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A comparative analysis of road and rail freight transport through the Republic of Serbia from the aspect of external costs

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Abstract: Transport causes significant external effects that have a very harmful impact on the environment, human health, but also the economy. The costs of these external effects are not borne directly by those who caused them, but by other road users (congestion, accidents) and society as a whole (environmental pollution costs). This results in making wrong decisions in the transport market, which further leads to an inefficient use of available resources and loss of social welfare. The purpose of this paper is a comparative analysis of negative external costs arising from freight road and rail transport. The main goal of the paper is to quantify the external costs caused by two different modes of freight transport, based on the characteristics of the transport vehicles and the characteristics of the goods being transported, as well as the length of the goods transport. The road and rail freight transport through Serbia will be chosen as the case study.

Keywords: External costs; Internalisation; Modes of transport

I. INTRODUCTION

Transport significantly contributes to economic growth and market development, but in most cases, some transport modes have not only positive but also very negative effects on society itself [1]. The activity of transport results in negative external effects such as emissions, noise, congestion and infrastructural wear and tear [2]. The costs of these negative effects of transport are generally not borne by transport users, and are therefore not taken into account when deciding on the choice of transport mode. External costs are incurred by social and economic activities, in this case transport, of one group of persons, so that they are reimbursed by another group of persons, which appear as users, direct or indirect, of performed activities, i.e. transport services of the first group of persons.

In order to correctly define external costs, it is first necessary to make a difference between social and private costs. Social costs reflect all costs incurred due to the provision and use of transport infrastructure (costs of wear and tear of infrastructure, capital costs, congestion costs, costs of traffic accidents, etc.). Private costs originate directly from transport users (vehicle maintenance and energy costs, vehicle use costs, transport tariffs, taxes, fees, etc.)

The total external transport costs of the European Union countries by transport modes for 2019 amount to a total of 987 billion euros [3]. The largest part of these costs, 83%, goes to road transport, while other transport modes cost significantly less, 10% for sea, 5% for air, 1.8% for rail and only 0.3% for inland waterway transport. External costs, for 2019, incurred by transport activities were allocated to passenger transport in the amount of €625.2 billion and to freight transport in the amount of €195.1 billion. In addition, external transport costs account for a total of 5.7% of GDP (gross domestic product) in the European Union, i.e. 4.3% of passenger transport and 1.4% of freight transport [3]. The highest external transport costs, expressed in billions of euros, are in Germany, Italy, France, Great Britain and Spain, and the lowest in Slovenia, Latvia, Estonia, Cyprus and Malta.

The issue of external effects of transport in the Republic of Serbia is extremely complex, primarily due to lack of funds, regulatory mechanisms, ethics, environmental culture, etc. Despite the complexity of the problem, there are a number of reasons to solve it. Bearing in mind that external transport costs are difficult to define, quantify, and charge through certain economic mechanisms, the theory and practice in Serbia draw on the European experience which shows that economic, environmental and

transport policies are integrated to solve the problem of external transport costs.

Emissions of pollutants in the Republic of Serbia for the period from 1990 to 2018, in terms of types of pollutants, were decreasing from year to year, although this reduction was initially faster and more intense, while for the period from 2015 to 2018 one could say that the percentage of pollutant emissions was more or less stagnant, and that it was in balance, without a tendency to decline significantly [4].

In the freight transport of the Republic of Serbia, road transport dominates when it comes to external costs in all categories. External costs of road transport caused by traffic accidents and air pollution are many times higher than for other transport modes.

The internalisation of external costs using market-based instruments is considered a very effective way to limit the negative effects of transport. Transport users will certainly alter their behaviour in the form of changes in vehicle type, transport vehicle, transport mode, etc., when they can benefit from it.

The aim of this paper is to quantify and perform a comparative analysis of the external costs of road and rail freight transport from the perspective of air pollution and accidents on a practical example in the Republic of Serbia.

II. LITERATURE REVIEW

Based on the research in scientific databases, various techniques and procedures are used to calculate external costs separately for all transport modes from well-known different negative influences (air pollution, accidents, noise, climate change, etc.).

Transport costs are often analysed by different macro and micro economic models, but detailed cost calculations within transport companies are difficult to publish although this information is necessary to control transport operations. Traditional and improved costing approaches can be implemented in transport management. The principle of multistage allocation of total costs was adjusted to the specific characteristics of the transport used in the practical example in [5]. The model in [6] was developed for predicting the volume of railway transport that can be applied in different economic contexts and used as a means of transport planning.

In paper [7], the authors dealt with the creation and application of the calculator of external costs of transport services as an extension, i.e. emission calculator for transport services. Manufacturing and trading companies require carriers to report the environmental impact of their activities. Areas of concern are emission factors used to calculate emissions and aggregate them. The STN EN 16258 standard was used, which deals with the methodology of calculation and declaration of energy consumption and greenhouse gas emissions from transport services due to the fact that the existing emission calculators do not allow the calculation of external costs of transport services in the field of environmental transport services.

A large number of negative externalities are associated with freight transport. Paper [8] applied a quantitative model that explores and analyses the scenario of a coordinated EU approach to internalise the external transport costs of trade activities outside the EU. The results show a positive effect on real GDP and employment in the EU, provided that revenues from these trade charges are recycled back into the economy. The analysis identified policy options that ensure that transport prices reflect social costs. Several approaches are used to reduce external costs, such as prohibitions, regulations, taxes, levies and exchangeable permits. At the EU level, external costs related to the transport of goods are only partially reflected in transport prices.

In many developing countries, such as Mexico, there are no monetary estimates of the external effects of road transport. In paper [9], six categories of estimates were calculated using available data and well-established methods. The results showed that road externalities amounted to at least 59.42 billion US dollars per year or 6.24% of GDP. Per components, accidents accounted for the largest share (28%), followed by congestion (22%), greenhouse gases (21%), air pollution (13%), infrastructure (7%) and noise (9%).

A simulation-based approach for calculating and internalising correct dynamic price levels using two external factors simultaneously is given in [10]. For a real-world case study, it was shown that an iterative price calculation based on cost estimates from the literature makes it possible to identify the amplitude of the correlation between the two external effects under consideration. Economic assessment indicators for the common price policy make it possible to compare other policies with this reference state of the transport system.

Companies working to reduce their environmental impact operate on three levels: optimising existing networks and flows; transport mode optimisation; increasing the efficiency of routes and travel. Many actions aimed at reducing the cost of transport pollution include minimising empty trucks, encouraging cooperative retail distribution, launching more efficient vehicles; all measures that, before reducing pollution and congestion costs, have a significant benefit of reducing operating costs paid directly by the companies. Paper [11] reviewed the literature and analytical aggregation of different results, in order to obtain a homogeneous function of

transport costs, and then introduced several applications to explain the proposed models.

The use of the multi-criteria method, Analytical Hierarchical Process (AHP), to rank different strategies for reducing emissions on the road, including strategies to reduce, avoid and replace, was carried out in paper [12]. The data were obtained on the basis of a survey of experts in the field of transport and climate sciences. The aim of the model was to estimate the potential carbon dioxide reduction for a given allocation strategy. The conducted survey did not identify any difference between the ranking of reduction, avoidance and replacement strategies for our urban and medium-small urban areas. The contribution of research is reflected in the detailed assessment of generic scenarios and their application to real-world case studies. Also, the application of the presented methodology includes a ranking of transport strategies for mitigation of carbon dioxide emissions, assessment of strategies, setting budget priorities and developing estimates of mitigation potential.

Several research projects and models have been implemented in Europe to define and evaluate external costs in the transport sector starting from 2004 [13]. Among the most important are: HEATCO (Developing Harmonised European Approaches for Transport Costing and Project Assessment, 6th Framework Programme), CAFE CBA (Clean Air for Europe Programme, Cost Benefit Analysis of Air Quality), TREMOVE policy assessment model, ASSET (ASsessing SEnsitiveness to Transport) GRACE (Generalisation of Research on Accounts and Cost Estimation, 6th Framework Programme). The most important results of these projects were summarised in the IMPACT project in 2008, which resulted in the Handbook on estimation of external costs in the transport sector [14]. The latest update related to external costs is provided in the Update of the Handbook on External Costs of Transport [15]. On the basis of manuals it is possible to calculate unit costs of pollutants in the form of €/tonne which take into account the negative consequences of traffic functioning such as: harmful impact on human health (mortality, morbidity), impact of emissions of harmful substances on facilities and materials, negative impact on the biosphere, detrimental effect on biodiversity and ecosystems, impact on the generation of greenhouse gases.

III. METHODOLOGY - QUANTIFICATION OF EXTERNAL EFFECTS

In order to more easily eliminate the negative consequences that accompany the entire transport process, it is necessary to note that external costs do not apply to the individual or direct user of the transport service when they occur, such as: Operating costs of using the vehicle, Costs of own travel time and Costs of fees and charges in transport. External costs clearly cover all those costs that relate to society as a whole, and the following costs are then included: Accidents, Congestion, Air pollution, Climate change, Noise, Well-to-tank emissions and Habitat damage [16].

The internalization of external costs implies that such effects are part of the decision-making process of transport users. This can be done directly (by regulating both command and control measures) and indirectly (by providing better incentives for the transport of users, i.e. market instruments).

1. Air pollution

Air pollution caused by traffic activities leads to different types of external costs. The most important external costs are health costs due to cardiovascular and respiratory diseases caused by air pollutants. The most important air pollutants related to traffic are particles (PM_{10}, $PM_{2.5}$), Nitrogen Oxides (NO_x), Sulfur Dioxide (SO_2), Volatile organic compounds (VOC), and Ozone (O_3) as an indirect pollutant [17].

For road transport, the most important impact on costs is the emission standards for vehicles, which partly depend on the age of the vehicle. The emissions of road vehicles also depend on vehicle speed, fuel type and fuel combustion technology and exhaust gas treatment technologies, load factors, vehicle size, type of drive and geographical location of the road. The results of using a simulation model to estimate the fuel consumption of a light commercial vehicle in road traffic cycles are given in [18].

The quantification of external costs of pollutant emissions in road transport when transporting goods can be carried out depending on a particular category of vehicle and its emission class, i.e. euro standards. The costs of air pollution depend on the area through which a particular vehicle carries out the transport of goods. Costs are expressed in €c per vehicle-kilometer. The highest costs of air pollution are recorded passing through a city zone, while the lowest costs of air pollution are recorded on highways [15].

The key cost impacts for rail transport are: vehicle speed, load factors, a combination of power generation plants and the geographical location of plant installations. Calculating air pollution costs involves the use of linear functions and calculations that are included in the top-down model, which are also linear functions. Marginal costs of air pollution are approximately equal to the average cost of air pollution. External costs of air pollution from road and rail transport can be calculated on the basis of the form [19]:

$$C_m = \sum_{c,i} \left(Vk_{m,c,i} \cdot MC_{m,c,i} \right) \qquad (1)$$

Where C - Air pollution costs per trip (€/trip), Vk - Vehicle kilometers (vkm/trip), MC - External marginal air pollution costs, i -Type of infrastructure (urban road, interurban road, motorway), c – Country and m –mode.

2. Accidents

Accident externalities represent the most important external costs of road transport [20]. These social costs include the costs of material damage, administrative costs, treatment costs, production losses and non-material costs (shortening life expectancy, suffering, pain, sadness, etc.) [21].

The most important impacts on costs in road transport, in addition to mileage, vehicle speed, road type, the characteristics of the driver (such as driver behaviour, experience, speed), the volume and speed of traffic, time of day (day/night) and interaction with weather conditions, the level of infrastructure maintenance, the degree of utilisation of the capacity of the infrastructure, and the level of segregation of road traffic lanes. The following form can be used to calculate the cost of traffic accidents in road transport [19]:

$$C_m = \sum_{c,i} \left(Vk_{m,c,i} \cdot MC_{m,c,i} \right) \quad (2)$$

Where C - Accident costs per trip (€/trip), Vk - Vehicle kilometers (vkm/trip), MC - External marginal air pollution costs, i -Type of infrastructure (urban road, interurban road, motorway), c – Country and m –mode.

According to German statistics, the share of fatal HGV (Heavy goods vehicle) accidents on highways is 50% of all fatal HGV accidents, which is very high compared to other countries. Combined with traffic flow data, this gives a marginal value in the case of an accident for highways that is higher than for other types of roads. In the original data in Switzerland, the share of motorway accidents was only 20% [15].

The main impacts on rail transport costs are traffic volumes, weather conditions, maintenance levels and level of segregation between systems, especially between road and rail transport and between different types of trains. To calculate the cost of accidents in railway transport one can use the form [19]:

$$C_m = \sum_{c} \left(Vk_{m,c} \cdot MC_{m,c} \right) \quad (3)$$

Where C - Accident costs per trip (€/trip), Vk - Vehicle kilometers (vkm/trip), MC - External marginal air pollution costs, c - Country and m -mode.

In the rail transport sectors of the EU, accidents are much less common than in road transport. Therefore, the cost estimation of accidents must be based on the average number of accidents in the past few years. All incident costs can be considered as external, because the marginal costs are equal to average costs.

IV. ECONOMIC MEASURES AND INSTRUMENTS FOR SOLVING EXTERNAL EFFECT PROBLEMS

In order to preserve human health and natural resources of the environment, it is necessary to introduce certain measures aimed at reducing the negative impact of transport on the environment and human health. Economic instruments are a system of incentives, which are established with the aim of influencing the behaviour of economic entities as well as the decisions they make in order to protect and preserve environmental resources. In this way, environmental resources receive appropriate prices that will ensure their proper allocation and efficient and sustainable use. The application of economic instruments ensures that economic entities behave in a different way than before. Namely, they no longer treat the ecological good as free of charge and do not transfer the costs of endangering the environment to society, but take responsibility for them themselves. The European Environment Agency groups external instruments into five basic categories [22]: 1. Transferable permits, 2. Environmental taxes, 3. Environmental fees, 4. Environmental subsidies and incentives, and 5. Liability and compensation programmes.

1. Transferable permits are authorisations granting the right to emit pollutants. These permits are issued by the competent regulatory authority. The right to emit pollutants actually represents the amount of pollutants that an economic entity can produce. As a rule, these permits are sold to those who offer the highest price. The definition and introduction of the system of transferable licences is carried out in three steps: determining the total amount of quotas, allocation or distribution of licences to individual economic agents and trade in licences.
2. Environmental taxes are defined as mandatory payments imposed on products and processes that are harmful to the environment. These taxes have three basic functions: covering costs, encouraging behaviour change, and generating revenue. In the countries of the European Union, the following classification of environmental taxes is found:
   - tax on energy sources (on petrol, on diesel, on mineral oils, on heating oil, on kerosene, on natural gas, on electricity consumption and on CO_2),
   - tax on transport (on the registration and use of motor vehicles, on the import and sale of motor vehicles, on the use of roads and highways and on passengers in air traffic),
   - tax on pollution and resources (air pollution (SO_2, NOx), water pollution, waste

(landfills), batteries, tires, available containers, plastic bags, pesticides and fertilisers, wastewater and industry), ozone pollution, nuclear energy and noise).

3. Environmental compensations are a mechanism created with the aim of partially or completely covering the costs of environmental services and mitigation measures such as wastewater treatment or waste disposal. Depending on the legislation, the taxpayer may pay these fees, may be exempted from them, or may be reimbursed, while a reduction in the payment of the fee may also be granted, if these funds are used to reduce environmental pollution.
4. Environmental subsidies and incentives include a set of government measures designed to stimulate new technologies, develop new markets for environmental products and services, encourage consumer behaviour change through eco-purchasing programmes and provide temporary support to businesses to ensure a higher level of environmental protection. Thus, in contrast to the taxes that are intended to punish polluters, subsidies are intended to influence the change in the behaviour of various actors in order to reduce pollution and improve the quality of the environment. Similar to environmental taxes, subsidies can be classified into four groups: energy-related subsidies, resource-related subsidies, pollution-related subsidies, and transport-related subsidies.
5. Liability and compensation programmes aim to provide adequate compensation for damage caused as a result of activities that are harmful to the environment and thus to provide funds for prevention and restoration.

Economic instruments to solve these problems have both positive and negative sides. The advantages of these instruments include: creation of additional state revenue, ensuring cost efficiency, ensuring dynamic efficiency through the operation of innovative activities in the long run, greater flexibility as they provide easier acceptance and adaptation of stakeholders to these instruments, and control of a large number of small and widespread pollution sources, which is especially characteristic of the transport sector, given that there are a large number of vehicles in it. The shortcomings of these instruments that are most often mentioned are: uncertainty when it comes to the appropriate level of duty, uncertainty about the time gap, uncertain and unstable revenues and effects on competitiveness.

V. Results and discussion of research - Calculation of external costs of railway and road freight transport through the Republic of Serbia

Negative external effects caused by daily activities of all modes of transport can only be expressed in the form of monetary units in order to assess their impact on both the individual and society as a whole.

The paper presents the calculation of external costs (air pollution and accidents) caused by different modes of transport (road and rail) between the border crossings of the Republic of Serbia with Hungary and North Macedonia, and on the route between the Kelebija and Preševo border crossings (**Fig. 1**).

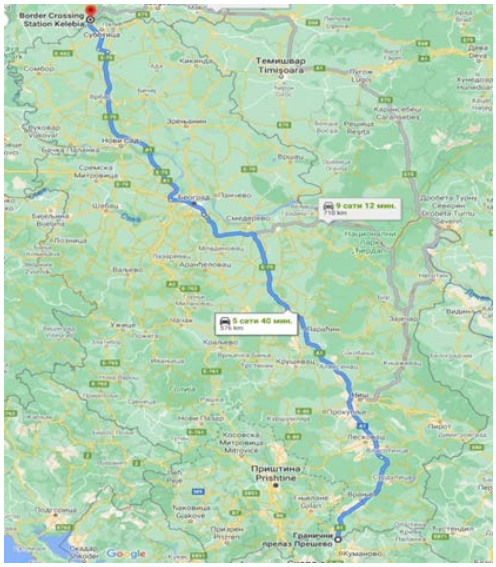

Figure 1. *Movement path of the truck*

The assumed cargo to be transported is 20 TEU (Twenty-foot Equivalent Unit) containers (adopted average weight is 10.5 t/TEU). The transport is considered for the following vehicle categories:

- Truck (Rigid HGV), Gross vehicle weight 24-40 t, Emission class Euro V,
- Train (Short train, Train weight 500 t, electrified and diesel).

The lengths of the routes of transport vehicles of different modes of transport through the Republic of Serbia are given in **Table 1**.

External costs caused by air pollution and traffic accidents for road and rail transport are calculated on the basis of equations (1) to (3) and adopted characteristics of transport vehicles [15, 19].

Table 1. *Length of road and rail freight transport routes through the Republic of Serbia*

	ROAD	**RAIL**
Republic of Serbia	BC Kelebija – BC Preševo = 576	BC Kelebija – Subotica – Novi Sad – Belgrade = 183 Belgrade – Niš = 241 Niš – Preševo – BC Preševo = 157
TOTAL (km)	576	581

Table 2. *External costs caused by air pollution for road and rail transport*

Freight transport through the Republic of Serbia			**€**
	Regional road	Highway	
km	34	543	
Coefficient [23]	1.455		
	Electrified (diesel)		
km	581		
Coefficient [23]	0.177		

Table 3. *External costs caused by traffic accidents for road and rail transport*

Freight transport through the Republic of Serbia			**€**
	Regional road	Highway	
km	34	543	
Coefficient [23]	1.891		
	Electrified (diesel)		
km	581		
Coefficient [23]	0.115		

Table 4. *Total external costs caused by air pollution and traffic accidents for road and rail transport*

	Freight transport through the Republic of Serbia		**Total €**
	Air pollution	Traffic accidents	
ROAD	176.302	229.132	405.434
RAIL	21.596	14.031	35.627

The obtained results are given in **Table 2** and **Table 3**, respectively.

If 20 TEU containers were transported through the Republic of Serbia by road or rail, external costs would amount to €405,434 and €35,627, respectively (**Table 4**). Regarding the comparison of the obtained results, the external costs of freight road transport are about 11 times higher than freight rail transport. When observing external costs caused by air pollution, freight road transport affects air quality about 8 times more than freight rail transport, while when it comes to external costs caused by traffic accidents, freight road transport affects traffic safety about 16 times more than rail freight transport.

From the obtained results, it can be concluded that the transport of 20 containers through the Republic of Serbia, from GP Kelebija to GP Preševo, from the point of view of external costs is best done by rail, which has the least impact on air pollution and traffic accidents.

In Serbia, it is necessary to direct as much of the freight road transport to the rail transport in order to reduce the negative external effects. The next step would be the introduction of high-speed rail systems in the freight transport that are still in the making. The business idea of high-speed rail systems would be "Faster than trucks, cheaper than airplanes". The fact that Serbia aspires to become a member of the European Union and as such must follow the environmental protection measures implemented in the European Union (it would be desirable for it to at least start implementing them), only gives all this greater significance.

Freight transport is essential for economic activities and quality of life. Well-organized freight transport also contributes to sustainability and increased energy efficiency. In Serbia, the most appropriate strategies in dealing with the environment and problems of freight transport are:

a) Mandatory legislation with appropriate enforcement measures, and
b) Gradual dissemination and adoption of the best EU environmental practices.

Serbia is the only country among the pre-accession countries that applies the EU guidelines in the internalisation of external costs of road, rail, air, inland waterway, intermodal and multimodal transport.

VI. CONCLUSION

A particularly important strategic role of transport is reflected in its contribution to the opening of underdeveloped regions or economies and their integration into national, European and global economic flows. Transport is one of the most important factors in achieving the overall economic prosperity of a country and the economic well-being of its citizens. The increase in transport in the world economy has a number of shortcomings, such as congestion, increased noise and stress among traffic participants, environmental pollution by emissions, etc. Consideration and quantification of these effects were the first steps towards modelling alternative development scenarios and their costs, and later moving on to their internalisation. Both in the professional circles and in the public, it is understood that the costs of transport do not include only what the state or users pay for the transport service, but that they cover a much wider set of costs. They can be considered from the aspect of individual direct users, from the aspect of transport companies and from the aspect of society in two ways, as a direct user of transport services in some cases, when at some level public transport is required and paid, and as an indirect user of transport, those on which the traffic system operates in any way. The principle of internalisation of external costs involves adding external costs to the individual costs of polluters. The internalisation of external costs has the effect of increasing the price of pollutant products and reducing the demand for their products. It is not only important to determine the value or type of external transport costs, but it is also necessary to dedicate oneself to solving the problems that arise from that. Involving as many stakeholders as possible, as well as using a wide range of instruments, is crucial to solving these problems.

A comparative analysis of the representative negative external costs, which arise from freight road and rail transport, should lead to redirecting users or decision makers to an acceptable mode of transport. An example of transporting 20 TEU containers through Republic of Serbia and quantifying the use of two transport modes shows that the highest external costs are incurred when using trucks, while the lowest external costs are caused by rail transport.

When choosing a particular mode of transport for the transport of goods, it is necessary to consider all costs, as far as possible, and not only the cost of transport services.

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AUTHOR CONTRIBUTIONS

N. Petrović: Conceptualization and Supervising.

V. Jovanović: Conceptualization and Experiments.

B. Nikolić: Writing and Reviews.

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DISCLOSURE STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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