Method of evaluation of external costs in combined transport coal

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Abstract
Transport of goods is of great importance in socio-economic life of societies. In Poland, where the power industry is based partially on bituminous coal extracted in mines of Upper Silesia, the transportation of coal is of great significance. The coal transportation acquires special importance in the corridor of the Odra River, where the Power Station Opole, Kogeneracja Wrocław, industrial complex of Power Station Dolna Odra, and numerous other industrial companies, that rely on such energy carrier are located. Location (intentional) of coal consumers, as well as historical determinants, created the chance of functioning of alternative transport systems: rail and inland waterborne ones. Intuitive interest in inland waterborne transportation as mass transportation that is cheaper and safer for natural environment, is the subject of present paper. Main objective is the presentation of the method for evaluation of so-called external costs in multimodal transportation of coal including the non-alternative rail transport between coal mines and the port of Gliwice, and inland waterborne transportation from the port of Gliwice to the consumers located by the Odra River.

Introduction
Transportation plays an important and indisputable role in the socio-economic (civilization) life of societies. It is also the reason of adverse external events that require action, related to their identity and the need to reduce. The fact, that the transport does not cover the full social costs of operation, leads to a disruption of competition in the transport market conditions.

One of the components of transport costs are external costs, defined in economic literature as the difference between the social transportation costs and the company costs [1].

The need to develop methods for assessing external costs for combined carbon transportation, requires to determine the relation between the rail and inland waterway transport of coal, and to identify and expose the operating parameters that affect the level of external costs, generated by these modes of transport.

Combined transport of coal
The literature describing the transportation of bulk cargo identifies broken or combined transportation. In the broken transportation, cargo is shipped by at least two different modes of transport, and at each the load is carried by another carrier. The combined transport is understood as a special kind of intermodal transport, conditioned by existence of so called surface of transport process [2]. One of them is the technical and technological surface. It involves an adaptation the transport vehicles of various modes and loading equipment to operate the same, unified unit load.

On the Odra River corridor there is a problem of mass transportation of coal from Silesian mines to different customers using rail, inland waterway or broken / combined transport.

Along the Odra or directly in its neighbourhood there are many energy companies. In 2007, to these companies (from Silesia) coal was provided, in quantities:
• Opole Power Plant – 3.5 million tons;
• ZEC Wrocław – 800 thousand. tons;
• Dolna Odra Power Plant – about 3 million tonnes.

The ZEC Wrocław supplies the coal by water (about 600 thousand. tons) only. In addition, to ZEC Wrocław, two power plants in Szczecin (which are parts Dolna Odra Power Plant) have their own loading docks.

There are plans to expand the Opole Power Plant. After the expansion, coal consumption will increase by about 4 to 4.5 million tonnes per year.

In 2010, the four voivodeships of Odra (Lower Silesia, Lubusz, Opole and West Pomerania) consumed 15.9 million tons of coal. 7.3 million tonnes of this amount were consumed by power plants [3]. Despite the decline of coal mining in Poland, for many more years coal will be the primary source of energy, especially in the power industry. The statistics show a significant share of the energy mix of imported coal. In 2009, coal export amount to 13.8% of domestic production of coal.

Taking into account only the transport of coal, the Odra Waterway (ODW) could be used to transport more than 23 million tonnes of cargo per year [4]. Currently, coal is transported from Silesia down the Odra. Directorates of energy companies (listed above) in the development strategies do not exclude the possibility of purchasing exported coal. The coal would be transported from the port complex Szczecin-Świnoujście. In addition, to listed, the main recipients of coal could be also: Power Plant Głogów, Zielona Góra, Opole, paper mills in Kostrzyń.

Available railway infrastructure enables transportation of bulk cargo between the mines of Upper Silesia and the port complex Szczecin-Świnoujście on a large scale. Its capacity is sufficient for both the current and potentially increased the transportation needs. The occurrence of a fairly large number of alternative rail routes (especially in the south) increases the reliability of supply and optimizes the utilization of capacity on all operating segments.

External costs of transport

External cost is the cost, or part of the social costs, that cannot be borne by companies forming this cost. Those costs are born by those, who have nothing in common with its creation, and they bear the negative consequences of its operation.

The external costs of transport include:
• the costs of congestion and scarcity of infrastructure (categories: increased travel time, increase of operating expenses and operating the vehicle, increasing social costs of travel, additional fuel consumption, decrease the reliability of transport operations, the lack of slots (alternative services related to the punctual start / end of the journey), the lack of positive externalities associated with improved quality of service);
• accident costs (categories: property damage costs, administrative costs, medical costs, costs associated with the loss of production, cost of suffering);
• costs associated with air pollution particulate emissions (short-cut PM) nitrogen oxides (NOx), sulfur dioxide (SO2), volatile organic compounds (VOCs), (categories: the cost of loss of health, loss of property, loss of harvest and losses for ecosystem);
• noise costs related to an an acoustic wave intensities and frequencies, burdensome to humans and the environment (categories: reduction of satisfaction with leisure time activities, discomfort during rest, sleep problems, hearing loss, stress, hormonal changes);
• costs of climate changes, caused by the emission of greenhouse gases such as carbon dioxide (CO2), nitrous oxide (N2O), methane (CH4), (elements: fuel consumption, the carbon content of the fuel));
• other costs (landscape transformation, water pollution, soil contamination) – most often overlooked, because of difficulty in estimating.

Broken/combined transportation of coal including rail and inland waterway allows to rationalize its costs, taking into account the social dimension of external costs.

The operating parameters in a system of rail transport

Rail transport is characterized by a number of operating parameters. These include:
• organization of a train movement;
• cruising speed (average);
• maximum speed;
• the frequency of acceleration and deceleration process of a train;
• length of sections between stops;
• the type and capacity of wagons;
• the length of trains;
• geographical location of trail (size and number of hills and curves, the length of low ambient temperatures and the snow cover on the trail);
• condition of rail-road;
• length of trail in urban and non-urban area;
• distance between trail and settlements;
• the period of circadian (day / night) traversing urban sections of the trail;
• number of rail crossings (guarded / unguarded);
• the ability to build a noise barriers;
• the possibility of fencing the trail and building a grade-separated crossings for animals.

The main operating parameters in rail freight using electric traction are [5]:
• type of electric vehicle;
• speed of train;
• distance between stops;
• the size of ascents and slopes;
• local traffic volume (important for the possibility of energy recovery during braking);
• ambient temperature;
• parameters of the power plant, which charges the traction electricity.

The optimal composition of the train in terms of energy shall be: the maximum weight (for the route, timetable and locomotive) with a minimum number of axles (maximum permissible load of the wheel-set).

Electricity generation (for railway)

The problem of generation the electricity for rail transport, trail: Gliwice–Opole–Wrocław–Szczecin, is limited to Opole Power Plant and a complex of Dolna Odra Power Plant. The efficiency of electricity generation in the complex of the Dolna Odra Power Plant (ZEDO) in 2006 was set in the range of 38.13% – 70.05% [6].

The efficiency of electricity generation in BOT Opole Power Plant in 2007 was 37% [10].

Electricity consumed by the receivers (including for own use, loss of transmission and transformation) is 81.8% of energy produced [7].

The efficiency of resulting power electric locomotive as the product of the average efficiency of 38.61% and transfer 81.8% is 31.6%.

Taking into account the specific consumption of electricity for the freight train at a level $E = 10 \text{ Wh/tkm}$ and efficiency of the production and transmission of electricity at the level of 31.6%, specific energy, demand for rail freight is at a level of 31.65 Wh/tkm.

The operating parameters in a system of inland waterway transport

The operating parameters in inland waterway transportation system are:
• type and capacity of the ship;
• type and size of the drive motors;
• type and quality of fuel;
• direction of the ship (with a current / under current);
• specific fuel consumption.

With these components, mentioned at the beginning of the chapter, the external cost of inland transport waterway are taken into account:
• costs of accidents;
• costs of air pollution;
• costs of noise;
• costs of climate change.

The most important costs component is the cost of air pollution and climate change associated with the level of fuel consumption.

Statement of uniform indicators of external costs

In the table 1, summarized developed on the basis of the information contained in the papers [5–22], rates of components of external costs for railway and inland waterway transportation in standardized units of € cent/tkm.

In the analysed source materials, congestion costs were presented only for rail transport, expressed in € / train km. This unit was converted to the desired form € cent/tkm taking parameters such as train weighing 1,000 tonnes on 100 km trail. It allowed to set congestion costs ratio at a high level of negative 0.02 € cent/km (greater weight of the train and / or longer track decrease the ratio).

Table 1. Indicators of external cost components (based on [5–22])

<table>
<thead>
<tr>
<th>No.</th>
<th>Costs components:</th>
<th>Railway</th>
<th>Inland waterway</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>congestion</td>
<td>0.02</td>
<td>–</td>
</tr>
<tr>
<td>2</td>
<td>accidents</td>
<td>0.06</td>
<td>0.03</td>
</tr>
<tr>
<td>3</td>
<td>air pollution</td>
<td>0.05</td>
<td>0.12</td>
</tr>
<tr>
<td>4</td>
<td>noise</td>
<td>0.84</td>
<td>–</td>
</tr>
<tr>
<td>5</td>
<td>clima changes</td>
<td>0.18</td>
<td>0.11</td>
</tr>
<tr>
<td>6</td>
<td>building and maintaining</td>
<td>1.86</td>
<td>0.82</td>
</tr>
<tr>
<td>7</td>
<td>Overarching costs indicator</td>
<td>3.01</td>
<td>1.10</td>
</tr>
</tbody>
</table>

Overarching indicators (also called as an aggregate indicators) of external costs of coal transportation for the analysed transport modes (railway and inland waterway), shows inland waterway transport more attractive.

The calculation algorithm for the analysis of the broken transport system by taking into account environmental issue

Presented set of the indicators, allowed to calculate an algorithm analysing the operating costs of...
coal transport system including environmental aspects.

The simplest algorithm, setting the annual external costs of transport, based on the aggregate rate of external costs, is shown below. Other input values are the mass of carbon / goods transported during the year and the distance between the locations of loading and unloading of goods [22].

**RAILWAY TRANSPORTATION OF COAL**

Annual external costs $K_{rk}$ of railway coal transportation:

$$K_{rk} = \frac{m_{rk} \cdot d_k \cdot W_k}{10^6}, \text{ million } €/\text{year} \quad (1)$$

where:

- $m_{rk}$ – transported mass of carbon per year, t;
- $d_k$ – the length of the route, km;
- $W_k$ – overarching (aggregate) external costs indicator in railway transportation, €/cent/km.

**BROKEN TRANSPORTATION**

**Railway**

Annual external costs $K_{rh}$ of railway coal transportation is determined by the formula (1).

**Inland waterway**

Annual external costs $K_{rw}$ of inland waterway coal transportation:

$$K_{rw} = \frac{m_{rw} \cdot d_w \cdot W_w}{10^6}, \text{ million } €/\text{year} \quad (2)$$

where:

- $m_{rw}$ – transported mass of carbon per year, t;
- $d_w$ – the length of the route, km;
- $W_w$ – overarching (aggregate) external costs indicator in inland waterway transportation, €/cent/km.

Annual external costs of broken transportation $K_{rd}$, million €/year:

$$K_{rd} = K_{rk} + K_{rw} \quad (3)$$

On the basis of the annual external costs, the ratio of external costs of broken transport can be calculated. Important and significant only for specific conditions of transport (on a specified route):

$$W_{k \text{ PLN}} = \frac{K_{rd} \cdot 10^6}{m_{rw} \cdot (d_k + d_w)}, \text{ €/tkm} \quad (4)$$

**Influence of technology of coal transport on external costs**

To present the functioning of the proposed method for determining the external costs of transportation, the analysis of transportation costs for selected coal Power Plants, located along the Odra river with the use of rail and inland waterway transport were presented. Calculated using the algorithm presented above.

Distances for railway and inland waterway transportation of coal are presented in the table 2.

<table>
<thead>
<tr>
<th>Trail</th>
<th>Distance for railway, km</th>
<th>Distance for inland waterway, km</th>
</tr>
</thead>
<tbody>
<tr>
<td>mines – Gliwice</td>
<td>17.4</td>
<td>–</td>
</tr>
<tr>
<td>Gliwice–Opole</td>
<td>76.7</td>
<td>105</td>
</tr>
<tr>
<td>Gliwice–Wrocław</td>
<td>160.0</td>
<td>198</td>
</tr>
<tr>
<td>Gliwice–Szczecin</td>
<td>499.6</td>
<td>678</td>
</tr>
</tbody>
</table>

The external costs of railway transportation of coal from the mines – Gliwice (distance 17.4 km) for the masses of coal designed for customers in Opole, Wroclaw and Szczecin are presented in the table 3.

<table>
<thead>
<tr>
<th>Customer</th>
<th>Coal masses tons/year</th>
<th>External costs, million €/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Opole</td>
<td>3.5</td>
<td>1.83</td>
</tr>
<tr>
<td>Wroclaw</td>
<td>0.8</td>
<td>0.41</td>
</tr>
<tr>
<td>Szczecin</td>
<td>3.0</td>
<td>1.57</td>
</tr>
</tbody>
</table>

The external costs and the indicator for customers of specific annual masses of carbon in Opole, Wroclaw and Szczecin in different transport subsystems are listed in the table 4.

According to the proposed algorithm, the ratio of external costs in broken transportation decreases with the increases of length of the waterway trans-

<table>
<thead>
<tr>
<th>Trail</th>
<th>mass of coal</th>
<th>Railway</th>
<th>Inland Waterway Transportation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>million tons / year</td>
<td>km</td>
<td>million € / year</td>
</tr>
<tr>
<td>mines – Opole</td>
<td>3.5</td>
<td>94.1</td>
<td>9.913</td>
</tr>
<tr>
<td>mines – Wroclaw</td>
<td>0.8</td>
<td>177.4</td>
<td>4.272</td>
</tr>
<tr>
<td>mines – Szczecin</td>
<td>3.0</td>
<td>517</td>
<td>46.685</td>
</tr>
</tbody>
</table>
port. Detailed analysis of the costs of transportation coal from the selected mines to Opole Power Plant showed a significant effect of external transportation costs in total costs [22]. For example, the cost of rail transport of coal from the Mysłowice mine to the Opole Power Plant is 68.015 PLN/t. In these, external costs amounted to 11.045 PLN/t. The total cost of broken transportation is 57.712 PLN/t, including external transportation costs: 5,422 PLN/t. The broken transportation was implemented in relations: mine – Gliwice port by rail, port Gliwice Opole Power Plant – inland waterway transport.

Despite the obvious financial and environmental benefits arising from the use of inland waterway transport, this transport mode is marginalized in Poland. It is also contrary to the EU transport policy.

Conclusions

The issue of external costs in the transportation plays an important role in the organization of economic activities in the European Union and consequently was recognized in Poland, as evidenced by the presented work. The proposed method for assessing the external costs in combined / broken coal transport is based on the values assigned overarching indicators of the costs for two considered transport subsystems. The determined values’ relations of the attractiveness of combined transport is a function of the shares of transport by inland waterway and railway transport. The calculation using the external costs indicate the advantage of inland waterway transport on the railway. It should be an important factor favoring the development of inland waterway transport in Poland.

References

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