Application of the methodology related to the emission standard to specific railway line in comparison with parallel road transport: a case study

Iwona Rybicka[1,*], *Ondrej* Stopka[2], *Vladimír* Ľupták[2], *Mária* Chovancová[2], *Paweł* Droździel[1]

[1]Lublin University of Technology, Faculty of Mechanical Engineering, Nadbystrzycka Street 36, 20-618 Lublin, Poland
[2]Department of Transport and Logistics, Faculty of Technology, Institute of Technology and Business in České Budějovice, Okružní 517/10, 370 01 České Budějovice, Czech Republic

Abstract. At present, the impact of transport on the environment constitutes a serious problem. This mainly concerns energy consumption and production of greenhouse gases (GHG) that via their participation in greenhouse effect intensification contribute to global warming. In this paper, the calculations provided by the EN 16258: 2012 methodology will be applied to two modes of transport: railway and road transport. Subsequently, the methodology will be applied to a case study of a selected non-electrified railway line in comparison with parallel road transport. In particular, energy consumption and production of greenhouse gases will be monitored depending on traveling the distance between selected cities in the Czech Republic.

Keywords: emission, transport, railway line

1 Introduction

Transport represents an essential part of the economic stability and development of every state, but also a means for easier cultural exchange or preservation of genetic diversity. Transport has become so much a part of us that at present few people can imagine life without a car or the opportunity to use public transport at any time. The growing importance of transport and the demands we make on it lead to the world being flooded with traffic. Moreover, the amount of traffic tends to permanently increase and the severity of its negative impacts on human health and the environment is growing. In the last thirty years, the European policy has sought to limit the production of emissions from transport and industry to a minimum, and has also managed to ensure a significant reduction in the production in certain aspects. The need for a political fight against emissions from transport is also evidenced by the increasing urgency of the global warming trend, caused mainly by greenhouse gases generated predominantly by transport. It is stated that transport emits around 23% of all anthropogenic CO_2 production on Earth [1].

* Corresponding author: i.rybicka@pollub.pl

Reviewers: *Kateryna* Kravchenko, *Pavol* Kukuča

The paper focuses on this negative aspect of transport and offers a comparison of two modes of transport on a chosen transport route in order to comprehend all the side effects and load levels that these possibilities bring. The individual calculations of GHG emissions will be based on the methodology set out by the EN 16258: 2012 standard, which is a full-fledged part of the European policy for combating emissions from transport [2, 3]. In addition, the paper presents the main producers of transport emissions and describes their significant impact on the environment. It also includes graphically illustrated results of the comparison of the railway and bus passenger transport on the given transport route with respect to their production of emissions and energy consumption depending on the number of transported people [1].

2 European standard EN 16258:2012

This European standard specifies and describes the methodology for calculating and determining energy consumption and the number of GHG emissions concerning any mode of transport. It can be applied to both different modes of transport (road, sea, etc.) and various transport items (passengers, cargo, combinations) [6]. The methodology details the general steps, necessary definitions, relationships, calculation methods, divisions, and recommended information as support for an accurate and standardized calculation that presents energy consumption and greenhouse gases production in all modes of transport. Every calculation of energy consumption and greenhouse gases production requires the necessary amount of information about the situation [5].

For the calculations of energy consumption and GHG emissions in transport services, the methodology introduced in the EN 16258: 2012 standard was used. The calculations based on this methodology naturally take into account the following aspects: all vehicles used for the performance of transport services (including subcontracting), the total fuel consumption of each energy carrier used by single vehicles, and all journeys performed by both full and empty vehicles [4, 7, 8].

Thus, every calculation must produce results for four unknown variables that are:

- well-to-wheels energy consumption (Ew);
- well-to-wheels GHG emissions (greenhouse gas emissions) (Gw);
- tank-to-wheels energy consumption (Et);
- tank-to-wheels GHG emissions (greenhouse gas emissions) (Gt).

The final calculations of these unknown variables give us information on energy consumption and greenhouse gas emissions, both in the sum of primary and secondary emissions and in the value of primary emissions only [9].

Steps of calculating energy consumption and greenhouse gas emissions for a specified transport service.

The calculation for a specified transport service must be performed according to the following steps:

- step 1 - Identification of the various journeys (legs) that make up the specified transport service;
- step 2 - Calculation of energy consumption and greenhouse gas emissions for each leg;
- step 3 - Sum of the results for each leg [19, 20].

Secondary steps of calculating energy consumption and greenhouse gas emissions for a leg of a specified transport service

The calculation for a leg of a specified transport service must be performed using the following steps:

- secondary step 1 – Determination of the vehicle operation system (VOS);

- secondary step 2 – Calculation of total fuel consumption for the VOS;
- secondary step 3 – Calculation of total energy consumption and GHG emissions for the VOS;
- secondary step 4 - Allocating the leg a share from each of the four results of the partial step [19, 20].

3 Categories of values used for the calculation

The calculation method set out by the EN 16258: 2012 standard uses two kinds of value categories. The first category includes general values that include general data. The second category refers to preselected values, the values of which are clearly stated in the EN 16258: 2012 standard and the use of their declared values is essential for achieving results [2].

The category of general values includes fuel consumption, distance, fuel consumption with respect to distance, cargo, load factor, and vehicle capacity [10].

The category of preselected values includes such values that are stated in the EN 16258: 2012 documentation. It is advisable to check whether the latest version of the standard is available. The values should correspond to the mode of transport and to the available general values to make the results as accurate as possible [11].

3.1 Calculation principles at the level of vehicle operation system (VOS)

Secondary step 1 Determination of VOS related to a specified leg – In order to calculate each leg of the transport route, it is necessary to start by selecting the VOS for a particular leg. As a minimum requirement, the VOS must be a consistent group of vehicles operation relevant to the particular leg. In determining the VOS, the factors that affect the range and composition of the VOS (the number of vehicles and the time of operation of these vehicles) should be taken into account. The choice of the VOS is an arbitrarily chosen quantity relating to the selected criteria, but it must also consider journeys performed by empty vehicles [12, 13, 14].
Secondary step 2 Calculation of total fuel consumption for the VOS - The above mentioned value category is used for the calculation. If a vehicle uses more than one type of energy, each energy carrier must be calculated separately.

Secondary step 3 Calculation of total energy consumption and GHG emissions for the VOS - the recalculation from the total fuel consumption for the VOS to the amount of consumed energy and the greenhouse gas emissions is to be done using the following formulas:

- for well-to-wheels energy consumption VOS: Ew (VOS) = F (VOS) x ew;
- for well-to-wheels GHG emissions VOS: Gw (VOS) = F (VOS) x gw;
- for tank-to-wheels energy consumption VOS: Et (VOS) = F (VOS) x et;
- for tank-to-wheels GHG emissions VOS: Gt (VOS) = F (VOS) x gt.

where:

- F (VOS) is overall fuel consumption used for the VOS;
- ew well-to-wheels energy factor for fuel used;
- gw well-to-wheels GHG emissions for fuel used;
- et tank-to-wheels energy factor for fuel used;
- gt tank-to-wheels GHG emissions for fuel used.

Secondary step 4 Calculation for one leg - After the implementation of secondary steps 1, 2 and 3, we must allocate the transport service legs the share of Ew (VOS), Gw (VOS), Et (VOS), Gt (VOS) corresponding to its relative share of transport activity performed within VOS [12, 13, 14].

Therefore, the relevant formulas are as follows:

- S (leg) = T (leg) / T (VOS);

- Ew (leg) = Ew (VOS) x S (leg);
- Gw (leg) = Gw (VOS) x S (leg);
- Et (leg) = Et (VOS) x S (leg);
- Gt (leg) = Gt (VOS) x S (leg).

where:

- S (leg) is the factor used for calculating the share of energy consumption and emissions of the VOS that is allocated to a transport service for a particular leg. This share is based on the ratio of transport activity for the leg and for the associated VOS;
- T (leg) it is the transport service of transport activity for a specified leg;
- T (VOS) refers to transport performance of the VOS that concerns the leg;
- T (leg) a T (VOS) must have the same allocation of parameters and units [15].

4 Application of the european standard EN 16258: 2012: a case study

The main objective of the case study is to determine energy consumption and greenhouse gas emissions for two modes of transport (railway passenger transport and road passenger transport). After obtaining the results, two modes of transport will be compared and the more ecological alternative will be chosen. The case study will be applied to Jihlava-Brno transport section [16].

The length of Jihlava-Brno route by rail is 104 km. The capacity of a railway car is of 98 passengers. The railway car uses engine diesel oil as a fuel and a fuel consumption for developing enough power and travelling the distance is calculated at the level of 59.43 l/100 km.

Due to the fact that several types (814, 841, 842 and 854) of motor railway cars (integrated railway units) are deployed on this particular transport section, thus for objectification within this research study, calculation of the average values of fuel consumption of individual deployed motor units and the average capacity value of individual units are taken into consideration. Consumption of individual units is determined based on the technical parameters and specifications declared by the manufacturer.

Even though the bus service transports passengers between the same two cities - Jihlava and Brno - it uses road communications. The final distance is 92 km. The vehicle is fully occupied and therefore carries 50 passengers. The average power consumption for the route is 32 l/100 km. The line bus also uses diesel oil as a fuel.

Table 1. Final values of energy consumption

	Final values of rail transport 1st leg + 2nd leg (50% of passengers)	**Final values of road transport 1st leg + 2nd leg (50% of passengers)**	**Final values of rail transport 1st leg + 2nd leg (no passengers)**	**Final values of road transport 1st leg + 2nd leg (no passengers)**
E_w(TS)	80.76 MJ	75.42 MJ	2666.09 MJ	1282.22 MJ
E_t(TS)	73.57 MJ	68.71 MJ	2428.82 MJ	1168.12 MJ

The values from Table 1 indicate that railway transport has higher energy requirements for transport. In all conditions, rail transport requires more energy for its movement. When considered, this result has also a logical justification; although it is true that the friction generated by the movement along the rails is lower than that of the tire movement on the asphalt road, the weight of the motor railway car is more than doubled. The energy consumption to move more than 50 tons is significant.

Table 2. Final values of GHG emissions

	Final values of rail transport 1st leg + 2nd leg (50% of passengers)	Final values of road transport 1st leg + 2nd leg (50% of passengers)	Final values of rail transport 1st leg + 2nd leg (no passengers)	Final values of road transport 1st leg + 2nd leg (no passengers)
G_w(TS)	6.13 $kgCO_{2e}$	5.72 $kgCO_{2e}$	202.30 $kgCO_{2e}$	97.20 $kgCO_{2e}$
G_t(TS)	5.05 $kgCO_{2e}$	4.71 $kgCO_{2e}$	166.71 $kgCO_{2e}$	80.17 $kgCO_{2e}$

In this case, railway transport produces higher levels of greenhouse gas emissions in all examined values. Therefore, in terms of the amount of greenhouse gas emissions, it is a less environment-friendly mode of transport on Jihlava-Brno transport route. The reason is that in the case study we took into account the values of the motor railway car. If we were to use a unit of driving car and propelled car as a railway vehicle, it would probably reduce the amount of emissions calculated according to the analytical method because the increased number of passengers would reduce the ratio of the amount of pollutants to passenger-kilometers [17, 24, 25].

The case study deals with the significance of the number of transported passengers as an aspect affecting the final results of energy consumption and greenhouse gas emissions. Before the implementation of the application part, it was not exactly clear how significant the influence of the number of transported people was on the calculation process and on the final results. In the calculations two variants of the return route were chosen, which varied only in the number of passengers transported by the vehicle. Using this simulation, it was possible to present the maximum possible impact of passengers, as the maximum and minimum occupancy rates of the vehicle were included in the calculation. The table below shows the differences in values caused only by the change of the passengers who were part of the transport [17, 21].

Table 3. Final results and the influence of the number of passengers

	Final values of rail transport 1st leg + 2nd leg (50% of passengers)	Final values of road transport 1st leg + 2nd leg (50% of passengers)	Final values of rail transport 1st leg + 2nd leg (no passengers)	Final values of road transport 1st leg + 2nd leg (no passengers)
E_w(TS)	80.76 MJ	75.42 MJ	2666.09 MJ	1282.22 MJ
E_t(TS)	73.57 MJ	68.71 MJ	2428.82 MJ	1168.12 MJ
G_w(TS)	6.13 $kgCO_{2e}$	5.72 $kgCO_{2e}$	202.30 $kgCO_{2e}$	97.20 $kgCO_{2e}$
G_t(TS)	5.05 $kgCO_{2e}$	4.71 $kgCO_{2e}$	166.71 $kgCO_{2e}$	80.17 $kgCO_{2e}$

As shown by Table 3, which contains all the final values analyzed in this study, the number of passengers has a significant impact on understanding the final results. We can say with exaggeration that the significant differences in values are only caused by the reasonability with which the movement of the means of transport was carried out. The transport was meaningful if it was able to attract some passengers, which led to the values on the left of the table that are considerably smaller. The values on the right are several times larger due to the fact that there was no passenger on board of the vehicle for half of the transport route. In principle, the production of emissions and energy consumption of the vehicle do not change too much. This methodology demonstrates that the production of GHG emissions can be understood from a completely different point of view [18, 22, 23].

5 Conclusions

Last but not least, it is necessary to focus on specification of the proposals concerning the case study and the data analyzed in this paper, where it is necessary to point out the need for gradual electrification of railways in the Czech Republic. At present, roughly a third of the railway network is electrified, which is below average compared to Western Europe. Unfortunately, the fact is that railway transport in the Czech Republic does not reach the required level. Consequently, the share of transportation by rail in this country is rather below average.

Important tools for developing high-quality public transport, which is an important means for reduction of world emissions from transport, are also integrated transport systems within territorial units. Simplification, connection, but also uniformity of carriers, where the use of one personal document enables the use of different modes of transport, leads to a future priority of mass transport and to reduction of congestion and other negative aspects of glutted transport.

A possible way to decrease production of emission gases is to use alternative power sources such as magnetic trains or hybrid power traction. The possibilities for road transport are even wider, ranging from electric vehicles to hydrogen-powered cars. However, many alternative technologies have not achieved the necessary development in order to, for acceptable financial investment, offer an adequate replacement of current means of transport.

References

1. E. Demir, W. Burgholzer, M. Hrušovský, E. Arıkan, W. Jammernegg, T.V. Woensel, *A green intermodal service network design problem with travel time uncertainty.* Transportation Research Part B: Methodological, vol. **93**, 789-807 (2016)
2. T. Skrucany, S. Semanova, T. Figlus, B. Sarkan, J. Gnap, *Energy intensity and GHG production of chosen propulsions used in road transport.* Communications - Scientific Letters of the University of Zilina, vol. **19**, no. 2, 3-9 (2017)
3. W. Zhu, M.P. Nowak, S.O. Erikstad, *Emission allocation issues in repositioning transporttation.* International Journal of Sustainable Transportation, vol. **10**, no. 4, 365-375 (2016)
4. F. Kellner, *Allocating greenhouse gas emissions to shipments in road freight transportation: Suggestions for a global carbon accounting standard.* Energy Policy, vol. **98**, 565-575 (2016)
5. F. Kellner, *Exploring the impact of traffic congestion on CO_2 emissions in freight distribution networks*. Logistics Research, vol. **9**, no. 1. (2016)
6. T. Skrucany, M. Kendra, M. Skorupa, J. Grencik, T. Figlus, *Comparison of chosen environmental aspects in individual road transport and railway passenger transport.* Procedia Engineering, 806 (2017)
7. F.Cavallaro, F.Maino,V.Morelli, *A new method for forecasting CO_2 operation emissions along an infrastructure corridor*. European Transport - Trasporti Europei, no. **55**, (2013)
8. Y. Cheng, Z. Liu, J. Yan, *Comparisons of PM10, PM2.5, particle number, and CO_2 levels inside metro trains traveling in underground tunnels and on elevated tracks.* Aerosol and Air Quality Research, vol. **12**, no. 5, 879-891 (2012)

9. G. Dalkic, O. Balaban, H. Tuydes-Yaman, T. Celikkol-Kocak, *An assessment of the CO2 emissions reduction in high speed rail lines: Two case studies from Turkey*. Journal of Cleaner Production, vol. **165**, 746-761 (2017)
10. M. Tomášiková, M. Lukáč, J. Caban, F. Brumerčík, Controllability and stability of a vehicle. Logi - Scientific Journal on Transport and Logistics, vol. **7**, no. 1, 136-142 ISSN 1804-3216 (2016)
11. G.J. Hull, C. Roberts, S. Hillmansen*, Simulation of energy efficiency improvements on commuter Railways.* IET Seminar Digest, (2016)
12. T. Kirschstein, F. Meisel, *GHG-emission models for assessing the eco-friendliness of road and rail freight transports*. Transportation Research Part B: Methodological, vol. **73**, 13-33 (2015)
13. M. Mohsen, M.B. Ahmed, J.L. Zhou, *Particulate matter concentrations and heavy metal contamination levels in the railway transport system of Sydney, Australia*. Transportation Research Part D: Transport and Environment, vol. **62**, 112-124 (2018)
14. X. Tao, Q. Wu, L. Zhu, *Mitigation potential of CO2 emissions from modal shift induced by subsidy in hinterland container transport*. Energy Policy, vol. **101**, 265-273 (2017)
15. Y. Ge, J. Long, F. Xiao, Q. Shi, *Traffic modeling for low-emission transport*. Transportation Research Part D: Transport and Environment, vol. **60**, 1-6 (2018)
16. F. Ma, W. Wang, Q. Sun, F. Liu, X. Li, *Ecological pressure of carbon footprint in passenger transport: Spatio-temporal changes and regional disparities*. Sustainability (Switzerland), vol. **10**, no. 2. (2018)
17. H. Novak, V. Lešić, M. Vašak, *Hierarchical coordination of trains and traction substation storages for energy cost optimization*. IEEE Conference on Intelligent Transportation Systems, Proceedings (2018)
18. W. Yang, S. Wang, X. Zhao, *Measuring the direct and indirect effects of neighborhood-built environments on travel-related CO2 emissions: A structural equation modeling approach*. Sustainability (Switzerland), vol. **10**, no. 5. (2018)
19. V. Hromádka, E. Vítková, H. Kovářová, P. Vařbuchta, *Environmental impacts in the evaluation of transport infrastructure projects.* International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM, 201 (2016)
20. M. Kendra, *Integration of individual car transport and public passenger transport in cities*. OPT-i 2014 - 1st International Conference on Engineering and Applied Sciences Optimization, Proceedings. 1582 (2014)
21. M. Vojtek, M. Kendra, V. Zitrický, J. Daniš, *Principles of logistics applied to railway passenger transport*. MATEC Web of Conferences. (2017)
22. F. Brumerčík, Simulation of an unconventional vehicle transmission. Logi - Scientific Journal on Transport and Logistics, vol. **3,** no. **1**, 36 - 44 (2012)
23. R. Mielnik, M. Sułowicz, W. Jakubas, K. Ludwinek, M. Jaśkiewicz, *The reliability of critical systems in railway transport based on the track rail circuit. Analysis and simulation of electrical and computer systems,* The 13th Conference on Selected Problems of Electrical Engineering and Electronics WZEE, 219-228 (2016)
24. J. Caban, A. Marczuk, B. Sarkan, J. Vrabel, *Studies on operational wear of glycol-based brake fluid.* Przemysl chemiczny, vol. **94**, Issue **10**, 1802-1806 (2015)
25. M. Jurkovic, T. Kalina, A.F. Teixeira, *Possibilities of Using Alternative Fuels for Transport Solution in Brazil.* The 21tst International Scientific Conference, 724-728 (2017)