ABSTRACT

The aim of the paper is to assess the possibility of decreasing the chosen environmental indicators like energy consumption, greenhouse gas (GHG) production and other exhaust pollutants in the selected region in Slovakia by introducing Liquefied Natural Gas (LNG) buses into bus transport. The assessment is carried out by comparing the consumption and emissions of current buses (EURO 2) in real operation, with potential buses (EURO 6) and with pilot LNG buses testing on the same lines. Comparison took place under the same conditions over the same period. The study measures the energy consumption and GHG production per bus. The research paper also compares two methodologies of calculation. The first calculation is according to the European Standard EN 16258: 2012 which specifies the general methodology for evaluation and declaration of energy consumption and GHG emissions (all services - cargo, passengers or both). The second calculation is according to the Handbook of Emission Factors for Road Transport (HBEFA). The results of the calculation are compared by both methods, and the most suitable version of the bus in terms of GHG emissions is proposed.

KEYWORDS
liquefied natural gas; diesel; bus; GHG emissions; consumption;

1. INTRODUCTION

Petrol and diesel should be replaced by alternative fuels. Alternative fuel vehicles should be financially preferred, and also they should be exempted from different registration fees [1]. The Ministry of Economy of the Slovak Republic has prepared twelve measures to promote alternative fuels, such as electricity, liquefied and compressed natural gas, liquefied petroleum gas, hydrogen or liquid biofuels. The Ministry of Economy of the Slovak Republic wants to stimulate the sale of vehicles with alternative drive, such as direct financial incentives. The construction of alternative fuel infrastructure should also be encouraged [2]. Another measure is also to shorten the depreciation period for such vehicles or to introduce low-emission zones in towns and villages to which only alternative fuel vehicles should have access. This should be seen as an EU support for alternative fuels [3]. At the end of the 20th century, the production of GHG from the transport sector increased by 250% (since 1970). The increase in transport sector is higher than in other sectors. Therefore, solutions are currently being sought to reduce the greenhouse gas emissions from transport [4].
The case study deals with the issues of emission production in bus transport in Slovakia. It compares the production of the GHG emissions of the current diesel bus fleet operated in the Central Slovakia. Emissions are calculated according to real data on four transport lines by two methods. Each line has a different profile, so the research shows the average operating parameters in bus transport in Slovakia. The daily range, the number of stops as well as the route profile were set according to the average real parameters on the given lines. The current fleet was tested and compared with EURO 6 emission class buses and LNG buses. The amount of emissions from bus operation is one of the important factors influencing the choice of a new vehicle fleet.

2. LITERATURE REVIEW

The environmental impacts caused by public bus transportation systems have been solved in previous studies [5, 6], that examined the benefits of alternative fuels in bus transportation. Several other studies [7, 8] focused on emission production have been carried out in the past. The results show that CO₂ levels have increased by about 7% over the last ten years. The transport sector produces around 23% of total CO₂ emissions, representing almost a quarter of the total CO₂ produced [9]. Carbon dioxide equivalent CO₂e is a standard unit for measuring carbon footprints. Carbon footprint consisting of lots of different greenhouse gases can be expressed as a single number - CO₂e [10].

Bus transport in Slovakia is still the most widespread way of transporting people for short and medium distances. Most often it is about transporting people to work or school. Over the last decade, bus availability in Slovakia has been at the same level [11]. Currently, the main bus fleet in Slovakia is represented by diesel buses, electric buses and Compressed Natural Gas (CNG) buses. LNG buses are currently not used in bus transport in Slovakia. One of the main reasons is the lack of sufficient infrastructure [12].

The use of natural gas in the form of CNG in bus transport is verified and used in many cities in Slovakia and in other countries LNG is emerging as a new alternative [13]. The greatest advantage of LNG buses is a higher total range (approx. 750 km, while in CNG version it is only about 350 km) [14]. Another advantage is a significantly shorter refuelling time (LNG takes about 5 minutes, CNG approx. 20-30 minutes) and the fact that the tanks are not placed on the roof, resulting in a reduction of the centre of gravity and the safer passing under the overpasses [15].

Natural gas has many benefits as a fuel in transportation. Compared with automotive gasoline the diesel fuel is produced by burning fewer impurities [16]. Natural gas is composed of methane (83-99.7%), ethane, propane, butane, and nitrogen and has the lowest carbon content compared to petroleum fuels [17]. During the combustion process, natural gas emits less CO₂ and less other pollutants than diesel fuel [18]. Previous studies compared natural gas and diesel and they show that natural gas can potentially reduce CO₂ up to 20%, NOₓ up to 90% and SOₓ and particular emissions by almost 100% [19, 20]. The biggest problem in Slovakia is to identify ways in which to supply LNG fuel stations and the increased acquisition costs of LNG buses in comparison with diesel versions [21].

One of the limiting factors for the use of natural gas at normal temperature and pressure is its gaseous state [22]. These shortcomings are to a certain extent circumvented using natural gas at a higher pressure (CNG - 20 to 25 MPa) or low temperature (LNG - 162°C). By liquefaction, the original volume of natural gas decreases to one-sixth [23].

In addition to the already mentioned alternative fuels, there are other fuels whose emissions are incomparably lower than those of traditional fossil fuels. There had been many previous studies comparing alternative drivetrains for light duty vehicles and buses [24, 25]. Hydrogen drivetrain currently combines the best of fossil and electric drivetrain. It is refuelled quickly and similarly to petrol cars. The range is the same as petrol vehicles, but the impact on the environment is smaller than with electric ones. The vehicles with hydrogen fuel cells can refuel the tank as fast as traditional gas-powered vehicles. Hydrogen is considered a highly explosive type of gas. Hydrogen fuel cells are the technology of the future, but currently economically unprofitable. Insufficient infrastructure in the form of cryogenic hydrogen refuelling stations is also a weak spot. However, electric cars also face the same challenges, especially where their penetration is rising too fast due to subsidies and tax breaks [26].

Developments in the production of greenhouse gas emissions from transport in Slovakia are influenced by environmentally unfavourable road transport. In 2017, greenhouse gas emissions were recalculated using the COPERT V methodology and the
values of CH₄ and N₂O emissions recorded a significant decrease. In the period from 2000 to 2014, N₂O emissions were of a balanced nature with minimal year-on-year fluctuations. Only CH₄ emissions decreased in the period from 2000 to 2017, which represented a decrease of 65.5% compared to 2000. The most unfavourable were the CO₂ emissions, which recorded year-on-year increases, while in 2017 the increase was 71.05% compared to 2000. In the period from 2000 to 2017, despite the fluctuating nature, CO₂, CH₄ and N₂O emissions developed unfavourably. CH₄ emissions decreased throughout the period under review. CO₂ emissions from transport increased by 33.7% between 2000 and 2017, despite a year-on-year decrease and increase until 2014, after which they increased. The development of emissions is shown in Figure 1. N₂O emissions in the observed period recorded a more significant decrease until 2010 and after this year they already had a growing trend. After 2010, N₂O emissions grew at a slower pace until 2014, and after that year, a more significant increase continued until 2017. In the period 2000-2017, the increase was 42.7%. CH₄ emissions from transport are the most positive, with a decrease in 2017 of 65.5% compared to 2000 [27].

For this reason, natural gas can be regarded as one of the fuel options for transport, either in the form of compressed natural gas or in liquefied natural gas. Currently, 12 public CNG filling stations and one private LNG station are available in Slovakia [12]. With respect to the most efficient use of capacities, all LNG filling stations for truck and bus transport should be in the L-CNG version, which would allow the use of natural gas as a fuel in both CNG and LNG forms [28]. In terms of infrastructure building, three to five public filling stations at LNG by 2025 seem to be the optimum conditions for the Slovak Republic. The necessary average distance between filling stations should be maximally 400 kilometres for road transport [29].

3. RESEARCH METHODOLOGY

European Standard EN 16258: 2012 specifies the methodology for evaluation and declaration of energy consumption and GHG production from transport services (cargo, passengers or both). It specifies general principles, definitions, system boundaries, methods of calculation, allocation rules (allocation, assignment) and recommendations on information to support standardized, accurate, reliable, and verifiable declarations [30, 31].

The methodology for calculating GHG emission and its specific steps based on this standard are presented in a study by Skrucany & Gnap [30].

The methodology does not consider only the secondary production of GHG and energy consumed during the fuel combustion (energy conversion from the chemical energy of the fuel to the mechanical energy for vehicle movement), as well as primary, incurred in the extraction, production and distribution of the fuel to the consumer [30].

\[
E_{CPV}^w = S_{km} \cdot e_w, \quad E_{CPV}^t = S_{km} \cdot e_t
\]

where:

- \(E_{CPV}^w\) – energy consumption by vehicles according to the “wtw (well-to-wheel)” approach [MJ/100km];
- \(E_{CPV}^t\) – energy consumption by vehicles according to the “ttw (tank-to-wheel)” approach [MJ/100km];
- \(S_{km}\) – vehicle fuel consumption [l/100km];
- \(e_w\) – energy factor “wtw” for consumed fuel [MJ/l];
- \(e_t\) – energy factor “ttw” for consumed fuel [MJ/l].

\[
G_{CPV}^w = S_{km} \cdot g_w, \quad G_{CPV}^t = S_{km} \cdot g_t
\]

where:

840 Promet – Traffic&Transportation, Vol. 32, 2020, No. 6, 837-847

Buses were operated in a shuttle service in the city of Dunajská Streda (line A – average distance between two stops: 1.2 km, average speed: 42 km/h), in intermodal transport on the line Voderady – Trnava (line B – average distance between two stops: 28 km, average speed: 67 km/h), in urban conditions in the town Prievidza (line C – average distance between two stops: 6.5 km, average speed: 52 km/h) and in the suburban connection Zvolen – Cerin (line D – average distance between two stops: 22 km, average speed: 64 km/h). The routes of the tested lines are shown in Figure 3. The number of the test days was not the same. It depended on the availability of transport company buses for the research. Minimum test time was set to 4 days.

The assessment is carried out by comparing the consumption and GHG emissions of current buses (EURO 2) in real operation, with potential buses (EURO 6) and with pilot LNG buses testing on the same routes/lines. Comparison took place under the same conditions over the same time period. The annual range of the currently used diesel bus is 49,700 km.

The calculation of the average fuel consumption during LNG bus testing is shown in Table 1. It is the sum of the distances during the reference period on the selected lines as well as the amount of LNG fuelled.

4. RESEARCH RESULTS

This study compares the environmental aspects of different buses in the same operation. The research was carried out by solo buses from the manufacturer Solbus (diesel EURO 2, diesel EURO 6 and LNG bus shown in Figure 2) were tested on 4 lines in the year 2018.

In order to determine the average consumption, buses were deployed in different modes of operation [35]. The measurements were performed on all lines by one driver, in the same weather, at the same time of day, with the same number of passengers. Buses were operated in a shuttle service in the city of Dunajská Streda (line A – average distance between two stops: 1.2 km, average speed: 42 km/h), in intermodal transport on the line Voderady – Trnava (line B – average distance between two stops: 28 km, average speed: 67 km/h), in urban conditions in the town Prievidza (line C – average distance between two stops: 6.5 km, average speed: 52 km/h) and in the suburban connection Zvolen – Cerin (line D – average distance between two stops: 22 km, average speed: 64 km/h). The routes of the tested lines are shown in Figure 3. The number of the test days was not the same. It depended on the availability of transport company buses for the research. Minimum test time was set to 4 days.

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![Figure 2 – Basic dimensions of the LNG bus](image-url)
The results show that the average LNG fuel consumption was lower than declared by the producer (the declared fuel consumption by the producer is 32 kg/100 km).

The vehicle speed profile is shown in Figure 4. This is an example of the real actual vehicle speed reached during the measurement (axis Y) and elapsed time of measuring (axis X). There are visible five groups of speed columns separated by gaps. This fact represents five measuring days – vehicle operating time - and the gaps are night hours, when the vehicle was out of operation. This is the speed profile of the vehicle operated on line B. Other vehicles on other lines reached similar profiles.

The HBEFA database application estimates the emission factors of several pollutants per vehicle category, EURO stage, specific year and for a wide variety of traffic situations. The traffic situations are mainly represented by four parameters: area type (rural, urban), road type, road speed limit and service level (free flow, heavy, saturated, and stop-and-go).

It provides sufficiently accurate data and allows the user to select the accurate values of factors according to immediate conditions of vehicle operation.

The input parameters for the simulation and selection of precise conditions of the vehicle operation were emission limits of vehicles (EURO 2 and EURO 6), speed profile of vehicles operated on lines, vertical alignments of the lines and the most important - average fuel consumption.

The calculation of the average fuel consumption during diesel EURO 2 bus tests is shown in Table 2. It is the sum of the distances during the reference period on the selected lines as well as the amount of diesel fuelled. The results about fuel consumption are introduced in two different units per 100 km – litres and kilograms. Both units are used because of the common and most used expression of the consumed volume of diesel (litres) and better comparison to the consumed amount of LNG expressed in kg. It is possible to compare the results also in the amount of consumed fuel (kg to kg) and in the following step of consumed energy (MJ).

The calculation of the average fuel consumption during diesel EURO 6 buses testing is shown in Table 3. It is the sum of the distances during the reference period on the selected lines as well as the amount of diesel fuelled. The results show that the average diesel fuel consumption was higher than declared by the producer (declared fuel consumption by the producer is 29 l/100 km).
Figure 5 describes the value of energy consumption of each compared bus. Left columns “ttw” describe the value of energy consumed during combustion of the fuel. Right columns “wtw” consider both the primary and secondary consumption. The results represent differences between older and newer diesel buses and buses equipped by an LNG spark ignition Internal Combustion Engine (ICE). Opposite to the fact that the LNG bus equipped by new and environmentally friendly drive, it reaches higher values of energy intensity than diesel buses. This reality is caused by the amount of consumed LNG during bus operation and the energy density of LNG as a fuel.

Figure 6 describes the value of emission production of each compared bus. Left columns “ttw” describe the value of the secondary emissions produced during the combustion of the fuel. Right columns “wtw” consider both primary and secondary emissions.
emissions. The results show that the emission production of the EURO 6 diesel bus is 3.17% higher than the LNG version (tank-to-wheels assessment).

To ensure relevant results, the specification of the inputs was based on real conditions in which the selected types of buses were tested. The speed specification was also based on the measurement results.

The results based on HBEFA for CO$_2$e are compared in Figure 7 ("ttw" assessment).

According to the current scientific and technical procedures, buses are divided into five categories according to fuel types [37]. The HBEFA calculation was also based on this division. By comparing our results with studies already carried out that measured emissions of LNG buses and diesel buses under the same or similar conditions, it can be concluded that our results in principle coincide with the research carried out in other regions [38, 39].

The comparison of CO$_2$e emissions of European Standard EN 16258: 2012 and the calculation using HBEFA is shown in Figure 8. Relevant comparison of CO$_2$e emissions according to European Standard EN 16258: 2012 and HBEFA calculation can only be made in tank-to-wheels assessment.

There are several studies solving emissions from buses with alternative fuels. Study [38] analyses and estimates the emission levels of LNG buses in real operation conditions in China. The research is carried out using visualization and statistical methods, which evaluate the differences in emission distribution characteristics between LNG buses and other types of buses. Subsequently, using the Gradient Boosted Regression Trees (GBRT) approach, the emission rates of some emissions are estimated for the LNG bus. A similar study [40], aimed at replacing diesel buses with alternative
ones, was carried out in Taiwan. The measurement was performed on city buses in Tainan City according to the international standard for measuring the carbon footprint of various energy buses using the Life cycle assessment method. The results of study [41] suggest that an approximate 8.0% reduction in the life cycle of GHG emissions is estimated if diesel Heavy-Duty Vehicles (HDVs) are replaced with LNG HDVs in China. Study [42] compares changes in CO₂ emissions for traditional diesel buses and compares them with new alternative buses. It uses statistical approaches that significantly affect the emission rate. The study proposes a GBRT model to perform estimates of bus CO₂ emission rates. Our study, which presents a different approach in comparing the emissions by two different methods, combines GHG calculations through a standard and a GHG simulation, where the results were calculated from HBEFA based on partial emissions according to GWP.

The study also concludes that the implementation of LNG buses for the chosen region in Slovakia does not result in any energy consumption savings. The same conclusions can be drawn from studies carried out in other regions [43]. Therefore, appropriate measures must be adopted to improve the transport system in terms of resources consumed. One of the main problems with the deployment of alternative fuel buses in Slovakia is the lack of transport infrastructure. Within the framework of Directive 2014/94 / EU Alternative Fuel Infrastructure [44], the objectives and tasks aimed at creating our own functional infrastructure focused on the filling of alternative fuels (LNG, CNG, hydrogen and battery electric drivetrain) were clearly defined. Regarding LNG, it has been stipulated that LNG filling stations must be evenly distributed on the road, i.e. within 400 km of each other. As far as CNG is concerned, it was determined that the stations must be maximally 150 km apart. The results of the research have a direct impact on supporting the implementation of the mentioned directive in Slovakia in the form of two projects aimed at building the infrastructure of LNG and CNG filling stations on the main highway in the Slovak Republic. One of these projects also envisages the construction of an LNG production and storage terminal in Bratislava [45].

6. CONCLUSION

The study deals with issues of emission production in bus transport in the selected region of Slovakia. It compares the production of GHG emissions of the current diesel bus fleet of EURO 2, diesel buses EURO 6 and pilot tested LNG version meeting the same emission standard.

In terms of emission production, the LNG bus version produces lower emissions compared to diesel buses of both emission classes compared. However, the savings achieved are relatively low but are not negligible in terms of overall vehicle life. A possible replacement of the current diesel fleet (not only by LNG; other alternatives are possible) in almost every transport company in Slovakia would contribute to an overall reduction in emissions from transport.

The concluded comparison of the results from the conducted research shows that:
- according to the calculation based on the European Standard EN 16258: 2012 the GHG production is most convenient in the LNG bus version;
- according to the HBEFA calculation of GHG production, the most valuable option is also LNG bus.

The relevance of the results is confirmed by both ways of calculation of emissions production. The calculated CO₂e emissions according to the European Standard EN 16258: 2012 are the highest for EURO 2 diesel bus and the lowest for the LNG version. The order of HBEFA emissions calculation is the same.
According to the European Standard EN 16258: 2012, the diesel version of the EURO 6 bus produces 3.17% more CO$_{2e}$ than the LNG version. According to the calculation of HBEFA, the diesel version of the EURO 6 buses generates 2.7% more emissions than the LNG version. As a result of the emission difference, the mean of two calculations is used, which implies that the EURO 6 diesel bus produces 2.9% more CO$_{2e}$ emissions than an LNG bus of the same emission class.

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**REFERENCES**


[9] Keeling CD, Piper SC, Bacastow RB, Wahlen M,


[12] *FuelCNG*. Project supported by the CEF program.


[31] CEN. European standard EN 16 258:2012. Methodology for calculation and declaration of energy consumption and GHG emissions of transport services (freight and passengers); 2013.


[Accessed 20 February 2020].


