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LOGI – Scientific Journal on Transport and Logistics
Vol. 12 No. 1 2021 DOI: 10.2478/logi-2021-0003
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Assessing the Energy Intensity and Greenhouse Gas Emissions of the Traffic Services in a Selected Region

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Received: 8 December 2020; Revised: 22 April 2021; Accepted: 27 April 2021; Published: 20 May 2021

Abstract: The consumption of internal combustion vehicles and the resulting emissions associated with their operation have been at the forefront in the development of the automotive industry in recent years. This development is supported and required by a number of public administration organizations. This research deals with the monitoring of selected parameters for different types of means of transport, while the unifying element is consumption and emissions per passenger. The aim of the research is to determine the optimal vehicle for passenger transport for selected transport between two specific cities in Slovakia, Europe. The research used methods of analysis of energy intensity and emissions of individual transport units, while fuel consumption in a particular transport relationship is a decisive evaluation factor, which includes the calculation of experimental measurements in a real traffic situation. The various data and diagrams provide relevant data on the fuel consumption values achieved by the experiment converted to fuel consumption. The research is given as an example, and its principle can be applied in other specific localities. it can be applied to others, they may also apply to other transport routes.

Keywords: Transport, emissions, CO_2, consumption, energy

1. Introduction

Passengers particularly welcome effective, fast and cheap transportation. The article suggests a possible solution for choosing an optimal means of transport on a selected route in Western

Slovakia on the border with Moravia (Czech Republic) – a connection of two neighbouring district towns Nové Mesto nad Váhom – Myjava by recalculating the fuel consumption per passenger.

Authors [1] analysed a similar issue, explaining the reduction in CO2 emissions and energy consumption of buses by shedding vehicle weight. The study of automotive producers revealed substantial savings in cutting down the car and lorry ballast as a result of an increase in using polymer materials [2]. This considerable weight reduction involves optimizing the bodywork structure, using light materials, and implementing new manufacturing processes. Another possibility to cut emissions and energy intensity may be equipping the car fleet with vehicles complying with the highest European emission standard or buses with alternative fuel e.g. electricity.

Studies [3,4] argued that a reliable cost-saving methods of increasing engine performance is using low-viscosity oils to reduce losses caused by rubbing in lubricated movable engine parts that represent 10% of overall losses. In this way, the oils contribute to higher engine efficiency while cutting CO_2 emissions. Slovakian authors [5] examined noxious substances produced by buses and revealed that replacing old diesel buses with CNG alternatives may significantly contribute to reducing mass emissions PM10 and NO_x pollution in municipalities. Authors [6] came up with a similar solution of fuel effectiveness and ecological aspects of CNG buses in Belgrade public transport. They argue that CNG buses showed a more significant fuel economy than their conventional counterparts.

Study [7] tested six diesel-hybrid vehicles Euro VI and six traditional diesel double-decker buses Euro V. The comparison showed that hybrid buses Euro IV had only marginal advantages in fuel consumption. On the other hand, Euro VI technology brought about a significant reduction in NOx emissions. Authors [8] analysed a more effective and ecological transport in China, concluding that electrification is the best method to deal with decarbonisation. Study [9] also suggests replacing all diesel engines with buses run on natural gas or electric vehicles by 2040.

Authors [10] measured influences of ecological transport before and after the results, suggesting that the eco-friendly drive significantly (by 5% - 12%) reduces fuel consumption and CO_2 emissions in busy municipalities. Study [11] presents WtW (Well-to-Wheel) comparison of power units with increasing electrification, i.e. from conventional through electric to hybrid. The results indicated that hybrid engines considerably cut down fuel consumption and CO_2 emissions in comparison to the ordinary power apparatus (petrol or diesel).

This article deals with a similar issue in which the authors compare and evaluate individual types of vehicles and, based on their energy intensity, emissions production, and other factors, describe the selection of the optimal means of transport in the measured area.

2. Methodology

The comparison involved Citroen Berlingo (diesel), Seat Ibiza (petrol), Karosa C 954, and train 813-913. The measuring of Citroen and Seat took place on two different routes connecting both designated destinations, i.e. “a fast route” and “a slow route”, while the survey on the bus and train proceeded on a scheduled route; the latter tested on a separate railway. All examined courses were parallel or, even, partially identical.

Measurements on passenger cars were performed in August and took five days. Choosing summer mornings enabled us to reach a constant temperature of 15 °C, which is often the reference temperature in the standards (e.g. fuel density). This temperature represents the average daily conditions in the warm half of the year (April - September) in a given region. The average annual temperature is 9°C, but the measurement was performed in the summer morning due to stable no-precipitation weather, despite a slightly higher temperature than the annual average for the region.

Trains and buses were examined the last week of September when the temperatures were the same as when measuring cars. Public passenger transport vehicles did not follow the same procedure during the respective periods as passenger cars required a longer time to move the vehicle along the measuring section (along the line). This inconvenience would cause a large temperature difference during the summer. The problem was solved by all-day measurements on autumn days when the daily weather was stable enough to reach a temperature of about 15°C.

The measuring concerned the calculation and comparison of fuel consumption per passenger. The estimated energy intensity and produced emissions determine the optimal means of transport on a specific passenger traffic session. A schematic depiction shows results of fuel consumption of individual vehicles, while the evaluation and analysis of quantities complied with legally effective regulation “STN EN 16258 Methodology of the calculation and declaration of energy consumption and greenhouse gas emissions from transport services (passenger transport and haulage)”. The regulation governs the conventional methodology for calculating energy consumption and greenhouse gas emissions, involving principles, definitions, and calculations by accurate and reliable methods for all transport services. This official rule applies to all persons, organizations, and transport companies, including a duty to announce results of the measuring and energy consumption and emission assessment under the normalized methodology implicated by this regulation.

The evaluation of the energy intensity and greenhouse gas emissions followed TtW (Tank-to-Wheel) principle, considering only direct consumption and emissions from means of transport, and WtW (Well-to-Wheel) principle, including also a secondary part of energy consumption and emissions.

This regulation directly governs the evaluation of the energy intensity and emission production, including tables of factors for energy intensity and emissions. They comprise a classification by a proportional component of fuel biocomponents and division into direct and indirect values. A wise choice of a gas biocomponent led to a precise calculation of rates for measured means of transport.

2.1 Measuring Technique and Means of Transport

The measuring on cars involved OBD connector and iCar OBD2 adapter, which used mobile software to evaluate data on the vehicle during individual measurements. The technique comprised two car types (Citroen Berlingo and Seat Ibiza), conducting 20 measurings – 12 on Citroen Berlingo with one, three, and five people inside, and eight on Seat Ibiza with one and three people on the same route. The measuring with five people did not take place due to lower engine performance, which prevented the car from a steady pace in ascending segments, resulting in a considerably slackened average speed within the examined stretch compared to that of Citroen.

Table 1 Technical parameters of measured vehicles. Source: authors

Vehicle	Citroen Berlingo	Seat Ibiza	Karosa C 954	Train 813-913
Fuel	diesel	Petrol	Diesel	Diesel
Performance	mechanical	mechanical	mechanical	hydromechanical
Weight (kg)	1,373	995	10,800	39,000
Average fuel consumption (l/100km)	5.8	4.7	28.5	54.8
Vehicle size (l/w/h) (mm)	4380/1810/1801	4236/1693/1445	11990/2500/3165	28820/3073/3770
number of seats	5	5	49 + 1	78 + 5
Max. number of on-stand passengers	-	-	39	120

The bus was examined under operating conditions on a scheduled line – Karosa C 954. As traffic signs ‘No entry for buses’ occur almost through the entire ‘fast route’, the only line involved in the assessment was the passage traditionally used for passenger transportation.

The train measuring took place on unit 813-913. The railway is entirely concurrent with the slow route of the road communication banned for the bus.

2.2 The Measured Routes

The survey took place on route Nové Město nad Váhom – Myjava and Myjava – Nové Město nad Váhom and comprised two journeys for cars, one for railway transport and a specific line regarding the bus timetable.

The measurements were performed under the same weather conditions – an ordinary summer day in the region. The testing took place early in the morning at a temperature of about 15 ° C, in windless weather without rain and on a dry road. Given that the average speeds for each measurement were very similar, it can be deduced that the measurements were made under the same traffic flow conditions. As it was a daily time of measuring in the early morning, there were no cars on the road, or a minimum of cars, which did not affect the smoothness of the tested vehicle.

The following table suggests selected parameters of the measured routes. The suitable height profile enables the precise definition and comparison of the line with the respective fuel consumption. The exact calculation must involve height profile, average percent ascent and descent on individual routes.

Table 2 Route parameters of the means of transport involved in the measuring. Source: authors

	Route parameters				
	Length (km)	Average ascent (%)	Average descent (%)	Meters ascended (m)	Meters descended (m)
Fast route	25.6	0.8	-1.4	223	-360
Slow route	34.1	0.7	-1.1	249	-384
Bus route	32.4	0.8	-1.3	252	-412
Train route	35.9	0.7	-1.2	255	-434

The data analysis on the bus fuel consumption reflects information on two existing lines to comply with the complete route designed for cars. The overall route length is 32.4 km with a duration of 39 minutes from Nové Město nad Váhom to Myjava.

The train journey takes 48 minutes with a total length of 35.9 km, indicating acceptable duration compared to the car or bus route.

3. Results and Discussion

The measurements showed comprehensive data on the average speed, overall length and fuel consumption in litres. The evaluation of fuel consumption and per-unit fuel consumption on individual routes had to consider changing numbers of passengers, thus requiring conversion of the values to separate indicators that would be more suitable for picking an optimal vehicle. Route Nové Mesto nad Váhom – Myjava saw repeated measurements of different numbers of passengers. The achieved results provided grounds for interpreting and processing the data. The train measuring followed the same procedure as in the case of buses.

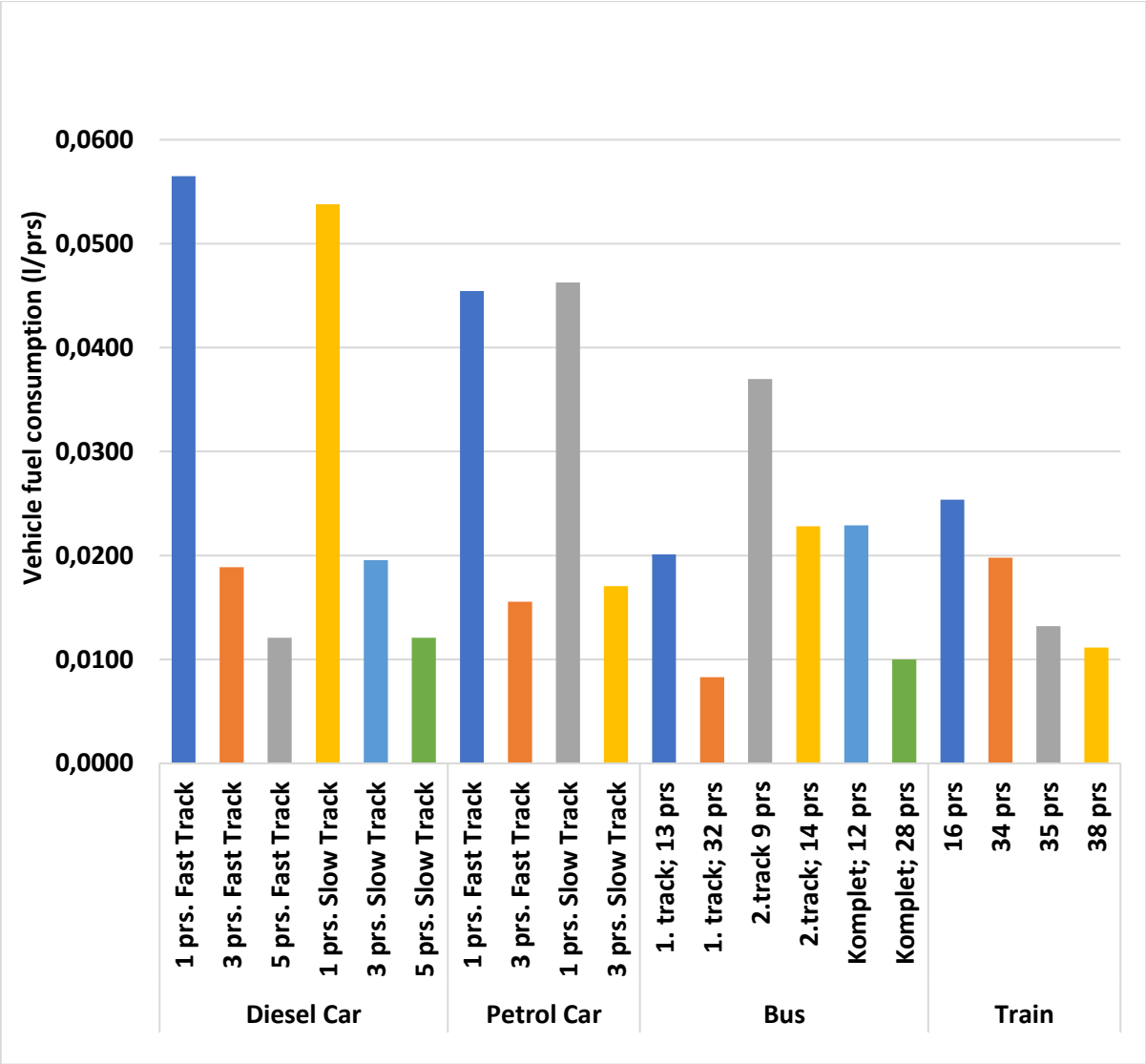


Fig. 1 Graphic elaboration of fuel consumption per passenger. Source: authors

What followed was analysing and processing emission and energy intensity values from the fuel consumption of given means of transport and added emission and energy factor under "STN EN 16258" Regulation. The results show the optimal vehicle for transportation within the examined segment upon integrating these values into specific fuel consumption. The tables and figures of the means of transport refer to individual outcomes.

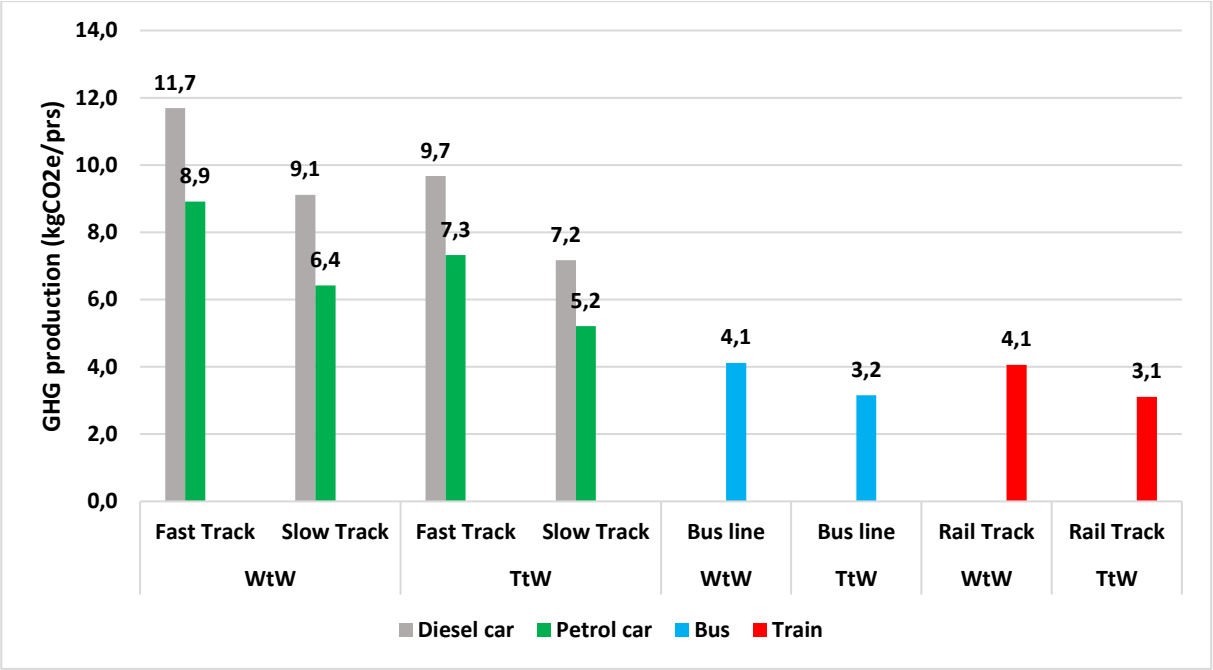


Fig. 2 Sessions per passenger in the given means of transport. Source: authors

Figure 2 and 3 illustrates the conversion and comparison of vehicles regarding emissions and energy production per passenger, also considering WtW and TtW factors and "slow route" and "fast route" in the event of cars, which involved only one person in the automobile – the driver.

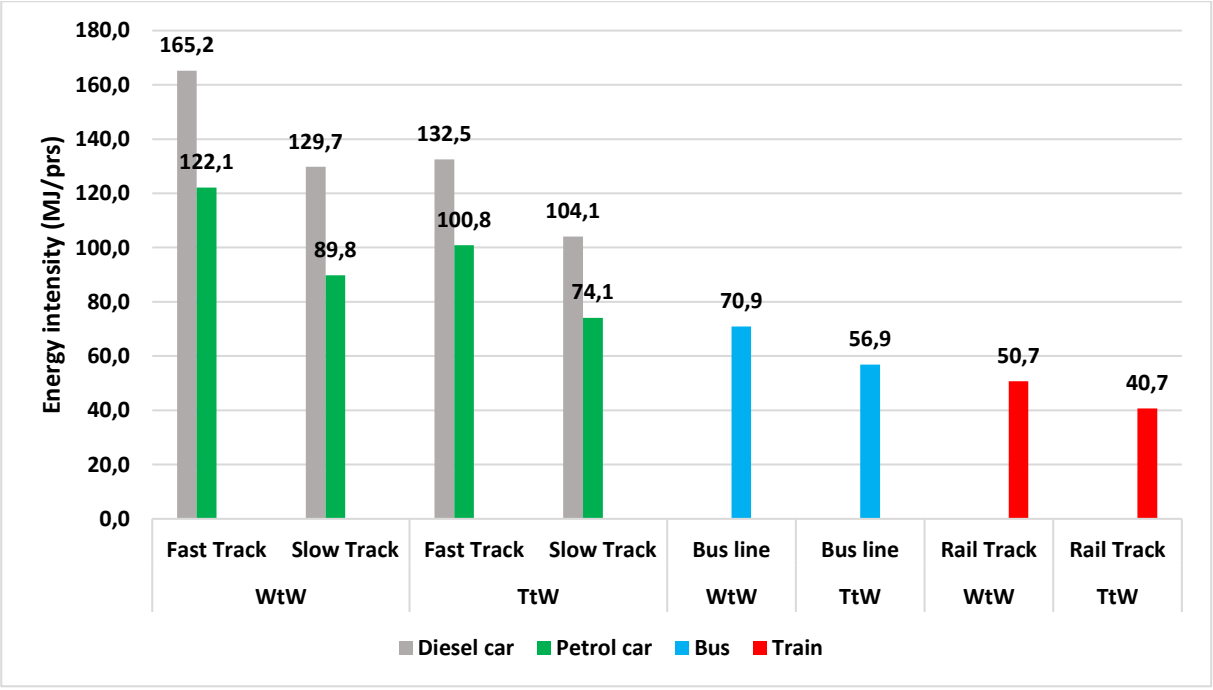
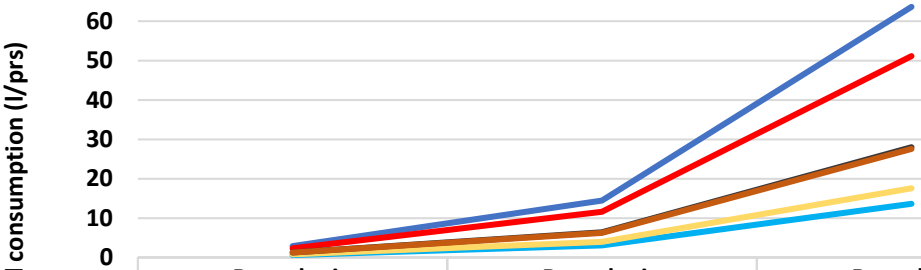


Fig. 3 Energy intensity per passenger in a specific means of transport. Source: authors

Figure 4 suggests fuel consumption for individual vehicles within a specific period. The measuring included the fuel consumption value per passenger for both cars, and the fuel consumption value for the full automobile – three people in the petrol car, five people for the diesel

car). The results did not involve “slow route” due to its ineffectiveness against “fast route”. The bus line required converting the values to one passenger for both journeys with the average number of passengers on the bus, which is 18. The same procedure applied to the train route – converting a value per passenger with the average number of passengers 31.



	Round-trip Daily fuel consumption (l/prs)	Round-trip Fuel consumption for 5 days (l/prs)	Round-trip Fuel consuption for 22 days (l/prs)
Diesel Car; 1 prs	2,89	14,46	63,64
Diesel Car; 5 prs	0,62	3,10	13,63
Petrol Car; 1 prs	2,32	11,62	51,14
Petrol Car 3 prs	0,80	3,99	17,57
Bus	1,27	6,36	28,00
Train	1,25	6,26	27,56

Fig. 4 Evaluating fuel consumption per passenger within a period. Source: authors

What is evident within the examined 22 working days is a substantial increase in the difference between cars and buses and trains. The bus experiment estimates diesel consumption to 28 litres per passenger in a working month. In the event of the train, the consumption dropped by another 0.5 litres per working month.

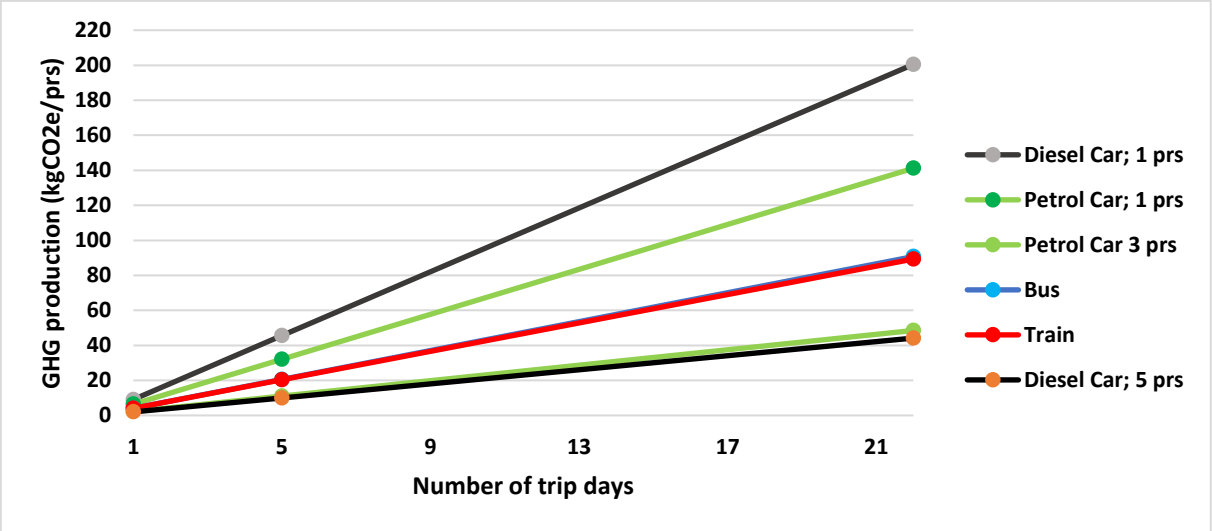


Fig. 5 Evaluating emissions of means of transport per period. Source: authors

Figure 5 again suggests the most limited effectiveness in the car experiment with the diesel automobile showing the worst results; its petrol counterpart ranks slightly better. However, this theory only holds when one person – the driver – is on board. On the other hand, the fully occupied car (five people in the diesel and three people in the petrol car) moves from non-ecological vehicles to eco-friendly ones in terms of greenhouse gas emissions. Regarding emissions per passenger, the train also indicated better results than its bus alternative.

These conclusions only apply by using capacities of means of public transport according to immediate data from traffic sessions. The values ranged from 9 to 31 of immediately transported passengers, i.e. 19 – 71% (18 people on average – 39%), 16 – 38 people on the train, 19 – 46% use of the seating capacity (31 people on average – 37%). If the means of public transport were full, CO_2 production per passenger would drop to a minimum, as it would show a triple decrease compared to values suggested in figure 5.

More than 70% of the European population lives in municipalities, continually pressing public transport systems and thus affecting the environment [12]. As exhaust emissions pose a big issue for citizens, today's world focuses on the conception of sustainable municipal logistics [13], aiming at the reduction of produced emissions. Measuring forms and methods may vary, but general findings [14] point to the quantification technique. Study [15] arrived at the same conclusion, arguing that per-passenger emissions considerably decreased compared to European diesel cars. Review [16] extensively analysed rail vehicles, automobiles and buses with analog results, revealing that the underground produces the least emissions – 42.3 times less than cars and 5.3 less than buses.

Analysis [17] indicated the same results, concluding that the full vehicle capacity is essential to assess and compare different means of transport regarding eco-friendliness. Packing to capacity depends on the demand for potential passengers, infrastructure and supply of regional public transport services. It is not easy to say which means of transport is better to use for various reasons; however, study [18] considers road infrastructure as a way to support regional development.

4. Conclusion

The article aimed at determining the optimal means of transport on traffic session Nové Mesto nad Váhom – Myjava based on energy consumption and greenhouse gas emissions. The experiment mostly involved measuring fuel consumption of all tested vehicles. This procedure was followed by the analysis and assessment of emissions and energy intensity. Various figures and schemes provide relevant data on fuel consumption values achieved through the experiment converted to fuel consumption per passenger, suggesting that the use of cars appears to be the least suitable solution.

The automobiles showed unsatisfactory results when driver-occupied, which is the most common case on the roads. Picking the optimal means of transport thereby fell between the bus and train.

Both vehicles indicated positive values and similar results with minimal differences. The fuel consumption ratios of the discussed means of transport showed that the bus and train substantially exceeded emissions and energy intensity against cars expressed per vehicle in table 1. Recalculating emissions and energy intensity per passenger when filled to medium capacity proved that the train achieved better results than the bus, implying the rail alternative to be the optimal pick.

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