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Environmental Costs Generated by Road Freight Transport in Poland

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Abstract: The sector of transport, on the one hand, contributes to the socio-economic development; on the other hand, it is the source of multiple external effects with a significant and adverse impact on the society and economy. In spite of many years' experiences in the study of external costs of transport, there are still large discrepancies in research approaches and methods. This article reviewed available studies in the scope of the estimation of external costs in transport and presented own estimations of the level of costs of climate change and air pollution generated by road freight transport in Poland. The estimation of external costs was conducted based on a method developed by Martinio et al. The obtained results of the study confirm the significant adverse effect of road freight transport on the environment. The results may be useful in the selection of appropriate transport policy instruments.

Keywords: road freight transport, external costs, costs of climate change, air pollution

1. Introduction

Problems connected with the protection of the natural environment against the harmful impact of the economic activity carried out by humans is one of the most significant challenges of today. These issues pertain to the exploitation of natural resources, pollution of the environment, climate change, destruction of natural habitats of numerous plant and animal species, as well as risks to entire ecosystems (Radim et al. 2019). These changes also result in increasing threat to the safety of people, their well-being and health (Pawłowska 2018).

Already in 1990s, transport was recognised as one of the most cumbersome sectors of human activity. Unfortunately, this tendency continues. In the aspect of transport, on top of risks connected with disturbing the balance in ecosystems, there are also the issues of transport accidents and related material and human losses (Pawłowska 2017). In terms of policies, the problems mentioned above have been addressed through the concept of sustainability, which is present in most of the programming documents of the European Union, both on the level of the entire economy of the group and in sectoral programmes. The concept of sustainability of transport is a response to the failures of the transport policy of the second half of the 20th century. Unsustainable transport causes pollution of the natural environment, absorbs enormous amounts of energy, and the increase of investments in this sphere does not cause the expected improvement of the quality of provided services (Baran & Górecka 2019, Jacyna et al. 2018). The aim of this article is to review available studies in the scope of estimation of external costs in transport and to present the results of own estimations of the level of costs of the climate change and air pollution generated by road freight transport in Poland. The obtained results of the research may be useful in the selection of appropriate transport policy instruments.

2. Literature review

In Poland, transport is a very important sector of economy, which is demonstrated e.g. by its 7.8% share in the GDP (Quarterly national accounts…, GUS 2020). The development of the transport sector is very closely connected with the process of socio-economic development on a feed-back basis. Transport connects markets, allows production to be increased, activates regions surrounding its infrastructure (Koźlak 2012). Transport is also the source of many major external effects that are negative for the society and the economy, resulting in significant social costs. The external effects of transport refer to a situation in which the user of transport does not pay all the costs connected with the transport process (including environmental costs, costs of congestion or road accidents) or does not receive full benefits connected with them (EC 1995).

Most of all, transport uses vast areas for the development of transport infrastructure, both non-linear and linear one, as well as seriously pollutes the atmospheric air, water and soil. Furthermore, transport activity distorts the natural terrain and landscape, leading to defragmentation of the ecosystem; it damages the structure of the bedrock, destroys plants and threatens animals. Transport has an adverse effect on human organisms by causing risks to their health and life. Generally, we can differentiate four areas in transport in which external effects occur (Rothengater 2000, Gołębiowski et al. 2020). Firstly, the expansion of infrastructure may lead to both positive and negative external effects, which are not taken into account in market transactions. Secondly, users within the transport sector can affect each other, leading to unintended interactions rendering the sector ineffective. Thirdly, the financial structure of payments for the use of the infrastructure may prove falsified due to the unjust division of financial flows, i.e. tax-payers pay much more than the value of public services resulting from the functioning of the infrastructure, while private users pay less than the actual costs of using the infrastructure. The fourth area pertains to the fact that the activity carried out on or thanks to the transport infrastructure affects third parties from outside the transport sector, e.g. through noise, accidents, air pollution (Pawłowska 2018).

Apart from the above-mentioned categories, also significant are the costs of up- and downstream processes. This group of costs includes the costs of air pollution and climate change generated by the production of electricity and fuels for transport, costs of emissions connected with the production and maintenance of means of transport and transport infrastructure, and costs of managing waste generated by the transport activity (Burdzik et al. 2014).

Since the start of 1990s, the estimation and internalisation of external costs of transport have been important subjects of studies. In recent years, many studies under numerous research projects – both on a EU level and the level of individual EU countries – have been conducted with an aim to develop the methods of estimation of the external costs of transport. Table 1 presents a summary of major studies focusing on the costs of climate change and air pollution generated as a result of the activity of various branches of transport.

Table 1. Summary of studies and research in the scope of external costs of air pollution and climate change generated by transport

Year	Institution conducting the works/Authors	Branch of transport	Scope of research	Climate change	Air pollution
2018	UBA	road	Germany	+	+
2016	CE Delft	transport	EU 28	+	+
2015	Petruccelli U.	road, railway	UK, Italy, Germany	+	+
2014	Ricardo-AEA	all	EU	+	+
	Mindur L. et al.	road, railway	Poland	+	+
	Huderek-Głapska S.	all	EU	+	+
2012	Trela M.	road	Poland		+
	Poliński J.	road, railway	Poland	+	+
	Becker J. et al.	road	UE 27		+
2011	European Commission	all	EU	+	+
	HEIMTSA	road, railway	EU		+
	CE Delft, INFRAS, Frauhafner, Delft JSI	all	EU	+	+
2010	Martinio A. et al.	all	EU	+	+
	NERI	road	EU		+
	Victoria Transport Policy Institute	road	EU	+	+

Table 1. cont.

Year	Institution conducting the works/Authors	Branch of transport	Scope of research	Climate change	Air pollution
2008	CE Delft (IMPACT)	all	EU	+	+
	CE Delft (OECD)	all	EU	+	+
	Fondazione Eni Enrico Mattei	road, railway, sea, air	Italy	+	+
	Leeds University (GREACE)	all	UE 25	+	+
	LEBER/INFRAS	road, railway	Basque Country	+	+
2005	WHO	all	EU		+
	Bickel P. et al. (HEATCO)	road, railway	UE 25		+
2004	Van Essen H.P. et al.	road, railway, air	UE 15		+
	CE Delft	all	Netherlands	+	+
2004/ 2000	INFRAS/IWW	all	EU 15, Norway, Switzerland	+	+
2002	Leeds University (UNITE)	road, urban rail, water, air	EU 15, Hungary, Estonia, Switzerland	+	+
2001	Weinreich S. et al. (RECORDIT)	all	3 European corridors	+	+
	COWI	road, railway	Estonia	+	+
	Leeds University (CAPRI)	road, railway, air	EU	+	+
	Boiteux Report	road, railway	France	+	+
	Commission of the European Communities	all	EU	+	+
2000	Nash C. et al. (PETS)	road, railway, air	EU	+	+
	INFRAS/IWW	all	EU	+	+
	Experts assuming advisory roles of the High Level Group for charging for the transport infra-structure	road, railway	EU		+
	KBN	road, railway	Poland	+	+
1998	Sansom T. et al. (ITS)	road, railway	UK	+	+
	ECTM	road, railway	EU 15, Norway, Switzerland	+	+
1992	European Commission	all	EU	+	+
	European Commission	all	EU	+	+

Source: Zych-Lewandowska et al. 2020

3. Aim, materials and methods

The aim of the article was to estimate the level of costs of climate change and air pollution generated by road freight transport in Poland, using the method proposed by Martinio et al. (2009). It has been found that the method of Martinio et al. (2009) is the most appropriate approach to the estimation of external effects, standing out against the previously published proposals (cf. Table 1). This document was ordered by the EU Committee on Transport and developed by TRT Transporti e Territorio, a company specialising in research projects in the scope of economics and transport, including: planning, modelling, quantitative analyses and economic evaluation of transport. The work of Martinio et al. (2009) summarises research available at the time in the scope of the analysis of external costs of transport and, additionally, the manual IMPACT (*Maibach* et al. 2008) and the transport package of the European Commission (Green Transport Package 2008).

The basic assumption of the applied method of Martinio et al. (2009) is the division of external costs into six groups: accidents, climate change, air pollution, noise, congestion, other (Table 2). In terms of research, this article focuses on an analysis of external costs connected with the environment, i.e. costs of air pollution and climate change generated by road freight transport.

The research facility was selected on purpose. The research concerned the sector of road freight transport. The choice was affected by the fact that road transport in Poland in 2018 performed 85.5% of the total shipping work. The research covered the period 2005-2016. The scope of research started in 2005 due to Poland's accession to the European Union and the necessity for state agencies to collect statistical data necessary for conducting this research. The source material for the study was data from Statistics Poland and the National Emissions Balancing and Management Centre.

Table 2. Division of external effects into groups in line with the recommendations of the EU Committee on Transport

External effect	Cost components	Basic factors influence on cost
accidents	– material losses, – administrative costs, – medical costs, – production losses, – risk value,	– kind/characteristics/maintenance of vehicles, – speed of vehicles, – traffic, – time of day, – weather conditions, – deployment of infrastructure, its technology and maintenance,
air pollution	– costs of human health, – costs of material losses, – crop losses,	– population density and settlement density, – density of receptors close to emission sources, – sensitivity of the area, – level of emissions,

Table 2. cont.

External effect	Cost components	Basic factors influence on cost
climate change	– costs of prevention aimed at reducing the risk of climate change, – costs of losses caused by the increase of temperature,	– kind of vehicle and its equipment, – speed, – driving style, – fuel consumption and carbon content in the fuel,
congestion	congestion: – costs of time, – operational costs, deficiency: – costs of delays, – costs of lost opportunities,	congestion: – kind of infrastructure, – traffic intensity and capacity depending most of all on the time of day, place, accidents and the kind of structure of the infrastructure, deficiency: – kind of infrastructure, – level of traffic and capacity depending most of all on the time of day and place,
noise	– nuisance, – medical costs,	– time of day, – density of receptors close to emission sources, – existing noise levels,

Source: Martinio et al. 2009

4. Research results

According to Martinio et al. (2009), climate change, also referred to as the global warming, means "a change in the concentration of greenhouse gases causing a gradual warming at the surface of the Earth, mainly due to human activity." According to the study, the costs of climate change include: costs of losses in agricultural production, changes in the availability of water resources and the rise in the sea level, health effects, increase in transport emissions, and costs of coal use.

According to Maibach et al. (2008), the level of external costs of climate change is proportional to the volume of freight and fuel consumption, and is estimated based on the amount of CO_2 emissions. These emissions depend on: the type of vehicle and its equipment, characteristics of emissions depending on the speed of the vehicle, driving style, fuel consumption and type of vehicle.

In the EU countries, transport accounted for 33.4% of CO_2 emission (Statistical Pocketbook 2020). Aside from the listed variables affecting this value, it can be concluded that it also depends on the location. According to Gradziuk and Gradziuk (2016), in the territory of the analysed rural municipalities, transport accounted for 47% of CO_2 emission, i.e. much more than the European average, as the location where transport takes place has a direct effect on the above-listed properties, most of all on the driving style.

Martinio et al. (2009) presented suitable indicators for the estimation of the external costs of climate change caused by heavy goods vehicles transporting freight (Table 3). As part of the research, the external costs of climate change caused by road transport were estimated. Data from Table 4 was used, which included the volume of freights in consecutive years, which was then multiplied by appropriate indicators from Table 3. Calculation results are presented in Table 5. Due to the availability of data, the costs were aggregated to average values by dividing them into freight areas.

The costs of climate change in Poland caused by road freight transport, after an initial growing trend in 2008-2011, levelled off at the about PLN 2.5 bn a year (Table 5). These costs varied depending on the place of carriage, i.e. whether within a city, outside a city or on a motorway. In the studied period, the average cost of climate change caused by road transport on motorways was PLN 170 m, and was the lowest in comparison with other roads; its growth dynamics, however, was the largest. The highest costs were caused by inter-city transport, conducted not on motorways but on other roads, which were used for transporting the most goods. The level of costs of climate change on other roads reached on average PLN 1.5 bn annually. This was mainly caused by the lack of an appropriate number of express roads. Furthermore, the external cost of one vehicle-kilometre is higher on other roads than on motorways due to, e.g. a different driving mode (fewer instances of slowing down, accelerating and stopping at junctions, etc.), but also a closer proximity of human settlements, which can be directly affected by air pollution. In urban areas in Poland, the level of generated external costs of climate change can be deemed average compared with other analysed areas (it amounted to about PLN 750 m).

Air pollution is mostly made up of the emission of: nitric oxides, non-methane volatile organic compounds (NMVOCs), sulphur dioxides as well as $PM_{2.5}$ and PM_{10} particulate matter. Other pollutants include: carbon monoxide, ammonia, heavy metals (cadmium, mercury, lead, arsenic, chromium, zinc, copper, nickel), persistent organic pollutants (POP: dioxins, furans and polychlorinated biphenyls, hexachlorobenzene, benzo(a)pyrene and polycyclic aromatic hydrocarbon (PAH)), as well as total dust (TSP, which also contains $PM_{2.5}$ and PM_{10}) and carbon black dust. A detailed analysis in the case of road transport focused on the first group of compounds considered by Martinio et al. (2009) as the most significant one.

The main factors affecting the emission of pollutants by transport include: fuel composition, engine characteristics and maintenance, kind and basic characteristics of the vehicle, distribution of transport infrastructure, speed, congestion. The basis for the analysis of the external costs of air pollution by road transport were the multipliers recommended by the EU (Table 6).

Table 3. Indicators for the estimation of the external costs of CO_2 emissions for heavy goods vehicles in road transport divided into transport areas, mass of the vehicle and fulfilled fuel consumption standard

Mass of vehicle	EURO standard	Value of indicators by area [euro cent/ vehicle-kilometre]				
		metropolitan	city	inter-city	motorways	average
< 7.5 t	EURO 0	1.3	1.3	1.2	1.2	1.2
	EURO 1	1.1	1.1	1.0	1.0	1.0
	EURO 2	1.1	1.1	1.0	1.0	1.0
	EURO 3	1.1	1.1	1.1	1.1	1.1
	EURO 4	1.1	1.1	1.0	1.0	1.0
	EURO 5	1.1	1.1	1.0	1.0	1.0
7.5-16 t	EURO 0	2.0	2.0	1.8	1.7	1.7
	EURO 1	1.8	1.7	1.6	1.5	1.5
	EURO 2	1.7	1.7	1.5	1.4	1.5
	EURO 3	1.8	1.8	1.6	1.5	1.5
	EURO 4	1.6	1.6	1.5	1.4	1.4
	EURO 5	1.7	1.7	1.5	1.4	1.4
16-32 t	EURO 0	2.0	2.0	1.8	1.7	1.7
	EURO 1	1.8	1.8	1.6	1.5	1.5
	EURO 2	1.7	1.7	1.5	1.4	1.4
	EURO 3	1.8	1.8	1.6	1.5	1.5
	EURO 4	1.6	1.6	1.5	1.4	1.4
	EURO 5	1.7	1.7	1.5	1.4	1.4
> 32 t	EURO 0	2.9	2.9	2.5	2.3	2.3
	EURO 1	2.6	2.6	2.2	2.0	2.0
	EURO 2	2.5	2.5	2.2	2.0	2.0
	EURO 3	2.6	2.6	2.2	2.0	2.0
	EURO 4	2.4	2.4	2.1	1.9	1.9
	EURO 5	2.5	2.4	2.1	1.9	1.9

Source: Maibach et al. 2008

Table 4. Traffic in freight transport in Poland in the years 2008-2015

Type of road	Level of road freight traffic in years [millions of vehicle-kilometres]							
	2008	2009	2010	2011	2012	2013	2014	2015
Motorways	1,577	2,320	2,765	2,917	2,892	2,962	2,982*	2,986*
City roads	8,639	8,671	9,761	10,215	10,090	10,269	10,524	1,010
Other roads	19,527	18,832	21,112	22,067	21,760	22,115	21,999*	21,763*

* Data estimated based on data from Statistics Poland from corresponding years.
Source: own study based on data from Statistics Poland

Table 5. External costs of climate change caused by road freight transport in Poland in 2008-2015 divided into areas of transport

Type of road	External costs of climate change (PLN m) in given years:								Dynamics 2008/2015 (%)
	2008	2009	2010	2011	2012	2013	2014	2015	
Motor-ways	103	151	181	190	188	193	194	194	128
City roads	673	676	761	796	786	800	820	843	124
Other roads	1,354	1,305	1,463	1,530	1,508	1,533	1,525	1,509	115
Total	2,130	2,132	2,405	2,516	2,482	2,526	2,539	2,546	119

Source: own study

Table 6. Values recommended for the estimation of the costs of air pollution caused by transport

Specification	Values of indicators for pollutants [EUR/tonne]								
Pollutant	NO_x	NMVOCs	SO_2	$PM_{2.5}$			PM_{10}		
Context	N/A	N/A	N/A	Metropolitan area	Urban area	Non-built up area	Metropolitan area	Urban area	Non-built up area
Multiplier	3,900	600	5,600	174,500	56,000	52,400	69,800	22,400	20,900

Source: Martinio et al. 2009

The estimation of the level of the external costs of pollution in transport in Poland used the data of the National Centre for Emissions Management (KOBiZE), which concerned the amounts of emission of compounds broken into individual branches of economy. The amounts of pollution emitted by road freight transport in consecutive years and the external costs of this emission are presented in Table 7 and 8.

Total emissions of road freight transport in 2016, respectively: NO_x: about 150 k tonnes; NMVOCs: about 12 k tonnes; $PM_{2.5}$ and PM_{10}: about 5 k tonnes; SO_x: about 0.12 tonnes (Table 7). Road transport is an insignificant emitter of sulphur oxide, because the combustion of diesel and petrol fuel produce only trace amounts of sulphur. The conducted analyses confirm the downward trend in the emission of pollutants in road transport in the years 2005-2016, both in terms of volume and generated external costs. However, in 2016 there was a noticeable increase in the emission of the compounds in question. According to the National Centre for Emissions Management, it resulted from an increased amount of fuel consumed by road transport.

Table 7. Emissions of SO_x, NO_x, NMVOCs, $PM_{2.5}$ and PM_{10} caused by road freight transport in 2005-2016 in Poland

Year	Emission of a compound in given years [tonnes]				
	NO_x	NMVOCs	SO_x	$PM_{2.5}$	PM_{10}
2005	146,315.68	18,134.81	0.10	6,399.46	6,399.46
2006	162,252.54	20,548.24	0.10	7,225.93	7,225.93
2007	178,109.03	20,477.62	0.11	7,663.32	7,663.32
2008	168,503.95	17,969.19	0.11	6,830.44	6,830.44
2009	172,530.34	18,417.27	0.12	7,023.98	7,023.98
2010	168,313.28	15,629.97	0.12	6,237.34	6,237.34
2011	169,146.54	14,715.14	0.12	5,987.20	5,987.20
2012	155,500.96	13,774.20	0.11	5,480.27	5,480.27
2013	133,487.70	11,886.67	0.10	4,541.05	4,541.05
2014	131,159.97	11,077.65	0.10	4,305.54	4,305.54
2015	126,585.68	10,237.45	0.11	3,982.07	3,982.07
2016	148,022.24	11,692.65	0.12	4,669.48	4,669.48
Dynamics 2016/2005	101%	64%	120%	73%	73%

Source: own study based on KOBiZE

Table 8. External costs of the emission of compounds by road freight transport in 2005-2016 (PLN m)

Year	External costs of the emission of compounds by road freight transport (PLN m)						Unit costs PLN/ tkm
	NO_x	NMVOCs	SO_x	$PM_{2.5}$	PM_{10}	Total	
2005	2,459.42	46.90	0.38	2,600.95	1,039.83	6,147.10	0.051
2006	2,727.30	53.14	0.35	2,936.86	1,174.12	6,891.42	0.050
2007	2,993.83	52.96	0.35	3,114.62	1,245.19	7,406.61	0.046
2008	2,832.38	46.47	0.30	2,776.12	1,109.86	6,764.83	0.039
2009	2,900.06	47.63	0.29	2,854.78	1,141.31	6,943.78	0.036
2010	2,829.18	40.42	0.27	2,535.06	1,013.49	6,418.15	0.030
2011	2,843.18	38.05	0.28	2,433.40	972.84	6,287.48	0.028
2012	2,613.82	35.62	0.26	2,227.36	890.47	5,767.28	0.025
2013	2,243.79	30.74	0.24	1,845.63	737.86	4,858.03	0.019
2014	2,204.67	28.65	0.21	1,749.91	699.59	4,682.82	0.018
2015	2,127.78	26.47	0.20	1,618.45	647.03	4,419.74	0.016
2016	2,488.11	30.24	0.20	1,897.83	758.73	5,174.91	0.017
Dynamics 2016/2005	101%	64%	53%	73%	73%	84%	33%

Source: own study

A significant element of the analysis is the estimation of not only total emissions, but also unit emissions, i.e. expressed as tonne-kilometres, because only such approach presents the real level of the impact of road transport on the environment and allows it to be compared with other branches. Unit external costs of air pollution generated by road freight transport decreased year after year (Table 8). This trend continued, even though the volumes of freight in Poland increased each year. It may mean that the quality of the means of transport improved. In the case of road transport, it would be a constantly increasing share of newer vehicles, meeting the more and more restrictive engine standards. However, an analysis of the age of heavy goods vehicles does not confirm that, instead pointing to the ageing of the HGV fleet (Statistics Poland 2016). Therefore, the decrease of emissions in road transport must have been caused not by changes in the fleet of vehicles, but rather in the infrastructure. The increase of the length of express roads and motorways in Poland in the period from 2005 to 2016 was significant (motorways from 552 km to 1,637 km – increase by almost 300%; express roads from 258 km to 1,534 km – increase by almost 600%). Since the level of fuel consumption – and, consequently, the emission of pollutants – is directly affected by the traffic flow, then the expansion of the network of express roads could have been the cause of the decrease in the unit emissions of pollutants in road transport.

5. Conclusions

The achievement of sustainable transport development appears as the main priority of the transport policy in today's world. The EU has caused the development of specific methodological assumptions in the scope of the estimation of the external costs of transport, which may support further steps of internalisation of external costs and reform of transport charges. However, it is not possible to precisely identify the structure of the external costs of transport and to estimate their values as a function of time, because, on the one hand, the estimates of the external costs of transport entail a large error margin, and on the other hand there is a lack of access to required data which could be used for estimation. However, some methods of estimation of these costs can deliver estimated values of costs. In Poland, there are few publications and studies of the full estimate of the external costs of transport. In consideration of the above, and assuming that the analysis of external costs may become a significant element of transport costs, and, consequently, of logistics in the areas of deliveries, production and distribution, this article presented an estimation of external environmental costs of road freight transport.

Road transport accounts significant percentage of total emissions of harmful compounds. The results of the conducted studies, when compared to the previous research of the authors (Zych-Lewandowska et al. 2020, Zych-

Lewandowska 2020), demonstrate that, in terms of the emissions of SO_x, NO_x, NMVOCs, $PM_{2.5}$ and PM_{10}, road transport is in a much worse position than rail transport. This means that rail transport has a decisively less adverse effect on human health and natural environment than road transport.

In order to reduce the adverse external effects of road transport, various actions are undertaken. For the purpose of reducing the emission of harmful gases and particulate matter, exhaust emission standards (EURO) are introduced for new vehicles sold in the European Union (Merkisz et al. 2012). Furthermore, the automotive market presents new technologies for powering vehicles with alternative fuels, which have a smaller impact on the environment. Electric vehicles are introduced as well. Currently, they are not a popular choice due to their limited performance, range, charging time and, most of all, high costs of production of such cars as well as the necessity to adjust the infrastructure to them. However, the BEV (Battery Electric Vehicle) technology is the most discussed concept, which gives hope for the reduction of emissions of harmful pollutants to the environment.

The prevailing unfavourable branch structure of shipping, which is decisively dominated by road transport with its still growing share in shipping, impedes the achievement of the desired effects of actions taken. In addition, the continuing growing trends in the transport of passengers and goods result in the effects of actions taken being largely countered by the increased carriage work of both the goods and passenger transport.

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