ISSN 1330-3651 (Print), ISSN 1848-6339 (Online)

https://doi.org/10.17559/TV-20211109145649
Original scientific paper

Methodology of Comparing the Carbon Footprint in Means of Rail Passenger Transport: Case Study in the Slovak Republic on the Žilina - Rajec Railway Line

Juraj ČAMAJ, Adrián ŠPERKA, Milan DEDÍK*, Karol HRUDKAY

Abstract: Today, the transport of people and goods is an integral part of every country. For passengers and customers, the price and time of transport are dominant. Today, very few passengers and customers look at the ecological side of transport. The ecological side of transport is represented by various parameters and one of them, which is addressed in this article is the carbon footprint. The main task of the presented article is to create a methodology for comparing the carbon footprint on the Žilina - Rajec railway line. It is a non-electrified line of local significance. The comparison consists in the electrification of the line and the subsequent deployment of electrical units. The main task of the presented article is to create a methodology for comparing the carbon footprint on the Žilina - Rajec railway line. It is a non-electrified line of local significance. The comparison consists in the electrification of the line and the subsequent deployment of electrical units. The aim is to determine the advantage of electrification of this line from an ecological point of view based on this parameter. At the same time, it is possible to point out the beneficial effects of the use of rail transport in the long run for the environment.

Keywords: carbon footprint; motive power unit; passenger transport; railway line Žilina - Rajec

1 INTRODUCTION

Mobility is an important part of everyday activities in the regions and cities. The increasing number of passenger and freight vehicles on the transport infrastructure can cause several problems. At present, there is high traffic intensity level on the roads not only in big cities. It is caused by a great demand on individual car traffic and the growing sale and production of new passenger cars in the EU. The congestion level is also reflected in the accident rate, which is still very high despite the various measures to reduce it. Many traffic accidents in cities, traffic intensity, or inadequate capacity of urban communications result in the emergence of crisis situations. The consequences of these crises are not just problems with traffic jams, but also air pollution, greenhouse effect, essential problem with excessive energy consumption and so on.

Environmental protection is very important to achieve general sustainable development in the world. Significant part of this development is sustainable transport system. Current situation with actual modal split is not sustainable in the long run so certain measures should be taken. Therefore, it is very important to limit individual car traffic and to support public passenger transport. However, at present, in the context of the climate crisis, it is primarily necessary to support non-motorized transport and to use environmentally friendly transport means. Support of the public passenger transport needs a superstructure that consists of the use of electromobility and electric vehicles with a minimum carbon footprint. This is very important indicator of the environmental burden, which is derived from overall ecological footprints. It is the sum of greenhouse gas emissions, usually expressed in CO_2 equivalent. According to IEP data, the average carbon footprint of the Slovak population is at the level of less than 5.900 kg CO_2e (CO_2 equivalent) per year. This number is relatively high and even higher within the EU.

Therefore, the basic priority in the field of public passenger transport is the replacement of old non-environmentally friendly means for better vehicles with a lower carbon footprint. This applies to all modes of transport, including rail transport. However, in some cases for environmentally friendly trains to run on the railway infrastructure, firstly it is necessary to electrify it or make other modernization adjustments.

2 LITERATURE REVIEW

Carbon footprint accounting is becoming a topic of great interest, with special relevance in the passenger transport sector. That is not only due to environmental concerns but also to regulations and marketing issues (i.e., brand image, competition, or internal procedures for a better development) [1].

The basis in the fight for the environment is the gradual reduction of the carbon footprint, which is produced to varying degrees by the various modes of transport. To achieve this purpose, it is necessary to know and thoroughly analyze previous research through a detailed review of the relevant literature [2].

Carbon footprint is intricately related to the consumption and lifestyle pattern of individuals. The transport sector is one of the major sectors that effects lifestyle in a significant way and is the major contributor towards the city emissions. This paper attempts to estimate the carbon footprint arising from household's use of road transport in the city of Kolkata across various income categories [3].

Developed bus transport in Slovakia as a part of public transport in regional and district towns is also a producer of a significant carbon footprint. Therefore, almost all urban transport companies are switching from European Union subsidies to drives that are more environmentally friendly. The analysis of carbon footprint formation in LNG propulsion is discussed in article. At the same time, it suggests options for other cities that have not yet demonstrated their green town policy by buying new green buses [4].

In the area of individual road passenger transport, carbon footprint research focuses primarily on reducing it, as road transport produces too many pollutants into the air. In the article, the authors try to modify and adapt the methodology for calculating the consumption of carbon footprint and analyze the achieved results in different conditions of driving cars (speed, load, braking). The result of all the research is to point out the different levels of carbon footprint in the different situations that a car driver encounters [5].

The transport sector is an increasing contributor to Mexico's carbon footprint. Related to this trend are several other externalities such as congestion and increasing energy supply costs. In this paper the authors examined and cross-verified the publicly available transport activity, energy use, and emissions data to identify trends specifically at the Mexico City level. The results revealed a significant rise in several of these variables over time, yet the rise was accompanied by encouraging trends in fuel economy and mass transit ridership [6].

The increase in international trade due to globalization is evident in southeast Spain, which has become the top exporter of fruit and vegetables. Countries within the European Union, such as Germany and France, emphasize the sustainability and environmental impacts of these products. Hence, a greater understanding of the environmental implications of transporting fruit and vegetables between their origin and their destination might improve the sustainability of this commercial activity. The concept of a carbon footprint is a recognized environmental indicator that can be used for life cycle analysis [7].

Passenger transport has become a significant producer of carbon emissions in China, thus strongly contributing to climate change. In this paper, we first propose a model of ecological pressure of the carbon footprint in passenger transport (EPcfpt). In the model, the EPcfpt values of all the provinces and autonomous regions of China are calculated and analyzed during the period of 2006 - 2015 [8].

The largest producer of the carbon footprint is air transport. Despite its speed and safety, the same, if not more, attention needs to be paid to the environmental aspects of air transport, for example, as in article [9].

Transport greenhouse gas emissions are mainly caused using fossil fuels, e.g., gasoline and diesel. This case study for The Netherlands calculates how alternative fuels, e.g., electricity, hydrogen or biofuels, contribute to policy aims to decarbonize transport [10].

Urban configuration and urban transport system have an enormous impact on the travelling pattern of people. Travel can be characterized by trip frequency, travel distance, modal choice etc. With the rapidly growing economies and population, there is an increasing trend of urban sprawl and auto-mobilization. This has a direct effect on the level of transport demand, travel patterns and its impact on the environment. Present study focuses on trip profile of the commuters by available modes to estimate the carbon footprints for different mode-combinational trips (trip profile including access, egress and main line haul mode) in public transport systems existing in Delhi, the capital city of India [11].

The daily activities that man carries out cause the increase of greenhouse gases (GHG), which are naturally found in the atmosphere, but by increasing their concentration, their residence time provides a greater potential for global warming, since its concentrations in the past were lower than the current ones. All industrialized countries generate the largest contribution of these GHGs. Information and communication technologies (ICT) make their contribution to solving this problem with tools that help determine a CO_2 (carbon dioxide) index produced by a specific activity, which is measured in tons per year. The mobile application and web platform were developed with the agile SCRUM framework, which contains sprints and activities that were grouped into 4 stages [12].

Despite the efforts to green the global economy, the non-renewable resources are still one of the major components of energy mix. The growing energy demand and depletion of deposits around the globe make the production of oil in the Arctic region a more and more attractive option. However, heavy and high-viscosity oils (HVO), typical for the Arctic region, require considerable amount of energy to be extracted. This, in turn, could lead to increased greenhouse gas emissions producing more sever negative environmental impact than the production of non-renewable resources in other regions of the world. This research presents an approach designed to reduce carbon footprint related to hydrocarbons production in the Arctic region [13].

To combat global climate change moving towards sustainable, mobility is one of the most holistic approaches. Hence, decarbonization of the transport sector by employing electric vehicles (EVs) is currently an environmentally benign and efficient solution. The EV includes the hybrid EV (HEV), the plug-in hybrid EV (PHEV), and the battery EV (BEV) [14].

As one of the largest energy consumers, the transport sector (TS) has significant impacts on the environment. Shenzhen, a developed megacity in South China, plays a leadership role in promoting the development of energy efficient vehicles in China. This paper aims to assess the carbon footprint (CF) of the TS in Shenzhen via a Streamlined Life Cycle Assessment method. Consequently, the current environmental performance of the TS is evaluated, and improvement potentials are examined [15].

This study involved an environmental assessment of retail channels using the simplified life-cycle assessment (LCA) method to quantify the environmental impact of packaged beverages consumed in 7-Eleven convenience stores (c-stores) and Carrefour hypermarkets, with the aim of offering shoppers more environmentally friendly chain stores [16].

Constantly increasing of the people mobility requires ensuring of the sustainable transport operation. One of the priorities in this area is a reduction of the energy consumption and the GHG production by transport. Emission limits are currently applied mainly to the transport vehicles. However, technical characteristics of the transport infrastructure may also affect the energy consumption and the GHG production of the transport operation. The article analyses the impact of the changes in the railway infrastructure parameters on the change in the energy consumption of the train operation and on the GHG production in railway passenger transport. The analysis is based on the simulation in the Dynamics program at the different slope ratios of the railway track. The calculation is made for the diesel traction of the vehicles [17].

A review of the relevant literature shows that the examination of the problem we have solved has a wide range of views of research teams in various areas of transport.

3 METHODOLOGY FOR CALCULATING CARBON FOOTPRINT CONSUMPTION IN RAILWAY TRANSPORT

The carbon footprint is the sum of greenhouse gas emissions expressed in CO_2 equivalents. It is a universal measure of the amount of greenhouse gas (carbon dioxide, methane, nitrous oxide, and others) that has the same effect on the climate system as carbon dioxide alone. It considers the exact degree of impact on the greenhouse effect in the atmosphere created by the individual components of greenhouse gases [18]. Carbon footprint can apply to individual, product, or action. It is an indicator of environmental load, which is derived from the overall ecological footprint [19].

According to the International Union of Railways (UIC), rail transport emits 50 to 300 tons of CO_2 per kilometer of infrastructure per year. It also states that the transport of people or tons of material causes emissions of 10 to 25 g/km [20].

The European Standard EN: 16258 will serve as the basis for the calculation of the carbon footprint. The Slovak Republic, as a member of CEN, implemented this standard into national standards in 2013 [18]. This standard is intended to calculate and declare the amount of greenhouse gases produced from the operation of means of transport based on the amount and type of fuel consumed. Calculations of energy consumption and emissions related to vehicles shall also consider energy consumption and emissions related to energy processes in the fuels and/or electricity used by vehicles (including the production and distribution of fuels). This ensures that the standard declares how to proceed with the calculations to consider a comprehensive approach and to quantify energy consumption and greenhouse gas production, considering all processes from obtaining energy sources to consuming them in the means of transport during operation [21].

The methodology is based on the flow chart shown in Fig. 1. Based on it, the individual relationships necessary to calculate the carbon footprint of the operation of motor passenger trains on the line will be derived.

The main part of the contribution is based on a proposal for a methodological procedure which contains several important partial steps. The main goal is to point out the method of calculating the carbon footprint in railway passenger transport, to compare kinds of vehicles and to choose the best alternative in terms of environmental friendliness. The mentioned procedure will be handled on the non-electrified railway line, so within a practical application must be selected non-electrified railway transport route.

The first step of the procedure is vehicle characteristics. It includes vehicle age-year of its production, commissioning, emission class for rolling stock and other technical and operational indicators and parameters. The next step is analysis of specific vehicle consumption for a specific year. This information should be available to the carrier operating those vehicles. This data can be different each year, so it is important to use data of the monitored year. The proposed methodological procedure is optimally to solve on a specific example, it means concrete railway line or transport route. Therefore, it is necessary to know the frequency of passengers on the monitored railway line per year. After determining the transport currents, it is possible to calculate net tons per year, it is considered that the average weight of one passenger is 80 kg. Subsequently it is important to determine number of connections per all year. The number of train connections on working days, holidays and weekends must be known. The number of working days, holidays, and weekends in monitored year must be also known. In addition, it is necessary to know the exact order of individual train connections during all days. Only based on all these important partial information it will be possible to determine the comprehensive value of the tare for all days in the observed year.

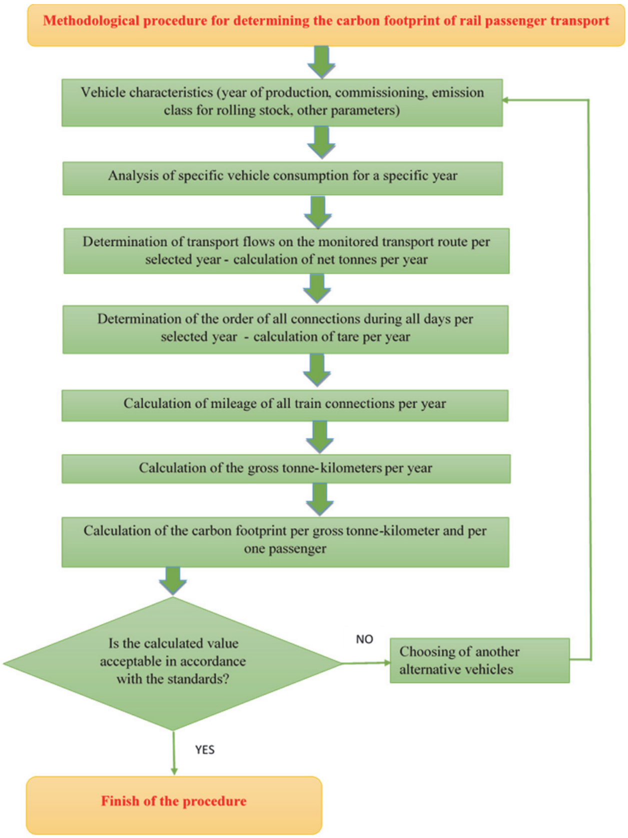


Figure 1 Methodical procedure in the flow chart

Consequently, the transport distance of the monitored transport route must be determined. However, to be able to calculate the total value of gross ton-kilometers for the whole year, it is necessary to know the mileage of all motive power units on all train connections. Once we know all the above values, it will be possible to calculate the gross ton-kilometers. The resulting value of this indicator is the sum of net tons and tare of the vehicles, multiplied by the number of kilometers driven by the motor's units of all train connections. Furthermore, it will be possible to calculate the carbon footprint per gross tone-kilometer and per one passenger using the above calculated value and internal data provided by the national passenger carrier ZSSK, j. s. c.

If all these values are already known, it is possible to compare them with the values of the standards. If the calculated value is acceptable in accordance with the standards, the procedure will be finished, and it will be possible to declare that vehicles running on the transport route meet the standards and it is not necessary to replace them. If the calculated value is not acceptable in accordance with the standards, it will be important to consider what other suitable alternative vehicles can be used on the transport route. Firstly, it is necessary to consider alternative more modern motive power units. If even in the case of these vehicles the calculated value is not acceptable in accordance with the standards, it will be necessary to take construction and reconstruction measures on the railway line and electrify the line. It will then be possible to use more modern and environmentally friendly electric units with a lower carbon footprint on the given line. Subsequently the calculated value should be acceptable in accordance with standards.

4 PRACTICAL APPLICATION ON ŽILINA - RAJEC RAILWAY LINE

The Žilina - Rajec railway line has been put into operation on October 10, 1899. It is 20.9 kilometers long (for calculation purposes, the value will be rounded to 21 km) [22]. The track is non-electrified along its entire length. The only electrified station is Žilina. 3 kV DC traction system. The characteristics of the line with basic data are given in Tab. 1.

Table 1 Basic operating data on the railway line [22]

Basic information and railway line parameters	
Infrastructure manager	Railways of Slovak Republic (ŽSR)
Track gauge	1435 mm
Number of main tracks Railway line class	1
	D3 (weight per axle 22.5 t) in the line section Žilina - Lietavská Lúčka
	C4 (weight per axle 20 t) in the line section Lietavská Lúčka - Rajec
Decisive rise in the line section Žilina - Rajec	13‰
Decisive rise in the line section Rajec - Porúbka	0‰
Decisive rise in the line section Porúbka - Žilina	17‰
Maximum track speed	60 km/h

The railway line consists of four railway stations and eight railway stops. These are listed in Tab. 2.

Table 2 Distribution of traffic points on the railway line [22]

Railway station	Railway stop
Žilina	Žilina - Zariečie
Bytčica	Žilina - Solinky
Lietavská Lúčka	Porúbka
Rajec	Poluvsie
	Rajecké Teplice
	Konskápri Rajci
	Zbyňov
	Kľače

The location of stations and stops is relatively close to each other. A passenger train that stops at each station and stop must therefore brake relatively often. At the entrance to each operating control point, the train must reduce the speed to 40 km/h.

4.1 Current State of the Žilina - Rajec Railway Line

Many types of rolling stock have changed on the railway line since the start of operation. Currently, 813-913 motive power units run on the track. The basic data needed to calculate the size of the carbon footprint are in Tab. 3, which is made according to the article [23].

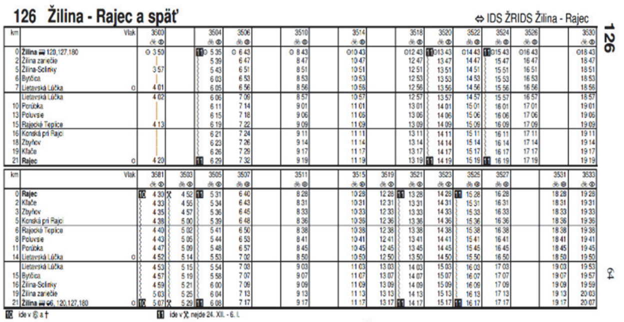
Table 3 Distribution of traffic points on the railway line [23]

Vehicle	Motive power unit 813/913
Years of production	2006 - 2009
Fuel	diesel
Power transfer	hydromechanical
Weight / t	39
Average fuel consumption / l/100 km	54.8
Type of engine	MAN D2876 LUE621
Maximum speed	90 km/h
Length over bumpers / mm	28820
Width / mm	3073
Height / mm	3770
Number of seats	78 + 5 with a bicycle
Total number of standing passenger	120

Fig. 2 shows the 813/913 motive power unit in railway station Rajec. This engine unit is the most widespread vehicle operated on Slovak local lines.

Figure 2 Motive power unit 813/913 on the Žilina - Rajec railway line

At present, a total of 11 trains in the direction Žilina - Rajec and 12 trains in the direction Rajec - Žilina run on the line during working days. During the weekend, trains run less despite the great tourist potential. The timetable for this line for the period of validity 2017/2018 is shown in Fig. 3.



126 Žilina - Rajec a späť

⇔ IDS ŽRIDS Žilina - Rajec

km	Vlak	3500	3504	3506	3510	3514	3518	3520	3522	3524	3526	3530
0	Žilina 🚌 120,127,180	⊖ 3 50	11 ⊖ 5 35	⊖ 6 43	⊖ 8 43	⊖10 43	⊖12 43	11 ⊖13 43	⊖14 43	11 ⊖15 43	⊖16 43	⊖18 43
2	Žilina zariečie	|	5 39	6 47	8 47	10 47	12 47	13 47	14 47	15 47	16 47	18 47
5	Žilina-Solinky	3 57	5 43	6 51	8 51	10 51	12 51	13 51	14 51	15 51	16 51	18 51
6	Bytčica	|	6 03	6 53	8 53	10 53	12 53	13 53	14 53	15 53	16 53	18 53
7	Lietavská Lúčka o	4 01	6 05	6 56	8 56	10 56	12 56	13 56	14 56	15 56	16 56	18 56
	Lietavská Lúčka	4 02	6 06	7 09	8 57	10 57	12 57	13 57	14 57	15 57	16 57	18 57
10	Porúbka	|	6 11	7 14	9 01	11 01	13 01	14 01	15 01	16 01	17 01	19 01
13	Poluvsie	|	6 15	7 18	9 06	11 06	13 06	14 06	15 06	16 06	17 06	19 06
15	Rajecké Teplice	4 13	6 19	7 22	9 09	11 09	13 09	14 09	15 09	16 09	17 09	19 09
16	Konská pri Rajci	|	6 21	7 24	9 11	11 11	13 11	14 11	15 11	16 11	17 11	19 11
18	Zbyňov	|	6 23	7 26	9 14	11 14	13 14	14 14	15 14	16 14	17 14	19 14
19	Kľače	|	6 26	7 29	9 17	11 17	13 17	14 17	15 17	16 17	17 17	19 17
21	Rajec o	4 20	11 6 29	7 32	9 19	11 19	13 19	11 14 19	15 19	11 16 19	17 19	19 19

km	Vlak	3581	3503	3505	3507	3511	3515	3519	3521	3523	3525	3527	3531	3533
0	Rajec	10 4 30	⚒ 4 52	11 5 31	6 40	8 28	10 28	12 28	11 13 28	14 28	11 15 28	16 28	18 28	19 28
2	Kľače	4 33	4 55	5 34	6 43	8 31	10 31	12 31	13 31	14 31	15 31	16 31	18 31	19 31
3	Zbyňov	4 35	4 57	5 36	6 45	8 33	10 33	12 33	13 33	14 33	15 33	16 33	18 33	19 33
5	Konská pri Rajci	4 38	5 00	5 39	6 48	8 36	10 36	12 36	13 36	14 36	15 36	16 36	18 36	19 36
6	Rajecké Teplice	4 40	5 02	5 41	6 50	8 38	10 38	12 38	13 38	14 38	15 38	16 38	18 38	19 38
8	Poluvsie	4 43	5 05	5 44	6 53	8 41	10 41	12 41	13 41	14 41	15 41	16 41	18 41	19 41
11	Porúbka	4 47	5 09	5 48	6 57	8 45	10 45	12 45	13 45	14 45	15 45	16 45	18 45	19 45
14	Lietavská Lúčka o	4 52	5 14	5 53	7 02	8 50	10 50	12 50	13 50	14 50	15 50	16 50	18 50	19 50
	Lietavská Lúčka	4 53	5 15	5 54	7 03	9 03	11 03	13 03	14 03	15 03	16 03	17 03	19 03	19 53
15	Bytčica	4 57	5 19	5 58	7 07	9 07	11 07	13 07	14 07	15 07	16 07	17 07	19 07	19 57
16	Žilina-Solinky	4 59	5 21	6 00	7 09	9 09	11 09	13 09	14 09	15 09	16 09	17 09	19 09	19 59
19	Žilina zariečie	5 03	5 25	6 04	7 13	9 13	11 13	13 13	14 13	15 13	16 13	17 13	19 13	20 03
21	Žilina 🚌 ⊖6, 120,127,180 o	10 5 07	⚒ 5 29	11 6 08	7 17	9 17	11 17	13 17	11 14 17	15 17	11 16 17	17 17	19 17	20 07

10 ide v ⑥ a †

11 ide v ⚒ nejde 24. XII. - 6. I.

126

64

Figure 3 Timetable for railway line Žilina - Rajec and back [24]

The timetable maintains the hourly rate in both directions in the morning and afternoon traffic peak. Otherwise, trains run in both directions every two hours. It can be seen from the timetable that the potential of the line is not fully exploited, as the last train in the direction Žilina - Rajec leaves Žilina at 18:43 and the last train from Rajec leaves at 19:28. One of the reasons is the parallel tracing of the road. The resulting "holes" are filled by buses of the carrier Slovenskáautobusovádoprava Žilina. To achieve the highest possible accuracy and reduce transmitted delays, trains at the Žilina railway station do not wait for any missed train connections.

One of the first indicators needed to calculate the carbon footprint is the number of passengers on the train. Data on the number of passengers boarding and getting out at individual railway stations and stops are based on an extensive survey carried out in 2018. These are internal data collected by the then expanding Integrated Transport of the Žilina Region. These data can be found in Tab. 4.

Table 4 Passengers´ frequency on the Žilina - Rajec railway line [25]

Traffic point	Boarding	Getting out	Σ
Žilina	1515991	1409148	2925139
Bytčica	1327	1844	3171
Lietavská Lúčka	1602	2077	3679
Porúbka	174	197	371
Poluvsie	445	511	956
Rajecké Teplice	6298	10626	16924
Konskápri Rajci	269	422	691
Zbyňov	255	424	679
Kl'ače	1273	1478	2751
Rajec	5575	7091	12666
Σ	1533209	1433818	2967027

Cities with the greatest potential for passengers are Žilina, as a regional and catchment area. In second place are Rajecké Teplice, which is known as a spa town and is frequently visited by tourists, especially in the summer months. The least passengers were transported from/to the Porúbka railway stop. This stop has very little potential because it is more than 2 km away from the village Porúbka. Other train stations and stops are within easy walking distance. The Žilina railway station also has good accessibility by day and night public transport.

The next step is to determine the average weight of one passenger. The methodology of the Railways of the Slovak Republic determines the average weight of an adult passenger at 80 kg, which is 0.08 t. Based on the total number of passengers carried by all trains in 2018 and the average weight of one passenger, the Eq. (1) can be used to calculate net tons per year 2018.

$$\begin{aligned} &Net\ tons = \\ &= number\ of\ all\ passengers \cdot average\ weight\ of\ passenger \end{aligned} \tag{1}$$

After substituting the appropriate values into the equation, they are net tons per year 2018 (during the validity of the timetable) total 237362.16 t. This value will be used in further mass calculations.

Now it is necessary to divide the traffic separately for the direction Žilina - Rajec and Rajec - Žilina. For both directions separately, the tare value for the year is calculated. The operational data needed to calculate this indicator are quantified in Tab. 5.

We can see from the table that a total of three motive power units provide passenger transport on the line. Most trains run on one train unit. In the peak hours of working days, two connected motive power units are deployed on selected trains to increase the total capacity. Only on the 3500 train in the direction Žilina - Rajec there are three connected motive power units. It is the transport of empty sets for driving in the opposite direction. It is also necessary to know the significance of the number of days in the year during which the individual sets run. This can be found in Tab. 6.

Table 5 Vehicle operational indicators on the Žilina - Rajec railway line

Direction	Train number	Number of days of operation of vehicle no. 1	Number of days of operation of vehicle no. 2	Number of days of operation of vehicle no. 3	Vehicle number per years
Žilina - Rajec	3500	365		242	972
	3502	242			242
	3504	365			365
	3506				
	3508				
	3510				
	3512	242			242
	3514	365	242		607
	3516	242			242
	3518	365			365
	3520				
Rajec - Žilina	3581	116			116
	3501	249			249
	3503	242			242
	3505	365	242		607
	3507				365
	3509				
	3511				
	3513	242			242
	3515	365			365
	3517	242			484
	3519	365			365
	3521				
	3523				
Σ		7657	1091	242	8990

Table 6 Significance of the number of days of travel of individual sets included in trains during the validity of the 2017/2018 timetable

Number of days	Runs frequency
116	the trains runs on Saturdays, Sundays and public holidays
242	the trains run on weekdays, except during the Christmas holidays
249	the trains run on weekdays
365	the trains run daily

From Tab. 5 we can see that most trains run daily and at peak hours are trains that run only on weekdays, except for the Christmas holidays.

In the next step, it is necessary to calculate vehicle kilometers per year. These are calculated according to Eq. (2).

$$\begin{aligned} &Kilometers\ per\ year = \\ &= vehicle\ number\ per\ year \cdot kilometers\ per\ day \end{aligned} \tag{2}$$

After substituting the values into this equation, Tab. 7 was created, where the values of vehicle kilometers for the year 2018 are calculated for both directions and all trains.

From the table we can see that the passenger train has the most vehicle kilometers 3500, because it runs daily and consists of three motive power units. The passenger train has the least vehicle kilometers 3581, which runs only on weekends and public holidays and at the same time consists of only one motive power unit.

Subsequently, it is necessary to calculate the total tare of all motive power units running on the line Žilina - Rajec in both directions. This is possible according to Eq. (3).

$$\begin{aligned} &Total\ tare\ per\ year = \\ &= total\ vehicle\ number\ per\ year \cdot one\ vehicle\ weight \end{aligned} \tag{3}$$

Table 7 Kilometres per year during the validity of the 2017/2018 timetable

Direction	Train number	Kilometres per year
Žilina - Rajec	3500	20412
	3502	5082
	3504	7665
	3506	
	3508	
	3510	
	3512	5082
	3514	12747
	3516	5082
	3518	7665
	3520	
Rajec - Žilina	3581	2436
	3501	5229
	3503	5082
	3505	12747
	3507	7665
	3509	
	3511	
	3513	5082
	3515	7665
	3517	10164
	3519	7665
	3521	
	3523	
Σ		188790

The total tare of all trains on the Žilina - Rajec line in both directions is 350610 t. The calculation is valid for train traffic diagram 2017/2018.

The next step is to calculate the total gross tons. These can be calculated according to Eq. (4).

$$\begin{aligned}&Total\ gross\ tones=\\&=net\ tones\ per\ year+total\ tare\ per\ year\end{aligned}\tag{4}$$

As a result, the value is 587972.16 t. The calculation is valid for train traffic diagram 2017/2018.

The last indicator used to calculate the carbon footprint is the total gross tonne-kilometers. This indicator is calculated according to Eq. (5).

$$\begin{aligned}&Total\ gross\ tone\ kilometers=\\&=total\ gross\ tones\cdot total\ kilometers\end{aligned}\tag{5}$$

During the validity of the 2017/2018 train traffic diagram on the Žilina - Rajec railway line, there are a total of 111003264086.40 gross tonne-kilometers. This data will be used in the calculation of the carbon footprint produced by one passenger when the train is 60% busy, which is the optimal value of occupancy in the conditions of passenger rail transport in Slovakia.

First, it is necessary to determine the basic data about the motive power unit in the context of fuel consumption. This information is given in Tab. 8.

Table 8 Energy profile of the motive power unit 813/913 [26]

Railway vehicle	Vehicle age	Emission factor	Fuel consumption	
813/913	12 - 15	0	12.14 l/1000 grtkm	0.01 l/1 grtkm

The standards mentioned in Tab. 8 are based on UIC standards [26]. At the same time, Tab. 8 shows that the emission factors from 2006, when the modernization of motive power units 810 to motive power units 813/913 began, were not the emission limits and rules as strict as they are today.

$$Total\ fuel\ consumption=fuel\ consumption\cdot total\ grtkm\tag{6}$$

After substituting the values, the result is 1347357619.48 l/total grtkm. This is one of the values that will be compared with the intended use of the 671 series electric vehicles.

We will now look at the production of other emissions that are generated by the operation of motive power units on railways. The names of the elements with their abbreviations and the measured values are given in Tab. 9.

Table 9 Values of other elements produced by a motive power unit of series 813/913

Element name and abbreviation	Value / g/1000 grtkm
Carbon monoxide (CO)	130.31
Hydrocarbon (HC)	34.75
Nitrogen oxide (NO_x)	260.62
Powder metallurgy (PM)	10.86
Carbon dioxide (CO_2)	38231.11
Σ	38667.65

The percentage of air pollutions by these substances is represented by the pie chart in Fig. 4.

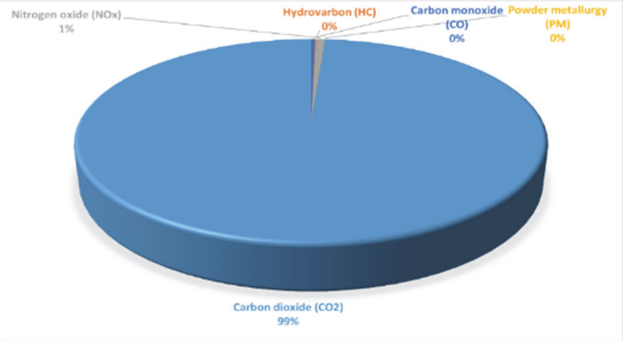


Figure 4 Percentage of air pollutants motive power unit 813/913

It is clear from the graph that the dominant part is carbon dioxide. The remaining elements are negligible.

As in the previous case, in the case of fuel consumption, it is still necessary to recalculate the total consumption of the production of these harmful substances per one kilometer gross. It is a number 0.04 kg/1 grtkm. Slightly modified Eq. (7), which is based on Eq. (6), determines the total consumption of air pollutants at total gross tonne-kilometers.

$$\begin{aligned}&Total\ emission\ consumption=\\&=emission\ consumption\cdot total\ grtkm\end{aligned}\tag{7}$$

After substituting the appropriate values, the result is 4292235699.95 total kg/total grtkm. The final but equally key phase will be the calculation of fuel consumption and the calculation of harmful emissions per passenger, respectively per seat on the train. First, it is necessary to determine the occupancy of the train. It varies according to the parts of the day, so it depends on the traffic peak or off-peak. In the realistic variant, an average occupancy of 60% can be considered. Summary Tab. 10 presents the methods of calculations of individual parameters and their results.

Table10 Conversion of fuel consumption and emission per passenger/per seat on the train

Indicator	Method of calculation	The result
number of vehicles per year	-	8990 motive power units
occupancy 60%	total passenger capacity × 0.6	116 passenger
60% occupancy per year	number of vehicles per year × occupancy 60%	1042840 passenger
total net tons per year	60% occupancy per year × average weight of one passenger	83427.20 tons
total tare per year	-	350610 tons
total gross tons	total net tons per year + total tare per year	434037.20 gross tons
total kilometres	-	188790 km
total gross ton-kilometres	total gross tons × total kilometres	81941882988 gross ton-kilometres
l/total grtkm per year	l/1 grtkm × total gross ton-kilometres	994610575.71 l/total grtkm
l/total grtkm per year to one seat on the train	l/total grtkm per year / total trains capacity per year	953.75 l/total grtkm per year to 1 seat on the train
kg/total grtkm per year	total kg/1 grtkm × total gross ton-kilometres	3168509299.31 kg/total grtkm per year
kg/total grtkm per year to one seat on the train	kg/total grtkm per year/total train capacity per year	3038.34 kg/total grtkm per year to one seat on the train

The green boxes are the steps to calculate occupancy, weight, and kilometers. The red boxes are the final calculations of fuel consumption and emissions. In principle, the more a train is occupied, the lower the fuel consumption and emissions.

4.2 Proposed Use of Electric Motor Train Set on the Žilina-Rajec Railway Line

The proposal to improve the operation and reduce the consumption of the carbon footprint assumes the electrification of the Žilina - Rajec line and the deployment of electric motor train sets. During electrification, the use of a 25kV, 50Hz AC traction system is prospectively considered, even though the entire Žilina railway junction is currently electrified by a 3kV DC traction system. However, as the Žilina node is currently under reconstruction, the switching of the traction system from one-way to alternating is also expected within its individual phases.

The authors consider the deployment of an electric motor train set of the 671 series to be the most suitable. It is a double-decker train, which is particularly suitable for its capacity. All basic data on the proposed electric motor train set unit are in Tab. 11.

Fig. 5 shows the 671/971 electric motor train set at the Žilina railway station after the arrival of a passenger train from Trenčín.

Figure 5. Electric motor train set 671/971 at the Žilina railway station

Table 11 Basic information about the proposed vehicle [27]

Vehicle	electric motor train set 671/971
Years of production	2010 - 2015
Fuel	electric energy
Continuous power	2000 kW
Power regulation	semiconductor
Weight / t	166.7
Energy consumption / kWh/1000 grtkm	34.41
Maximum speed	160 km/h
Length over bumpers / mm	79200
Width / mm	2820
Height / mm	4635
Number of seats	307 + 4 seats are reserved for wheelchairs
Total number of standing passenger	640

The timetable remains in force despite the change of vehicle as shown in Fig. 3. Thanks to better accelerations during start and stop, in real conditions the arrival and departure times to and from individual stations and stops would be reduced by a maximum of one minute. However, for the purposes of this article, the original version of the timetable shall suffice. The average weight of one passenger also remains valid. The number of passengers will also not change, as we will be based on the same period, i. e. Tab. 4. It follows that even net tons will not be changed. At the same time, the total tare and the gross tons will not change.

A fundamental change occurs in the operation of individual sets. The factor for the change is the number of seats, which will increase by 229 compared to the current situation. Therefore, it will not be necessary to run more than one set on one train. The new composition of the sets is in Tab. 12.

Table 12 Proposed distribution of seats during the year when vehicle change

Direction	Train number	Number of days of operational of vehicle no. 1	Vehicle number per years
Žilina - Rajec	3500	365	365
	3502	242	242
	3504	365	365
	3506		
	3508		
	3510		
	3512	242	242
	3514	365	365
	3516	242	242
	3518	365	365
	3520		
Rajec - Žilina	3581	116	116
	3501	249	249
	3503	242	242
	3505	365	365
	3507		
	3509		
	3511		
	3513	242	242
	3515	365	365
	3517	242	242
	3519	365	365
	3521		
	3523		
Σ		7657	7657

The train set for the direction Rajec - Žilina will be included in train 3500 without passenger frequency, empty and locked.

The individual calendar restrictions on trains, which are expressed over the number of days of running of each train during the year, also remain in force according to Tab. 6.

However, Tab. 7 will be modified. The change depends on the number of vehicles deployed according to Eq. (2). The new kilometers values per year are given in Tab. 13.

Table 13 New values of annual kilometers

Direction	Train number	Kilometres per year
Žilina - Rajec	3500	7665
	3502	5082
	3504	7665
	3506	
	3508	
	3510	
	3512	5082
	3514	7665
	3516	5082
	3518	7665
	3520	
Rajec - Žilina	3581	2436
	3501	5229
	3503	5082
	3505	7665
	3507	
	3509	
	3511	
	3513	5082
	3515	7665
	3517	5082
	3519	7665
	3521	
	3523	
Σ		160797

Based on the new values in Tab. 13, the values of the other key indicators also changed. Changes from the current situation are shown in Tab. 14.

Table 14 Mass value after change of rolling stock deployed

Weight indicators	Proposed state
Net ton per year	235223.04
Total tare per year	1276422
Total gross tones	1511645.04
Total kilometres	188790
Total gross-tonne kilometres	243067987496.88

The original and new values in the table are calculated based on Eq. (2) to Eq. (5). All values, except the number of annual kilometers, have increased. The annual kilometers have been reduced due to the creation of set trains that do not carry passengers.

The energy consumption of an electric motor train set differs from that of a motive power unit. Tab. 15 shows the electricity consumption values depending on the age of the vehicle and the emission class.

Table 8 Energy profile of the motive power unit 813/913 [27]

Railway vehicle	Vehicle age	Emission factor	Electric energy consumption	
671/971	6 - 11	E	34.41 kWh/1000 grtkm	0.03 kWh/1 grtkm

It is clear from the table that the electric motor train sets are younger than the motive power units that are currently deployed on the track. As electricity consumption is many times less burdensome for the environment, its value is acceptable. The calculation of electricity consumption will be based on a slightly modified Eq. (6).

$$\begin{aligned} &Total\ electric\ energy\ consumption = \\ &= electric\ energy\ consumption \cdot total\ grtkm \end{aligned} \tag{8}$$

After substituting the values, the result is 8276005806.86 kWh/total grtkm. As a result, we see that an electric motor train set consumes more electricity than a motive power unit consumes diesel. The difference is almost seven billion. It is essential to realize that electricity consumption is more environmentally friendly than consumption of diesel, which is harmful to the environment.

We will now look at the production of other emissions that are generated by the operation of electric motor train set on railways. The names of the elements with their abbreviations and the measured values are given in Tab. 16.

Table 16 Values of other elements produced by an electric motor train set of series 671/971

Element name and abbreviation	Value / g/1000 grtkm
Carbon monoxide (CO)	1.20
Sulfur dioxide (SO_2)	27.49
Nitrogen oxide (NO_x)	3.79
Powder metallurgy (PM)	0.19
Carbon dioxide (CO_2)	3507.17
Σ	3539.84

The main change in the production of harmful substances for the environment is the production of sulfur dioxide. At the same time, the electric motor train set does not produce hydrocarbons. The percentage of air pollution by these substances is represented by the pie chart in Fig. 6.

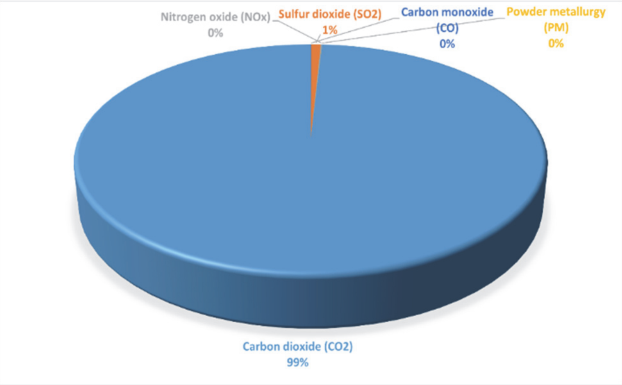


Figure 6 Percentage of air pollutants of electric motor train set 671/971

Within the percentage, it is again almost one hundred percent CO_2. In absolute numbers, however, this proportion is smaller when using electric traction than when using diesel traction.

As in the previous case, in the case of electric energy consumption, it is still necessary to recalculate the total consumption of the production of these harmful substances per one kilometer gross. It is a number 0.003 kg/1 grtkm. Compared to the originally used motor unit, this consumption is incomparably lower.

Substituting into Eq. (7), it can be stated that the emission consumption when using an electrical unit is 1160143312.34 total km/total grtkm. This number is again lower than when using a motive power unit.

Despite the higher comfort and better driving characteristics, we will also consider a 60% occupancy rate when using the 671/971 electric motor train set. Although it is assumed that the change of deployed vehicles on the track solved by us will increase the occupancy of the unit by passengers. At the same time, however, it is necessary to emphasize that the increase in the number of passengers on the Žilina - Rajec line does not only depend on the change of vehicles, but also on the parameters of the line. Only when the line would undergo a comprehensive reconstruction with an increase in line speed, it would be possible to expect an influx of passengers into the train. In the context of congestion in the morning at the entrance to Žilina and in the afternoon at the exit to Žilina, the train would be the number one choice for passengers. In Tab. 17, electricity consumption and emissions are converted to 60% occupancy.

Table 17 Conversion of electric energy consumption and emission per passenger/per seat on the train

Indicator	Method of calculation	The result
number of vehicles per year	-	7657 electric motor train sets
occupancy 60%	total passenger capacity × 0.6	384 passenger
60% occupancy per year	number of vehicles per year × occupancy 60%	2940288 passenger
total net tons per year	60% occupancy per year × average weight of one passenger	235223.04 tons
total tare per year	-	1276422 tons
total gross tons	total net tons per year + total tare per year	1511645.04 gross tons
total kilometres	-	160797 km
total gross ton-kilometres	total gross tons × total kilometres	243067987496.88 gross ton-kilometres
kWh/total grtkm per year	kWh/1 grtkm × total gross ton-kilometres	8264311574.89kWh/total grtkm
kWh/total grtkm per year to one seat on the train	kWh/total grtkm per year / total trains capacity per year	2810.71 l/total grtkm per year to 1 seat on the train
kg/total grtkm per year	total kg/1 grtkm × total gross ton-kilometres	860422799.11 kg/total grtkm per year
kg/total grtkm per year to one seat on the train	kg/total grtkm per year / total train capacity per year	292.63 kg/total grtkm per year to one seat on the train

A comparison of individual results is published in the final part of the article. However, it can already be stated that while the electricity consumption is higher than the diesel consumption, the exhaust gases discharged into the air are an order of magnitude lower when using an electric motor train set than when using an engine motive power unit.

5 DISCUSSIONS

It follows from the previous chapter that the benefits in the field of environmental protection are large within the considered electrification of the Žilina - Rajec line. From the point of view of the entire Slovak railway network, however, it is only a drop in the ocean. It is one thing to protect the environment, but today's world is looking primarily at the financial side of the whole project. Therefore, the authors further suggest that research should go in this direction.

The electrification of any line then influences the organization of the operation on the line. Whether it is the deployment of electric trains, at least a minimal reduction in travel times due to generally better traction characteristics or a general change in the concept of transport on the line in question. We can therefore summarize the mentioned criteria under a package of operational criteria [28, 29].

There are many traction systems around the world. The appropriate system is prioritized according to operational and economic criteria. At the same time, there are many components that support individual decisions [30].

The basis of all electrification projects is a technical and economic analysis of the pros and cons of the entire project. The strengths and weaknesses of the whole project will be identified and, depending on the resulting values, it will either proceed or will not be implemented. Today, alternative drives are also being addressed, most often hydrogen, often referred to as the drive of the future [31].

Various simulation programs of a mathematical-economic or financial nature are also a good helper for confirming or rejecting a decision [32].

Based on the above knowledge and research to date, the following questions need to be answered as part of the further direction of research:

1. What will be the next indicative data for the implementation of the project?
2. What methodology will be used to evaluate the pros and cons of the whole project?
3. What traction system will be used and why?
4. How will the eventual electrification of the Žilina - Rajec railway line change operations?

This is just a fragment of the questions that authors have in the context of electrification and environmental improvement. After answering them, however, a comprehensive material will be created as a basis for the possibility of electrification of the Žilina - Rajec railway line.

The proposed methodology may not only be applicable to the calculation or comparison of the carbon footprint, but may also be used as a means to introduce or cancel passenger rail transport on any line and in any country that is a member of the UIC. In terms of significance, it would only be a supporting and not a key element in the decision-making process. In such a case, the socio-economic consequences of such a decision should be taken into account as the main elements.

6 CONCLUSION

The conclusion will consist of three main units to follow each other. The basic indicators in relation to the environment will be compared.

First, it is the number of places when using the motive power unit at present and when using the electric motor train set in a possible scenario. In principle, the more a train is occupied, the lower the energy and environmental intensity will be quantified. Manufacturers of new means of transport used in public transport are also trying to produce in such a way that as many seats as possible are available. Especially on regional and long-distance routes. Often even at the cost of comfort, but in recent years this has been abandoned because it does not attract passengers, so comfort comes to the fore again. The total number of seats occupied (including seats for bicycles and/or immobile passengers) and the number of seats occupied at 60% occupancy are shown in Fig. 7.

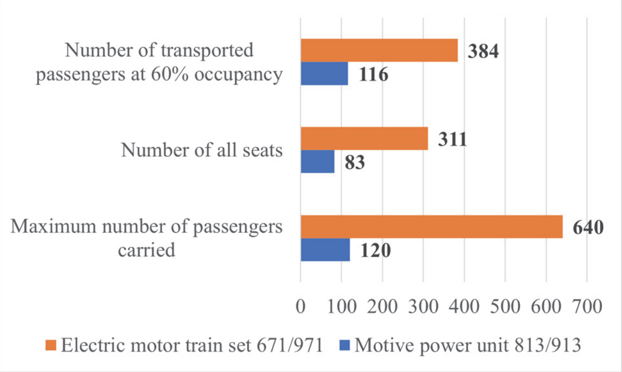


Figure 7 Capacity comparison of vehicle

It is clear from the figure that the deployment of an electric motor train set is a better solution in terms of capacity. Especially if we want to attract more passengers. This will then be reflected on the 1st class road, which runs parallel to the railway line from Žilina to Rajec. If rail transport is a priority for passengers, not only will there be fewer cars on the road and the environment will not be so damaged, but the congestion on this road will also be smaller and irregular.

Another indicator compared is fuel consumption. While the motive power unit consumes diesel, the electric motor train set consumes electricity. The annual fuel consumption and conversion per seat in the train is shown in Tab. 18.

Table 18 Comparison of fuel consumption when using independent and dependent traction

Fuel consumption	Motive power unit 813/913	Electric motor train set 671/971
l/total grtkm per year	994610575.71	-
l/total grtkm per year to one seat on the train	953.75	-
kWh/total grtkm per year	-	8264311574.89
kWh/total grtkm per year to one seat on the train	-	2810.71

The electricity consumption when using an electric motor train set is several times higher than the diesel consumption when using a motive power unit. In this case, however, it is beneficial for the environment because electricity is more acceptable than diesel and contains fewer harmful substances.

The last area compared is the consumption of harmful substances into the air. This consumption is also expressed as an annual indicator and calculated per seat at 60% occupancy. This comparison is crucial, especially from an ecological point of view, and should also be crucial in assessing the suitability of electrification of the Žilina - Rajec railway line. The comparison is shown in Fig. 8.

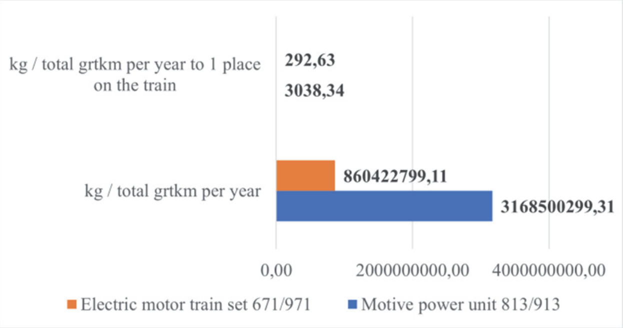


Figure 8 Comparison of ecological demands of individual vehicles

When using an electric unit, the emissions to air are several times lower, which is much more acceptable for the long-term use of this type of traction for the environment.

The authors therefore clearly recommend electrifying the line due to more environmentally friendly demands than in the current state. At the same time, they recommend the use of 671/971 series electric motor train sets, due to their good capacity and ecological properties. At the same time, they see the possibility of introducing new connections on the operational side.

The advantage of this methodology is that it is also applicable on other railway lines where passenger transport has potential. It can also be used in UIC member countries because of the values that this organization provides. It can also be one of the decision criteria when introducing or abolishing passenger rail transport.

Acknowledgment

"This publication was created thanks to support under the Operational Program Integrated Infrastructure 2014 - 2020 for the project: Innovative solutions for propulsion, energy and safety components of vehicles, with ITMS project code 313011V334, co-financed by the European Regional Development Fund"

EURÓPSKA ÚNIA
Európsky fond regionálneho rozvoja
OP Integrovaná infraštruktúra 2014 – 2020

MINISTERSTVO
DOPRAVY A VÝSTAVBY
SLOVENSKEJ REPUBLIKY

7 REFERENCES

[1] Bhandari, K., Advani, M., Panda, P., & Gagopadhyay, S. (2014). Consideration of access and egress trips in carbon footprint estimation of public transport trips: case study of Delhi. *Journal of Cleaner Production*, *85*, 234-240. https://doi.org/10.1016/j.jclepro.2014.05.013

[2] Aminzadegan, S., Shahriari, M., & Mehranfar, F. (2022). Factors affecting the emission of pollutants in different types of transportation: A literature review. *Energy Reports*, *8*, 2508. https://doi.org/2529. 10.1016/j.egyr.2022.01.161

[3] Craven, N., Braschi, A., Barrón, I., Ishii, T., Lee, C. K., Ashida, N., & Lémeri, J. (2016). *Carbon Footprint of Railway Infrastructure: Comparing existing methodologies on typical corridors Recommendations for harmonized approach.* https://uic.org/IMG/pdf/carbon_footprint_of_railway_infrastructure.pdf

[4] Jurkovič, M., Kalina, T., Skrúcaný, T., Gorzelanczyk, P., Ľupták, V. (2020). Environmental Impacts of Introducing LNG as alternative fuel for urban buses case study in Slovakia. *Promet-Traffic &Transportation*, *32*(6), 837-847. https://doi.org/10.7307/ptt.v32i6.3564

[5] Skrúcaný, T., Stopková, M., Stopka, O., Kalašová, A., & Ovčiarik, P. (2021). User's determination of a proper method for quantifying fuel consumption of a passenger car with compression ignition engine in specific operation conditions. *Open Engineering*, *11*(1), 151-160. https://doi.org/10.1515/eng-2021-0018

[6] Dimitriou, L. & Kartsonakis, T. (2016). Hierarchical Multi-objective Games of Transport Demand Reallocation for Minimizing Carbon Footprint in Developing Urban Areas. *IEEE Mediterranean Electrotechnical Conference MELECON*. https://doi.org/10.1109/MELCON.2016.7495472

[7] Dolara, A. & Leva, S. (2012). Multiconductor Transmission Line Models for PQ and EMC Analysis of Railway Electrification Systems. *International Review of Electrical Engineering IREE*, *7*(5), 5795-5807.

[8] Duan, H., Hu, M., Zuo, J., Zhu, J., Mao, R., & Huang, Q. (2017). Assessing the carbon footprint of the transport sector in mega cities via streamlined life cycle assessment: a case study of Shenzhen, South China. *International Journal of Life Cycle Assessment*, *22*(5), 683-693. https://doi.org/10.1007/s11367-016-1187-5

[9] Van Fan, Y., Perry, S., Klemes, J. J., Lee, C. T. (2018). A review on air emissions assessment: Transportation. *Journal of Cleaner Production, 194*, 673-684. https://doi.org/10.1016/j.jclepro.2018.05.151

[10] Ghate, A. T. & Qamar, S. (2020). Carbon footprint of urban public transport systems in Indian cities. *Case Studies on Transport Policy*, *8*(1), 245-251. https://doi.org/10.1016/j.cstp.2019.01.005

[11] Ghosh, A. (2020). Possibilities and Challenges for the Inclusion of the Electric Vehicle (EV) to Reduce the Carbon Footprint in the Transport Sector: A Review. *Energies*, *13*(10), 1-22. https://doi.org/10.3390/en13102602

[12] Hu, J., Wood, R., Tukker, A., Boonman, H., & de Boer, B. (2019). Global transport emissions in the Swedish carbon footprint. *Journal of Cleaner Production*, *226*, 210-220. https://doi.org/10.1016/j.jclepro.2019.03.263

[13] Integrovaná doprava Žilinského kraja. (2018). Interné údaje sčítania cestujúcich. Žilina: Integrovaná doprava Žilinského kraja.

[14] Kendra, M., Skrúcaný, T., Grenčík, J., & Šulko, P. (2018). Impact of Railway Track Parameters on Energy Consumption and GHG Production of Passenger Train Operation. *Proceedings of the International Conference on Road and Rail Infrastructure CETRA.* Zadar. https://doi.org/10.5592/CO/CETRA.2018.712

[15] Kocaarslan, I., Akcay, M. T., Ulusoy, S. E., Bal, E., & Tiryaiki, H. (2017). Creation of a dynamic model of the electrification and traction power system of a 25 kV AC feed railway line together with analysis of different operation scenarios using MATLAB/Simulink. *Turkish Journal of Electrical Engineering and Computer Sciences*, *25*(5), 4254-4267. https://doi.org/10.3906/elk-1612-84

[16] Lo-Iacono Ferreira, V., Vinoles-Cebolla, R., Jose Bastante-Ceca, M., & Capuz-Rizo, S. (2020). Transport of Spanish fruit and vegetables in cardboard boxes: A carbon footprint analysis. *Journal of Cleaner Production*, *244*, 1-12. https://doi.org/10.1016/j.jclepro.2019.118784

[17] Londono Gallego, J., Londono Marin, S., Lopez Romero, C., Vahos Montoya, J. D., Escobar Castrillon, L. A., & Rendon Pareja, S. (2020). Development of a mobile and web application that calculates the carbon footprint in the education and transport sector. *Revista Digital Lampsakos*, *23*, 45-55. https://doi.org/10.21501/21454086.3302

[18] Ma, F., Wang, W., Sun, Q., Liu, F., & Li, X. (2018). Ecological Pressure of Carbon Footprint in Passenger Transport: Spatio-Temporal Changes and Regional Disparities. *Sustainability*, *10*(2), 1-17. https://doi.org/10.3390/su10020317

[19] Massel, A. (2017). Operational criteria in the justification of electrification of railway lines. *13th International Conference Modern Electrifield Transport MET′ 2017.* Warsaw. https://doi.org/10.1051/matecconf/201818006005

[20] Massel, A. (2018). Impact of Line Electrification on Operation of Railways. *Transport Means.* Trakai.

[21] Piecyk, M. I. & McKinnon, A. (2010). Forecasting the carbon footprint of road freight transport in 2020. *International Journal of Production Economics*, *128*(1), 31-42. https://doi.org/10.1016/j.ijpe.2009.08.027

[22] Prispievatelia Wikipédie. (2020). *Železničná trať Žilina-Rajec*. (Wikipedia). https://sk.wikipedia.org/w/index.php?title=%C5%BDelezni%C4%8Dn%C3%A1_tra%C5%A5_%C5%BDilina_%E2%80%93_Rajec&oldid=6961487

[23] Prispievatelia Wikipédie. (2021). *Elektrická jednotka 671*. (Wikipedia). https://sk.wikipedia.org/w/index.php?title=Elektrick%C3%A1_jednotka_671&oldid=7173805

[24] Přispěvatelé Wikipedie. (2021). *Uhlíková stopa*. (Wikipedie: Otevřená encyklopedie). https://cs.wikipedia.org/w/index.php?title=Uhl%C3%ADkov%C3%A1_stopa&oldid=20115339

[25] Railways of Slovak Republic. (2017). *Timetable for passenger trains 2017/2018.* Bratislava: Railways of Slovak Republic.

[26] Skrúcaný, T. & Kendra, M. (2019). Environmentálne posúdenie vybraných vplyvov dopravnej obsluhy regiónu. *Svet Dopravy*, *2*(2), 42-46.

[27] Skrúcaný, T., Kendra, M., Čechovič, T., Majerník, F., & Pečman, J. (2021). Assessing the Energy Intensity and Greenhouse Gas Emissions of the Traffic Services in a Selected Region. *LOGI-Scientific Journal on Transport and Logistics*, *12*(1), 25-35. https://doi.org/10.2478/logi-2021-0003

[28] Slovak Institute of Technical Standardization. (2013). *STN EN 16258: 2013 Methodology for calculating and declaring energy consumption and greenhouse gas emissions from transport services (freight and passenger transport).* Bratislava: Slovak Institute of Technical Standardization.

[29] Stokenberga, A. & Schipper, L. (2012). Trends in Transport Activity, Energy Use, and Carbon Footprint in Mexico City, Mexico. *Transportation Research Record*, *2287*, 105-112. https://doi.org/10.3141/2287-13

[30] Val, S., Royo, B., & Cipres, C. (2019). Carbon Footprint Accounting in Freight Transport: Training Needs. *Towards Users-Centric Transport in Europe: Challenges, Solutions and Collaborations*, 223-236. https://doi.org/10.1007/978-3-319-99756-8_15

[31] Wang, J. & Lin, P. C. (2021). Should the Same Products Consumed in Different Retail Channels Have an Identical Carbon Footprint? An Environmental Assessment of Consumer Preference of Retail Channels and Mode of Transport. *Sustainability*, *13*(2), 1-12. https://doi.org/10.3390/su13020615

[32] Zenith, F., Isaac, R., Hoffrichter, A., Thomassen, M. S., & Moller-Holst, S. (2020). Techno-economic analysis of freight railway electrification by overhead line, hydrogen and batteries: Case studies in Norway and USA. *Proceedings of the Institution of Mechanical Engineeris Part F: Journal of Rail & Rapid Transit*, *234*(7), 791-802. https://doi.org10.1177/0954409719867495

Contact information:

Juraj ČAMAJ, assoc. prof.
University of Žilina,
010 26 Žilina, Slovakia
E-mail: camaj@fpedas.uniza.sk

Adrián ŠPERKA
University of Žilina,
010 26 Žilina, Slovakia
E-Mail: sperka@uniza.sk

Milan DEDÍK, PhD
(Corresponding author)
University of Žilina,
010 26 Žilina, Slovakia
E-mail: dedik@fpedas.uniza.sk

Karol HRUDKAY, PhD
University of Žilina,
010 26 Žilina, Slovakia
E-mail: hrudkay@uniza.sk