a quarter of global greenhouse gas (GHG) emissions [18, 19]. It is alarming that this figure may continue to grow in the years to come [20].

Apart from analyzing the connection between transport and environmental changes, some studies also focus on its further effects, including the effect of global warming on the functioning of transport. As shown by Gelete and Gokcekus [21], extreme weather phenomena, such as floods, hurricanes, and temperature growth, can affect increased consumption of transport infrastructure and vehicles, as well as significant increase of cost related to the construction of building new parts of the transport system. Climate change may also periodically interfere with the provision of transport services. Regmi and Hanaoka [22] as well as Koetse and Rietveld [23] also confirm these findings.

In view of the above, it is important to pursue activities aimed at reducing the level of environmental degradation. The EU is strengthening its emphasis on measures aimed at reducing climate change [24], including reducing greenhouse gas emissions and increasing the share of renewable energy sources in the EU energy mix [25]. As pointed out by Pietrzak and Pietrzak [26], activities related to the implementation of a more restrictive transport policy play an important role in limiting these changes. This policy includes, e.g. long-term recommendations stipulated in the legal and postulative frameworks – White and Green Papers of the European Commission, including those concerning development of low-carbon and zero-emission transport. Furthermore, it is also important to pursue activities related to introducing emission standards and limits [27].

The EU's transport policy refers to the principles of sustainable development, multi-faceted integration, and shifting some of the freight and passenger flows toward means of transport with limited negative influence on the environment [28, 29]. This necessitates the development and implementation of concepts and solutions at European, national, and regional levels that will contribute to meeting these goals.

4. LAND-SEA FREIGHT TRANSPORT CHAINS IN ZACHODNIOPOMORSKIE VOIVODESHIP

4.1. Characteristics of Freight Transport System in Zachodniopomorskie Voivodeship

In ZV, as in most regions in Europe, we can distinguish three subsystems of the cargo transport system, i.e.: inside, in-out, and transit subsystems (Fig. 1).

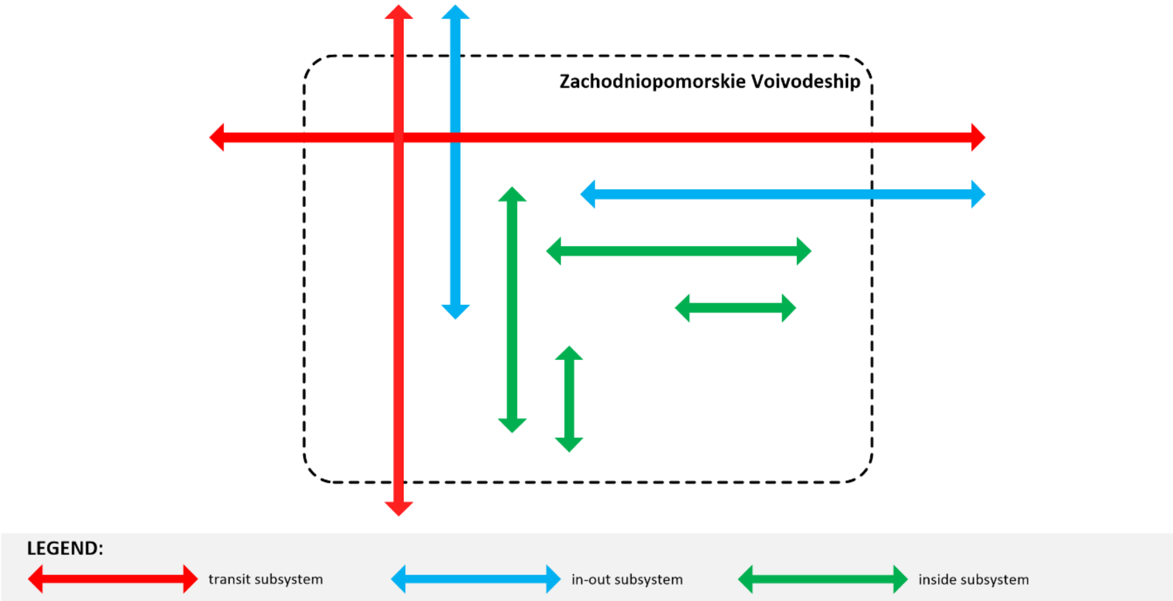

Fig. 1. Transport sub-systems included in the ZV transport system

Generally, the ZV inside subsystem mostly includes single-branch land transport chains using road transport. They include supply of wood from logging sites to sawmills or other processing plants, agricultural production from farmers to processing plants, food produced in the region to shops and markets, as well as construction materials for stores and construction sites. Rail and inland freight transport is not of significance in the inside transport subsystem of ZV, and is performed to a relatively small extent. The main technical elements necessary to provide transport in this subsystem include road transport infrastructure, loading and unloading locations for the road vehicles together with handling equipment and devices, as well as warehouses and road transport vehicles. The condition of the linear road infrastructure, ranging from municipal to international roads, is important for the efficiency of this type of transport. An interesting solution in ZV is the transport of aggregate down the Oder river from the Bielinek quarry to the port in Szczecin and further by road, through the aggregate handling terminal to clients within several dozen kilometers. The condition of linear and nodal transport infrastructure is significantly important for the efficiency of this type of transport.

As far as in-out subsystem is concerned, the freight transport can be divided into single and multi-branch land transport and multi-branch land-sea transport. In most cases, single-branch transport processes are carried out by road, and only few transports are performed by rail. In ZV, the examples of single-branch road transport chains include transport of Kronospan products to clients in Poland or Germany, goods from all over Poland to the Netto regional distribution center in Motaniec, or bulk deliveries to the Amazon logistics and distribution centers in Kołbaskowo and Zalando in Gryfino.

Under this subsystem, multi-branch land and land-sea freight transport processes can be divided into traditional and intermodal processes. Another division distinguishes the processes, in which means of transport are changed within the region and the processes, in which means of transport are changed outside the region. Land and land-sea transport processes in this subsystem are performed using road, rail, inland water, sea, and air transport. The necessary technical elements include branch transport infrastructure, points and transport nodes (seaports and an airport) together with handling facilities and equipment, warehouses, and means of transport.

The condition of the linear and nodal transport infrastructure as well as the equipment of transport hubs is important for the efficiency of this type of transport.

Within the framework of transit subsystem, the region implements a single- and multi-branch, land and land-sea freight transport processes. In ZV, the two main transit axes include Eastern-Western Europe (land transport) and Northern-Southern Europe (land-sea transport). These transports are performed in a traditional or intermodal arrangement. Another division distinguishes the processes, in which means of transport are changed within the region and the processes, in which means of transport are changed outside the region. Land and land-sea transport processes in the transit subsystem are performed using road, rail, inland, sea, and transmission transport. The necessary technical element include branch transport infrastructure, points and transport nodes (mainly seaports) together with handling facilities and equipment, warehouses, and means of transport. The condition of linear and nodal transport infrastructure as well as the equipment of transport nodes is important for the efficiency of this type of transport.

The transport infrastructure in ZV can be divided into the following core elements:

- Roads: A6 motorway, expressways: S3 (E65), S6, S10 and S11, national roads: 6, 10, 11, 20, 23, 26 and 31, and provincial roads,
- Railway lines: 273, 351 and 401 (E59 and CE59),
- The Oder from its mouth to the Oder-Havel Canal,
- Pomeranian Bay seawaterway - Szczecin,
- Seaports in Szczecin, Świnoujście, Police and Kołobrzeg,
- Szczecin Goleniów Airport, and
- Gas transmission pipelines connecting the LNG Terminal in Świnoujście with the Polish and Central European natural gas transmission system.

The aforementioned core elements of the linear and nodal infrastructure in ZV are supplemented by a local road network (commune and poviat roads), regional railway lines, and small seaports in Stepnica and Darłowo. In total, the region's infrastructure system makes it possible to perform freight transport under land and land-sea transport chains within the inside, in-out, and transit subsystems.

4.2. Characteristics of Land-Sea Freight Transport Chains in Zachodniopomorskie Voivodeship

Land-sea freight transport chains in ZV function as a part of the in-out and transit subsystems. From an organizational and technical standpoint, these chains are integrated, with part of the transport performed in a multimodal system, and part of the transport performed in an intermodal system. The seaports are the main integration nodes of the analyzed land transport chains. Fig. 2 presents three groups of ports, included in the land-sea freight transport chains constituting a part of the transport system of ZV.

Statistical data and classification from Eurostat and the Polish Central Statistical Office as well as the Regulation of the Minister of Infrastructure of 25 January 2010 on the registration form used in maritime transport were applied to describe land-sea transport chains in the region [30]. Changes in transport, handling, and storage techniques over the last 50 years have become the basis for Eurostat to introduce a new methodology for the analysis of land-sea freight turnover. This methodology distinguishes five type of cargo in land-sea turnover:

- liquid bulk goods,
- dry bulk goods,

– large containers,
– Ro-Ro mobile units, and
– other general cargo.

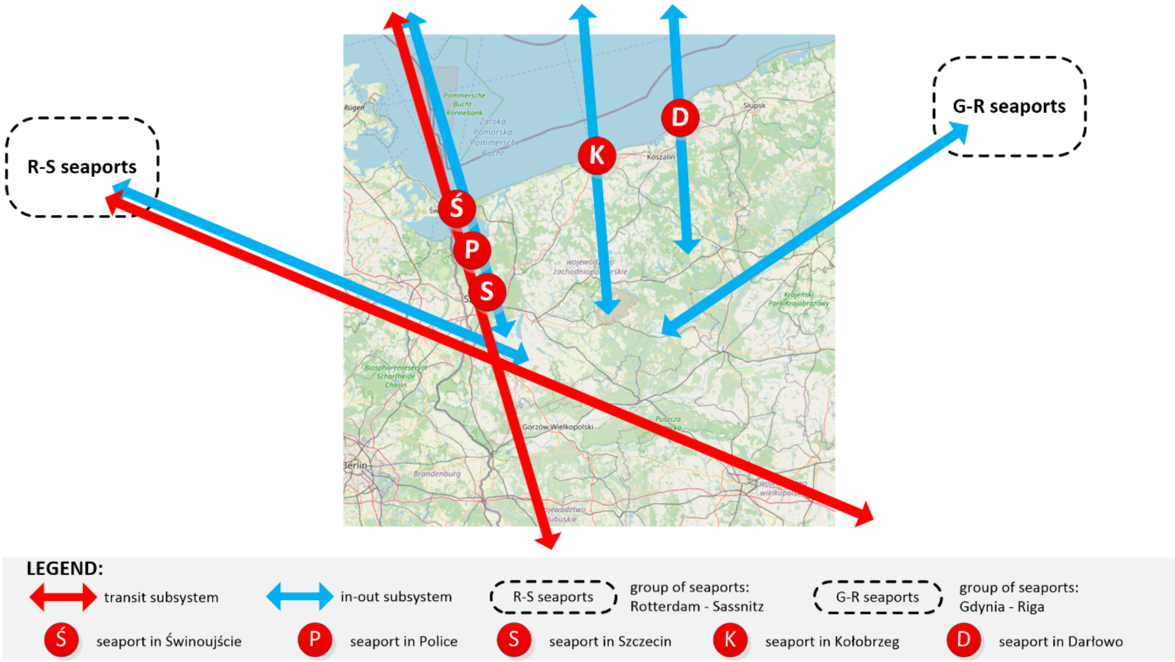

Fig. 2. Groups of seaports included in the land-sea transport chains within ZV

The freight division methodology in land-sea traffic adopted by the EU firstly takes into consideration the method of handling, storage, and transport of the cargo itself, recognizing its physicochemical features as of secondary importance. Thus, it is the technical and organizational side of the transport process that determines the classification of a given good in a particular cargo category. The adoption of this principle by the EU results from the containerization processes on the one hand and from the organization of transport processes on the other hand, in which various inter-branch integration techniques are used to increase the efficiency of land and land-sea transport chains. Hence, modern land-sea transport chains are of multimodal, intermodal, or combined nature [31].

The analyses of the land-sea transport chains of ZV contained data obtained from the Polish Central Statistical Office, the Szczecin and Świnoujście Seaports Authority, as well as the analyses and data of other ports are indicated in Figure 1. The interviews with freight forwarders and carriers operating in the region were also a source of information used in the analysis. Therefore, it was possible to determine the land-sea transport chains crucial for the regional transport system and indicate their core features. Table 1 presents the characteristics of land-sea transport chains in the studied region, using the classification of cargo distribution according to type of cargo.

In the case of ZV, land-sea transport chains are of multimodal and intermodal nature. These chains have a compact or dispersed form. Transit chains of bulk cargo - liquid and dry, have a primarily compact form. They relate to transport to/from the seaports of Szczecin, Świnoujście, and Police from/to Silesian industrial areas (mining and metallurgy), provided by rail transport in block trains using the following railway lines: 273, 351, and 401 (E59 and CE59).

Other land-sea transport chains in the region have a dispersed form, in which the land part of the transport is carried out by road. The North-South transit chains are composed of A6 and S3 road system, whereas the East-West transit chains are constituted by A6, S10, S6, and 10 roads. Owing to the dispersed form, the transport chains that begin or end in the region (in-out subsystem) use the roads of all classes, starting from motorway A6 and ending on communal roads.

The analysis of the characteristics of land-sea transport chains within ZV showed that the chains of combined nature using rail-road transport are not implemented. Hence, for the analyzed region in land-sea transport chains of intermodal nature, ITU (container, semitrailer, and swap body) are transported by road. It causes a number of negative phenomena connected with the external costs of transport. According to the Handbook on the External Costs of Transport [29], the road transport generates the highest external costs out of all transport modes. Thus, it needs to be stated that in the case of ZV, there is no sustainable development of land-sea transport chains at the moment, and the search for solutions aimed at reducing the level of external costs of freight transport is well justified.

Table 1

Characteristic features of selected land-sea transport chains within ZV. Current state

Type of cargo	Typical cargo / ITU	Character	Leading transport modes	Form	A group of ports	Subsystem
liquid bulk goods	LNG	multimodal	transmission and sea	compact	Region's seaports	Transit
	LPG	multimodal	road and sea	dispersed	Region's seaports	transit / in-out
	Petroleum products	multimodal	road and sea	dispersed	Region's / G-R seaports	transit / in-out
	chemical	multimodal	road and sea	dispersed	Region's / G-R seaports	transit / in-out
dry bulk goods	Coal	multimodal	rail and sea	compact	Region's seaports	Transit
	Iron ores and other ores	multimodal	rail and sea	compact	Region's seaports	Transit
	Grains	multimodal	road and sea	dispersed	Region's seaports	in-out
large containers	ISO container	intermodal	road and sea	compact	Region's / G-R / R-S seaports	transit / in-out
Ro-Ro mobile units	Truck / semi-trailer- trailer	intermodal	road and sea	dispersed	Region's / G-R / R-S seaports	transit / in-out
	Carriage	intermodal	rail and sea	compact	Region's seaports	Transit
other general cargo	Granite blocks	multimodal	road and sea	dispersed	Region's seaports	transit / in-out
	Cacao beans / coffee	multimodal	road and sea	dispersed	Region's seaports	transit / in-out
	Wood industry products	multimodal	road and sea	dispersed	Region's seaports	in-out
	Steel products	multimodal	rail and sea or inland and sea	compact / dispersed	Region's / G-R / R-S seaports	transit / in-out

5. EVALUATION OF A POSSIBILITY OF REDUCING EXTERNAL COSTS BY INTRODUCING COMBINED TRANSPORT IN LAND-SEA TRANSPORT CHAINS IN ZACHODNIOPOMORSKIE VOIVODESHIP

Sustainable transport aims at meeting society's mobility needs in a way that is least harmful to the environment and does not limit the mobility needs of future generations [32]. Thus, the technical and organizational solutions applied in transport systems should minimize the negative influence of transport on society and the environment, and be resource-efficient at the same time. It is possible to minimize the negative influence of transport on the environment through an appropriate use of a combination of economic, social, and environmental factors. This should help to maintain high efficiency of transport systems (economic factors) and reduce the external costs of transport generated in passenger and freight transport (social and environmental factors) [2, 33].

The key activities aimed at the development of sustainable land-sea transport chains in ZV should focus on building a combined transport system. In the short period of time (up to 5 years), the transport of large containers, semitrailers, and swap body (ITU) can be carried out by rail, and in the medium term (up to 15 years), it can also be performed by inland water.

In the short term, the key activities in the technical and organizational areas include the following:

1. Construction of an intermodal transport terminal in the port of Świnoujście and versatility of the intermodal terminal in the port of Szczecin. Annual freight handling and storage capacity of each terminal amounts to 200,000 TEU / ITU per annum.
2. Modernization of the whole Polish section of electrified railway lines E59 and CE59 in order to adapt it to ITU transport in selected combined transport techniques.
3. Construction of an intermodal/combined transport terminal in the special economic zone in Dunikowo, which is a part of the Szczecin Metropolitan Area (SMA). A new, gradually expanded intermodal terminal together with the zone will constitute a dry port with transport, logistics, and distribution and production functions.
4. Modernization of railway lines 202, 351, and 402 connecting Gdańsk-Gdynia seaports with SMA in order to adapt it to ITU transport in selected combined transport techniques.
5. The implementation of an innovative railway system - Light Freight Railway (LFR) in SMA (the assumptions of the LFR system and the possibilities of its application in ZV were investigated by Pietrzak and Pietrzak [28] and Montwiłł).
6. Establishment of a regional intermodal transport operator by one or several leading international forwarders, whose operations are not solely limited to land transport of containerized freight.

The key activities in the medium term include the following:

7. Upgrade of the Oder Waterway to the parameters of class IV according to the AGN Convention [34] concerning at least the inland port at Kędzierzyn Koźle.
8. Modernization (stage II) of the intermodal terminal in the port of Szczecin in order to adapt it for ITU freight loading onto/ from barges and sets of pushed barges.

The indicated key activities for the sustainable development of land-sea transport chains (1-8) may affect the reduction of negative social and environmental effects of transport, including accidents, congestion, fuel consumption, emissions, and environmental pollution. As a result, they can contribute to reduction of external costs generated in the process of transporting freight in ZV. What is important is that the implementation of freight transport in the combined transport system will not reduce their economic efficiency.

Two case studies were analyzed to achieve the research goal. Taking into consideration the selected key activities, each study estimates potential benefits in terms of reducing external costs generated by freight transport in ZV. The effects were estimated using the methodology included in the *Handbook on the External Costs of Transport. Version 2019 - 1.1.* [29] which concern the size of external costs generated by individual modes and means of transport, including all main negative externalities of transport:

- accidents,
- air pollution,
- climate change,
- noise,
- congestion,
- well-to-tank emissions,
- habitat damage, and
- other external cost categories (e.g. soil and water pollution).

According to this methodology, consistent with the EU's policy of sustainable transport development, the reduction of external costs amounts to 3.08 €-cent per 1 km of transport (4.2 €-cent/tkm-1.12 €-cent/tkm) due to the fact that 1 ton of freight was transported by rail instead of by Heavy Goods Vehicle (HGV) [29].

Case study I (covering activities: 1, 2, 6)

Goal – launching a system of semitrailer railway transport from the Sea Ferry Terminal in Świnoujście to the central and southern Poland as well as to the Czech Republic and Hungary. Between

2013 and 2018, the ro-ro cargo system handled 2,474,000 trucks (rolling freight), the majority of which were the sets of a trailer and a semi-trailer.

Effect – reduction of external costs of freight transport in ZV.

Effect estimates:

The data in the research process, obtained i.a. from the Ferry Terminal in Świnoujście [35], allowed to determine the reduction of external costs (per annum). This was due to shift of freight transport semitrailers from road to rail. The formula used for the calculation was as follows:

$$\mathbf{R_{EC}=n_{HGV}*d_{TS}}(\text{km})\mathbf{*w_{HGV}}(\text{t})\mathbf{*r_{EC}}(\text{€-cent/tkm}) \quad (1)$$

where: $\mathbf{R_{EC}}$ – reduction of external costs per year; $\mathbf{n_{HGV}}$ – the number of semitrailers shifted from road to rail on an annual basis; $\mathbf{d_{TS}}$ – road distance between the Ferry Terminal in Świnoujście and the village of Smolary - located at the southern border of ZV directly at expressway S3; $\mathbf{w_{HGV}}$ –average freight weight per one semitrailer calculated as a result of the division of the total freight turnover of the Ferry Base in Świnoujście between 2013 and 2018 by the number of trucks handled by the Base in land-sea relations having included railway carriages in the total turnover,

$\mathbf{r_{EC}}$ – unit reduction of external costs.

Table 2 presents three options of reducing external costs depending on the number of semitrailers shifted from road to rail.

Table 2

The level of reduction of external costs as a result of shifting semitrailers from road to rail *

d_{TS} (km)	w_{HGV} (t)	r_{EC} (€-cent/tkm)	n (pcs./per year)	R_{EC}-3% R_{EC} (€/per year)	R_{EC} (€/per year)	R_{EC} +3% R_{EC} (€/per year)
			50,000	3,352,087.2	3,455,760.0	3,559,432.8
170	13.2	3.08	100,000	6,704,174.4	6,911,520.0	7,118,865.6
			150,000	10,056,261.6	10,367,280.0	10,678,298.4

** the table presents the reduction of external costs taking into consideration the error, the margin of which was assumed at ± 3%.*

Case study II (covering activities: 3, 4, 6)

Goal – launching a system of rail container transport from the ports of Gdynia and Gdańsk to the intermodal terminal in Dunikowo (near Szczecin, the capital of ZV). At present, transport of containers from the aforementioned ports to the recipients in SMA is implemented by road in the technology of a dispersed system. The estimated annual volume is 120 - 150 thousand TEU (the data estimated on the basis of the interviews with representatives of the TSL sector –lack of statistical data from the Polish Central Statistical Office).

Effect – reduction of external costs of freight transport in ZV.

Effect estimates:

The data obtained in the research process allowed to determine the reduction of external costs (per annum). This was due to the fact that the transport of certain number of 20' containers (1Twenty Equivalent Unit - 1TEU) was shifted from road to rail. A single road transport allows to carry no more than 2 TEU, i.e. two 20' containers or one 40'/ 45' container. Therefore, a semi-trailer may carry: one 20'container (1 TEU)/ two 20' containers (2 TEU)/ one 40' container (2 TEU). Hence, the following formula was used to calculate the reduction of external costs:

$$\mathbf{R_{EC} = n_{TEU}*d_{TS}}(\text{km})\mathbf{*w_{TEU}}(\text{t})\mathbf{*r_{EC}}(\text{€-cent/tkm})\mathbf{*q} \quad (2)$$

where: $\mathbf{R_{EC}}$ – reduction of external costs per year; $\mathbf{n_{TEU}}$ – the number of TEUs transferred from road to rail on an annual basis; $\mathbf{d_{TS}}$ – road distance between the eastern border of ZV on road S6 and the planned intermodal terminal in Dunikowo; $\mathbf{w_{TEU}}$ – average freight weight per one 20'container (1 TEU) calculated on the basis of statistical data obtained from various European seaports, including both full and empty containers; $\mathbf{r_{EC}}$ – unit reduction of external costs; $\mathbf{q}$ – filling coefficient for 40' semi-trailer corresponding to the average number of TEUs on one semi-trailer, where **1** means the average of 1 TEU/semi-trailer and **0.5** means the average of 2 TEU/ semi-trailer.

Table 3 presents three options of reducing external costs depending on the number of containers (expressed in TEU) shifted from road to rail and the three levels of 40' semi-trailer's filling coefficient.

Table 3

The level of reduction of external costs as a result of changing mode of transport of containers from road to rail**

d_{TS} (km)	w_{TEU} (t)	r_{EC} (€-cent/tkm)	n (TEU/per year)	q	R_{EC} (€/ per year)	Q	R_{EC} (€/ per year)	q	R_{EC} (€/ per year)
211	10.5	3.08	10,000	0.6	409,424.4	0.7	477,661.8	0.8	545,899.2
			20,000		818,848.8		955,323.6		1,091,798.4
			30,000		1,228,273.2		1,432,985.4		1,637,697.6

*** adopting three different levels of semi-trailer's filling coefficient is necessary due to its fluctuations in time. This is because many recipients of freight placed in the container do not have container handling equipment, which means that in such cases only one 20' container is transported on 40'semi-trailer, which is unloaded without removing it from the semi-trailer.*

The results of the calculations presented in Tables 2 and 3 show the importance of all activities that aim at limiting the negative effects of transport on society and its environment in the ZV area. The studies have shown that the implementation of combined transport systems in regional land-sea transport chains can be an efficient solution to reduce the external costs of freight transport, and thus to implement the assumptions of the EU's sustainable development policy. The obtained results may form the basis for further research to be conducted in other regions of Europe.

Additionally, reducing the negative effects of regional transport may be supported by introducing innovative solutions in the field of rail transport, such as the LFR system [28, 36]. The authors are currently conducting research on the implementation of this solution in the ZV area.

6. DISCUSSION AND CONCLUSIONS

Transport, being one of the most important indicators of economic growth, is still one of the main sources of environmental pollution and global warming. One of the reasons is that car transport, dominant in the analyzed market, mainly uses Internal Combustion Engine Vehicles. Therefore, it is important to introduce effective changes in the organization of transport, so that freight is performed using more environmentally friendly modes.

The conducted research process allowed to characterize the transport system of ZV, Poland, together with an indication of land-sea transport chains. The goal of identifying the key activities that may reduce the negative effects of cargo transport in the region in terms of sustainable development was achieved. Some of the presented activities were used in the analysis of two case studies:

- case study I concerned launching of the system of semitrailer rail transport from the Ferry Terminal in Świnoujście to the central and southern Poland as well as the Czech Republic and Hungary.
- case study II concerned launching of the system of rail container transport from the ports of Gdynia and Gdańsk to the planned intermodal terminal in Dunikowo (near Szczecin, the capital of ZV).

Both case studies confirmed that the use of combined transport in ZV can considerably decrease the external costs generated when providing transport services.

The research results are consistent with the EU's transport policy, which refers to the principles of sustainable development, including those concerning development of low-carbon and zero-emission transport. The research methodology and results can be used to study the issue of transport systems in other EU regions.

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