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Pollution Emission Costs in Transport: A Comparative Analysis of Different Transport Modes

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Abstract:

Purpose: *The development of transportation is considered as one of the main elements of the economy development, but on the other hand its negative impact on the environment is noticeable. Based on the observation of the increase in demand for transport, more and more attention is paid to qualitative aspects. These include, among others, efficiency, safety, as well as the continuous efforts to reduce external costs, mainly related to the adverse impact on the environment. The aim of this paper is to calculate the emission of pollutants in road and inland waterway and to estimate the external costs of this emission on a selected route in Poland.*
Design/Methodology/Approach: *A simplified version of the estimation of external costs of air pollutants was carried out based on establishing external effects expressed in a quantitative form and assigning monetary values to them. Estimation of greenhouse gas emissions (CH4, CO2, N2O) from motor vehicles has been carried out using the COPERT IV program. For inland waterway transport, the emissions were estimated based on studies conducted by PLANCO (PLANCO Consulting GmbH, Germany).*
Findings: *The results presented in this article are a contribution to further research in this field, especially in relation to the currently carried out traffic surveys (GPR), as well as a basis for analysis of the management of transport systems and the implementation of modern technologies to improve environmental transport relations.*
Practical Implications: *This paper uses the method of calculating the quantity of pollutants emitted to the air from road transport and inland waterway on the route Gliwice - Szczecin, identifying the harmful substances influencing the natural environment and estimating the value of external costs of these pollutants emissions based on the quantity of polutants emitted by the means of transport used.*
Originality/value: *The paper develops an experimental method for determining the cost of emissions from transportation activities.*

Keywords: *Transport, environmental costs, external transport costs.*

JEL codes: *R41, R15.*

Paper type: *Research article.*

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1. Introduction

Transport plays a vital role in society and the economy. It affects the quality of life and development of countries. At the same time, it should be remembered that transport is the main source of negative environmental impacts and contributes to climate change, air pollution and noise. It also affects the land surface and contributes to urban sprawl, habitat fragmentation. The topic becomes important, as evidenced by the Nobel Prize Syukuro Manabe and Klaus Hasselmann awarded by the Nobel Committee in 2021 "for physically modelling the Earth's climate, quantifying variability and reliably predicting global warming" (The Nobel Prize 2021). Transport is the sector whose negative impact is increasing, in contrast to other sectors (Hong 2013).

However, the challenges faced by the sector, especially with regard to meeting the goals of the European Green Deal 2019, require not only a transport cost analysis, but also a cross-industry comparison and the definition of future strategic choices. Furthermore the development of international trade implies a strong increase in freight transport on a local, regional, national, international and global scale. This situation raises a whole range of problems and challenges related to the organisation of the flow of goods, especially taking into consideration the assumptions of transport policy, which is a part of the concept of sustainable development, reduction of external costs of transport and environmental protection (Kramarz, Dohn, Przybylska, and Knop 2020). This is the task we face when we consider the development of transport in Poland. One of the key activities is the more effective use of the inland waterways in transport. The aim of the paper is to calculate the amount of pollutant emissions in road transport and inland waterways and to estimate the external costs of this emission.

2. Effects of Transport Activities on the Natural Environment – Theoretical Background

In many ways, the development of modern transport and climate change go hand in hand. The technological innovations that have started new ways of travelling and shipping are the same technologies that have contributed to large-scale pollution of the planet (EPA 2021). Transport vehicles, cars, trains and steam-powered boats released large amounts of carbon dioxide into the atmosphere. These rising levels of carbon dioxide (Euchi and Kallel, 2021) generated a significant greenhouse effect that caused the planet to warm up at a much faster rate than before the industrial revolution. In 2017, the U.S. transportation sector generated the highest percentage of the country's greenhouse gas emissions 29%.

Globally, transport is thought to be responsible for 15-20% of emissions each year (EPA 2021). Motor vehicles are the main cause of air pollution, although other modes of transport such as airplanes (Daley, 2016) and ships (Oceana, 2021) generate higher emissions per trip per person. In the case of the EU, passenger cars, vans, trucks and buses generate more than 70% of total greenhouse gas emissions (CH_4, CO_2, N_2O) from transport (Eurostat 2020). The remainder comes mainly from sea and air transport. This means that transport is responsible for a significant part of the EU's greenhouse gas emissions. It is now responsible for more than a quarter of the EU's total greenhouse gas emissions (Eurostat 2021).

It should also be added that while most other sectors of the economy, such as energy and industry, have reduced their emissions since 1990, emissions from transport have increased. Reversing this trend is a key challenge in achieving the EU's climate protection goals (Green Deal, 2019). In addition, transport remains an important source of air pollution, especially in cities, and we are talking about particulate matter (PM) and nitrogen dioxide (NO_2) (EEA, 2020). Thanks to the introduction of fuel quality standards, emission standards and the use of cleaner technologies, air pollution from transport has decreased in the last decade. Unfortunately, these are not the levels that will allow you to achieve the goals of the European Green Deal 2019 and Sustainable and Smart Mobility Strategy - putting European transport on track for the future (2020).

Another serious environmental and health problem related to transport is noise (Meyer *et al.,* 2017). More than 100 million people in the EU Member States are affected by harmful noise levels. Moreover, transport and built-up infrastructure has a serious impact on congestion (Euchi and Kallel, 2021), and landscape changes (Hancock *et al.,* 2016). Each of the above elements are included in the group of factors generating external costs of transport, which cause material losses as well as psychological losses (Pawłowska, 2017; 2018; Burdzik. 2014). The "Handbook on the external costs of transport" (2019) distinguishes the following types of costs that make up the external costs of transport, i.e.:

- accident costs – accidents occur in all forms of traffic and result in substantial costs, consisting of two types of components: material costs (e.g., damages to vehicles, administrative costs and medical costs) and immaterial costs (e.g., shorter lifetimes, suffering, pain and sorrow),
- air pollution costs – health effects, crop losses, material and building damage, biodiversity loss,
- climate change costs - Transport results in emissions of CO_2, N2O and CH_4 (methane), all of which are greenhouse gases contributing to climate change,
- congestion costs - It is the result of mutual obstruction of traffic by vehicles as a result of limiting the speed of traffic and the breakdown of the fluidity of the flow,
- cost of well-to-tank emissions = costs of energy production,
- costs of habitat damage – area occupation,
- other external costs - Costs of soil and water pollution, Costs of up- and downstream emissions of vehicles and infrastructure, External costs in sensitive areas (e.g., mountainous regions).

Similar solutions regarding external costs are adopted in the literature on the subject (Fries and Hellweg, 2014; Petro and Konečný, 2017; Lier *et al.,* 2014; Caris *et al.,* 2014; Maibach *et al.,* 2008a; 2008b; Nocera, 2021; GUS, 2018).

Currently, over 262 million vehicles are registered in the European Union, of which almost 87% are passenger cars. In individual EU countries and within the EU, freight mass transport by road fluctuates between 80-87% of the freight mass annually. In 2020, freight transport by road (measured in tonnes) amounted to 89.2%, rail 8.3%, pipeline 2.0%, sea transport 0.3%, inland navigation 0.2% (GUS, 2021). Moreover, research carried out by the Central Statistical Office confirmed that in large cities the share of road transport in the total emission of pollutants is very high, reaching up to 90%. It should be remembered that road transport also includes hundreds of thousands of kilometres of roads and highways, which take up entire hectares of land, to which additional infrastructure must be added, such as parking lots or gas stations. Along the roads, in a strip of about 500 m, there are significant gas and dust pollutants, which contributes to the gradual degradation of soil and vegetation.

Reducing the negative effects of transport is an important EU policy objective. The main aspects of the activity are shifting transport to the least polluting and most efficient modes of transport, the use of more sustainable transport technologies, fuels and infrastructure, and ensuring that transport prices fully reflect the negative environmental and health impacts. On July 14, 2021, the European Commission adopted a package of legislative proposals to adapt the EU's climate, energy, transport and tax policies to meet the goal of reducing net greenhouse gas emissions by 2030 by at least 55%. compared to the 1990 level (Sustainable, 2021).

Achieving this goal in the next ten years is crucial for Europe to become the world's first climate neutral continent by 2050, thus making the European Green Deal (2019) and as agreed in the 2011 White Paper building the Single European Transport Area (SETA) a reality. The European Commission proposes targets to reduce carbon dioxide emissions from new passenger cars and vans:

- 55% reduction in passenger cars emission by 2030,
- 50% reduction in vans emission by 2030,
- zero emission from new passenger cars by 2035.

These goals are considered highly ambitious, especially in the context of the crisis caused by the COVID-19 pandemic. The effects of the pandemic in individual modes of transport, relatively high capital intensity of running a business in transport, as well as the existing restrictions and barriers in the implementation of innovative, pro-ecological solutions in transport, as well as limited availability of public funds - including EU funds - may result in significant difficulties in their implementation. For this reason, the activities have been strongly intensified - only in the years 2020-2021 the following have been implemented and it is planned to develop:

- Strategy for Sustainable and Smart Mobility to tackle emissions in the sector (December 2020);
- Promotion of less polluting modes of transport by exploring new ways to increase capacity on railways and inland waterways and presenting a revised Combined Transport Directive (2021);
- Actions on the role of the maritime, aviation and road transport sectors in the EU Emissions Trading System (2021);
- Reassessment of the ongoing revision of the Eurovignette Directive on road tolls (draft in the EU Council);
- Explore legislative options to increase the production and use of alternative fuels (from 2020) and revise the Alternative Fuels Infrastructure Directive (2021) and the TEN-T regulation, i.e., the Trans-European Transport Network (2021);
- Propose stricter air pollutant emission standards for vehicles with internal combustion engines and propose a revision of CO2 emission standards for passenger cars and vans (2021);
- Important role of digitization, in particular connected and automated mobility and intelligent traffic management systems.

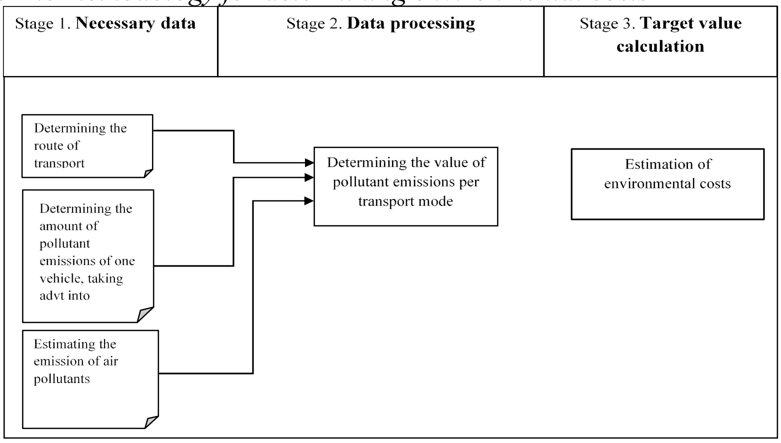
In Poland, the key document is the Strategy for Sustainable Transport Development until 2030, adopted in 2019 (Strategy 2019). It is part of the EU solutions and its main goal is to increase transport accessibility and improve the safety of road users and the efficiency of the transport sector by creating a coherent, sustainable, innovative and user-friendly transport system in the national, European and global dimension. Failure to achieve the set specific objectives may result in Atmoterm (2019):

- poor preparation of logistic nodes to provide intermodal services,
- failure to prepare inland waterways to take over some of the transport, which will result in the continued dominance of road transport,
- if the TEN-T network is not coherent and will have numerous bottlenecks in intermodal transport, the ports of the neighbouring countries of Germany, Russia and Lithuania will be more important, and in the east-west relation Slovakia and the Czech Republic in vehicle transport,
- East-West connections will continue to dominate, and the north and south of the country and Europe will not be connected.

3. Research Methodology

The determination of the costs of pollutant emissions in transport was made by comparing two modes of transport, road transport and inland waterways on the Gliwice - Szczecin route. The selected route is part of the Baltic-Adriatic transport corridor and is specific in terms of the use of inland waters in Poland for freight transport. In addition, this section is a key challenge for the European and national transport development strategy (Strategia, 2019). The tests took into account the load of 80 TEU units and the size and costs of pollutant emissions were compared for the compared branches. Figure 1 shows the methodology for determining environmental costs based on the bottom-up approach.

Figure 1. *The methodology for determining environmental costs*



Source: *Own work.*

The input data concern, on the one hand, the necessity to define the transport route and data concerning the load on the transport route for a given mode of transport. This burden mainly concerns road transport due to the high level of congestion in this mode of transport. On the other hand, air pollution indicators describing the amount of pollutants emitted to the air from motor vehicles should be taken into account, taking into account the analysed route, including nitrogen oxides NO_x, carbon dioxide CO_2, methane CH_4, nitrous oxide N_2O. Estimation of greenhouse gas emissions (CH_4, CO_2, N_2O) from motor vehicles was made using the databases of the COPERT IV system[3].

4. Results

In order to calculate the amount of pollutant emissions in road transport, the average daily annual traffic of vehicles on the Gliwice Port - Szczecin Port route was determined, taking into account the traffic intensity on the basis of general road traffic measurements[4].

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[3]*The data contained in the final report entitled Development of a methodology and estimation of external costs of air pollutant emissions from means of road transport at the national level. Szczecin 2018.*

[4]*Due to the COVID-19 pandemic and the introduction of the epidemic state in the country, road traffic measurements originally planned for March and May 2020 have not been carried out, and the deadline for their implementation on national roads has been postponed to the same period in 2021. Accordingly, the period for the development of GRT 2020 results has been extended. Data from 2015 were used for the analysis.*

Table 1. *Average daily annual traffic (adat) at measuring points in 2015*

No.	Road	Trucks (vehicles / day)		
		without trailer	with trailer	sum
1	E88 (11.1 km)	230	1560	1790
2	A4/E40(221 km)	1323	8735	10058
3	E65 (320 km)	522	2819	3341
4	A6 – S3 (11 km)	525	3197	3722
5	DK10 (11 km)	128	405	533

Source: *Own work.*

Then, the amount of air pollutant emissions from road transport was determined according to the types of vehicles and engine and the permissible total weight on the basis of the 2015 GRT. On this basis, the amount of pollutant emissions was determined for the Gliwice Port - Szczecin Port route, taking into account the average daily traffic of heavy goods vehicles, and finally the amount of pollutant emissions for the transport of 1 TEU unit was determined (Table 2).

Table 2. *Daily emission of pollutants for the Gliwice Port - Szczecin Port route for 1 TEU*

	Emission of pollutants (tonnes / 1 TEU)			
Details	**CH_4**	**CO_2**	**N_2O**	**NO_x**
Trucks for the Gliwice-Szczecin route (average - 3,889 TEU)	0.87	26,688.06	1.00	165.80
1 TEU	**0.00022**	**6.86245**	**0.00026**	**0.04263**

Source: *Own work.*

Estimation of external costs of air pollutants in a simplified version was carried out on the basis of determining the externalities expressed in quantitative form and assigning them monetary values. Using the Global Warming Potential (GWP) index, the amount of CH_4 and N_2O was converted into CO_2equivalent. The warming potential according to the IPCC [5]in case of CH_4 amounts 28, and in case of N_2O – 265. With regard to the emission of nitrogen oxides NO_x, each of them is characterized by a different harmfulness, which is the basic obstacle for the precise determination of the carbon dioxide equivalent.

Moreover, it is worth emphasizing that nitrogen oxides are not typical greenhouse gases. Their influence is described as indirect. The main negative effect of these compounds is the increase in air acidification. In terms of climate, nitrogen oxides have a twofold character. On the one hand, they can increase the absorbed energy, and on the other hand, they contribute to the decomposition of nitrous oxide, which reduces the influence of nitrogen compounds on the increase in global temperature.

[5]*Climate Change 2001: The Scientific Basis (on-line). Intergovernmental Panel on Climate Change, 2001.*

As a consequence, nitrogen oxides are not considered greenhouse gases and their GWP is rarely calculated. For the purposes of this study, based on the literature[6], the GWP conversion factor for nitrogen oxides was assumed to be 0.7. Taking into account the adopted assumptions, the amount of carbon dioxide emissions was determined, including its equivalent to other pollutants (Table 3).

Table 3. *The amount of CO_2 emissions with the equivalent for other pollutants for the Gliwice Port - Szczecin Port route for 1 TEU.*

Emission of CO_2 (ton /1 TEU)					
Details	**For CH_4**	**CO_2**	**For N_2O**	**For NO_x**	**Sum of CO_2**
Trucks for the Gliwice-Szczecin route (average - 3,889 TEU)	24.36	26,688.06	265	116.06	27093.48
1 TEU	**0.00616**	**6.86245**	**0.0689**	**0.029841**	**6.967351**

Source: *Own work.*

The values obtained were multiplied by the value of 1 ton of CO_2 2 (damage) amounting to € 61.29[7]. Ultimately, it was estimated that the transport of 1 TEU unit on the Gliwice Port - Szczecin Port route in road transport entails the value of € 427.03 in the cost of environmental emissions.

Taking into account transport by inland waterway, the possibilities of transporting containers on the Oder Waterway on the Gliwice Port - Szczecin Port route (814 km) were analysed assuming the transport of 20-foot 1CC containers. The average gross weight of this type of containers, converted into TEU units, is approx. 12.2 tons. Assuming an average weight of a container, a typical pushed train can carry around 80 containers. When transporting 2 layers of containers - the draught of the train is approx. T = 1 m. Pollution levels in relation to inland navigation based on PLANCO[8] are presented in Table 4.

To determine the amount of pollutant emissions[9] for 1 TEU, the load weight was calculated (when loading the BP 500 barge after conversion) for 80 containers (80 TEU) in a train, assuming a weight of 10 t for one TEU and assuming a half load, including the weight of empty containers at the level of 488 t (80 · 10 t · 0,5 = 400 t+88t - empty containers).

[6]*K. Prandecki, E. Gajos, Ekonomiczna wycena emisji wybranych substancji do powietrza w Polsce ze szczególnym uwzględnieniem rolnictwa. KNUV 2017; 3(53): 189-207*

[7]*According to the price of emission allowances, one tonne of carbon dioxide equivalent as of September 1, 2021.*

[8]*PLANCO Consulting GmbH. Verkehrswirtschaftlicher und Ökologischer Vergleich der Verkehrsträger Straße, Bahn und Wasserstraße. 2007. Available online: https://www.bafg.de/DE/08_Ref/U1/02_Projekte/05_ Verkehrstraeger/verkehrstraeger_lang.pdf?__blob=publicationFile*

[9]*No data available for the emission of nitrous oxide*

Table 4. *The amount of CO_2 emissions with the equivalent for other pollutants for the Gliwice Port - Szczecin Port route for 1 TEU.*

Pollution emission			
Details	**CH_4**	**CO_2**	**NO_x**
Inland navigation (t/tkm)	0.06	42.00	0.50
Pushed train vol. 80 TEU, distance: 814 km	0.02	16.68	0.20
Emissions of pollutants in relation to 1 TEU			
Gliwice - Szczecin route	**0.0003**	**0.2085**	**0.002**

Source: *Own work.*

Estimation of external costs of air pollution in relation to the transport of 1 TEU unit by inland navigation was carried out in a similar way to the determined costs in road transport. Taking into account the adopted assumptions, the amount of carbon dioxide emissions was determined, including its equivalent to other pollutants (Table 5).

Table 5. *The amount of CO_2 emissions with the equivalent for other pollutants for the Gliwice Port - Szczecin Port route for 1 TEU.*

Pollution emission				
Details	**For CH_4**	**CO_2**	**For NO_x**	**Sum**
Inland navigation (t/tkm)	1.68	42.00	0.35	44.03
Pushed train vol. 80 TEU, distance: 814 km	0.56	16.68	0.14	17.38
Emissions of pollutants in relation to 1 TEU				
Gliwice - Szczecin route	**0.0003**	**0.2085**	**0.0014**	**0.2102**

Source: *Own work.*

Ultimately, it was estimated that the transport of 1 TEU unit on the Gliwice Port - Szczecin Port route using inland navigation entails the value of €12.88 in the cost of environmental emissions. Due to the lack of data on the emission of N_2O pollutants in inland navigation, the analysis of pollution costs in road transport had to distinguish the same groups of pollutants (up to 6.89 t / 1 TEU), thus reducing the estimated costs of pollutant emissions to the value of € 422.81.

5. Discussion

Generally, it should be emphasized that road transport was and is an important element of the European integration process, closely related to the implementation of the common market of the European Union. Unfortunately, it significantly contributes to environment degradation and has a negative effect on human health. In this paper, calculations were made of the amount of pollutants emitted into the air by motor vehicles and inland navigation, as well as the estimation of external costs caused by these pollutants in relation to the selected route Gliwice Port - Szczecin Port was performed. On the basis of the obtained results, it should be clearly stated that the value of external costs of air pollution in road transport is over 32 times higher than the level of emission costs in inland waterways. Their level is respectively € 422.81 / 1 TEU for road transport and € 12.88 / 1 TEU for inland shipping. It should therefore be emphasized that the greatest environmental problems are caused by the large scale of activities of the broadly understood road transport, hence it should cease to play the main role in freight transport, becoming a means of delivery and transfer to points of transhipment for water and rail transport. The EU has high demands on it: by 2030 - 30%, and by 2050 - 50% of loads from long-distance road transport are to be taken over by rail and water transport. An important element here is also the connection of inland ports with the land transport network.

In terms of the length of the inland waterway network (over 3,500 km of operated waterways), Poland ranks fifth among the EU countries. At the same time, waterways of international importance are only 206 km, which is only 5.5% of the used waterways (Strategy 2019). If the goals and projects set out in EU and national documents are implemented, there is a chance for the development of multimodal transport, and thus for improving the value of external costs of transport. The developed methodology for calculating and estimating external costs of air pollution is experimental.

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