Advances in Science and Technology Research Journal

Advances in Science and Technology Research Journal, 2026, 20(1), 269–278
https://doi.org/10.12913/22998624/209114
ISSN 2299-8624, License CC-BY 4.0

Received: 2025.07.01
Accepted: 2025.09.07
Published: 2025.11.21

Compressed natural gas as an economic and environmental solution for sustainable transport

Lenka Kuhnová[1*], Marián Brontvaj[2], Roland Weiss[3]

[1] Department of Economics and Management, Faculty of Business Economics with seat in Košice, Bratislava University of Economics and Business, Tajovského 13, 041 30 Košice, Slovak Republic
[2] Department of Quantitative Methods, Faculty of Business Economics with seat in Košice, Bratislava University of Economics and Business, Tajovského 13, 041 30 Košice, Slovak Republic
[3] Department of Corporate Financial Management, Faculty of Business Economics with seat in Košice, Bratislava University of Economics and Business, Tajovského 13, 041 30 Košice, Slovak Republic
* Corresponding author's e-mail: lenka.kuhnova@euba.sk

ABSTRACT

The paper presents the results of a multi-year analysis of the environmental and economic impacts of the operation of vehicles powered by compressed natural gas (CNG) compared to Diesel vehicles. The study is based on real data collected by the EPIC (Environmental Performance Integrated Centre) project, which monitored fuel consumption, CO_2 and NO_x emissions, as well as fleet operating costs during the period 12/2015 – 6/2020. The aim of the paper was to analyse the environmental and economic impacts of operating CNG vehicles compared to Diesel vehicles, based on the data collected during the period under study. The results of the regression analyses confirm that CNG vehicles achieve significantly lower GHG emissions and at the same time bring significant financial savings. Specifically, CNG vehicles emitted approximately 122,504 kg less CO_2 than their Diesel counterparts, a reduction of around 28%. Emissions of NO_x were reduced by 65%, and particulate matter (PM) emissions were approximately 90% lower for CNG vehicles. Additionally, the regression analysis of fuel costs shows that Diesel fuel costs increase at a significantly higher rate than CNG, making CNG a more cost-effective solution, especially for high-mileage urban transport. Forecast models for the 2015–2030 period indicate a 22% projected reduction in emissions from CNG vehicles compared to just 7% for Diesel, and operating costs for CNG are expected to decline further, while Diesel costs continue to rise. CNG thus proves to be an effective transitional fuel in the context of a sustainable mobility and energy transition strategy in the transport sector.

Keywords: compressed natural gas, sustainable transport, CO_2 emissions, alternative fuels, environmental efficiency.

INTRODUCTION

The deployment of technologies such as CNG in public transport is not just an environmental issue, but part of a broader transformation of business processes towards sustainability and digitalisation. Digitisation enables efficient monitoring of fuel consumption, real-time tracking of emissions and optimisation of vehicle routes, thereby increasing the overall efficiency of operations. Transport is one of the main sources of greenhouse gas emissions in the European Union, accounting for approximately 23% of total CO_2 emissions in 2021 [1]. In order to achieve climate neutrality by 2050, the European Union has adopted several strategic documents, such as the European Green Deal, the Fit for 55 initiative and the REPowerEU roadmap, which highlight the need to transform the transport sector through alternative fuels and technologies. In this context, CNG appears to be a suitable transitional solution that can contribute to a rapid reduction of the emission burden without the need for large-scale investments in infrastructure or technical conversions of the vehicle fleet. CNG as a fuel has a number of environmental advantages over traditional fossil fuels, in particular in terms of emissions of carbon dioxide (CO_2), nitrogen oxides (NO_x), sulphur (SO_2) and particulate matter (PM). According to a report by the European Environment Agency [2], CNG vehicles can reduce CO_2 emissions by 20–30%, on average, compared to Diesel alternatives. A study by Sahoo and Srivastava [3] added that CNG-powered engines showed up to 29% lower CO_2 emissions compared to gasoline and significantly lower specific fuel consumption. In addition to the environmental benefits, the clean fuel CNG also has economic advantages as its market price is more stable and, in many countries, including Slovakia, it is supported by tax benefits. In Slovakia, the use of CNG is gaining prominence, especially in public transport. The 2019 National Policy Framework for the Development of the Alternative Fuels Market directly states the need to develop CNG infrastructure and to support the transition of vehicles to this type of fuel [4]. Real operational data from the EPIC project [5], which tracked the consumption, costs and emissions of 33 vehicles between 12/2015 and 06/2020, provides a valuable empirical basis for comparing CNG and Diesel technology in practice. The objective of this paper was to compare the environmental and economic impacts of operating CNG as well as Diesel vehicles based on data from the EPIC study and a complementary regression analysis. Not only the total CO_2, NO_x and PM emissions were analysed, but also the fuel costs as a function of the number of kilometres driven. The results can contribute to a better understanding of the potential of CNG as a tool for green transport transformation and also serve as a basis for public policy making.

BACKGROUND

As the world faces acute environmental challenges and commitments to reduce greenhouse gas (GHG) emissions, attention is increasingly focused on alternative energy solutions in transport. CNG has gained traction as a transitional fuel in the shift toward sustainable transportation, particularly in public and freight sectors where full electrification remains constrained by range limitations, infrastructure gaps, and high capital costs. The environmental benefits of CNG (lower CO_2, NO_x, SO_2, and PM emissions) are well documented in both experimental and lifecycle studies. Empirical studies confirm that CNG can make a significant contribution to the transformation of the transport sector towards sustainability.

Divekar et al. [6] demonstrated the fact that the use of CNG in medium and heavy-duty spark ignition vehicles leads to improved energy efficiency and reduced CO_2 emissions. Ali et al. [7] determined a low-risk index (0.266) for CNG in their environmental risk analysis, confirming its safety potential with properly designed infrastructure. Al-Mohannadi et al. [8] also pointed out the technical maturity of CNG systems in logistics and highlighted the advantage of existing distribution networks. Lower fuel costs and overall cost-effectiveness are confirmed by Rose et al. [9], who compared the life cycle of Diesel and CNG powered heavy duty collection vehicles (HCVs) based on real operational data in Canada. Their results found that CNG vehicles lead to significant reductions in GHG emissions (by about 24%) and other pollutants. In addition, they also have lower fuel costs, making them a cost-effective and environmentally friendly alternative for cities and municipalities. However, the challenge remains the need for public incentives and capital investment to create the conditions for its wider deployment. This resonates with European Union policy, where CNG and its renewable form (biomethane) are explicitly listed as part of transition fuel mixes in initiatives such as REPowerEU, Fit for 55 and Climate Neutrality 2050, with the common goal of reducing dependence on oil and gas imports and promoting local low-carbon production.

From an economic point of view, CNG appears to be an efficient option, especially in the cases where large-scale electrification is not available or financially feasible. Borgosano et al. [10] showed that under the conditions of limited infrastructure, CNG buses represent a suitable compromise between investment costs, technology availability and environmental impact. The efficiency of CNG use is also increased by infrastructure optimisation, as Özcan and Kılıç [11] showed that properly designed CNG stations can reduce energy intensity by up to 12% without affecting performance, which has a direct impact on the operating economy and environmental footprint. In the context of public finance, an interesting insight comes from the case study of Fabian and Janek [12], who analysed the return on investment of CNG buses compared to electric alternatives. The results show that CNG is more economically advantageous at lower levels of state support, while electric vehicles gain an advantage only at subsidies above 50%, suggesting the need for a flexible subsidy policy responding to local conditions and technical possibilities. At the same time, technological innovations are expanding the possibilities for CNG deployment in different transport segments. An important contribution in this direction is the research of Majczak et al. [13], who developed a hydraulically assisted CNG injector designed for Diesel engines. Such solutions allow CNG to be extended to hybrid and conversion systems without the need for a complete replacement of the combustion unit, thus lowering the barriers to entry and increasing the return on investment. These advances are particularly relevant for heavy-duty segments where performance and reliability requirements are still dominant. From a regional perspective, the implementation of CNG is promising in the countries with available natural gas supplies but poor electrical infrastructure.

Hussaini et al. [14] in their study from Nigeria identified CNG and LPG as the most realistic low-carbon mobility alternatives, underlining the importance of legislative framework and political will. This view corresponds with that of Valavanidis [15], who considers CNG as a "bridge technology" – a temporary solution leading to full electrification, especially in the contexts where the construction of a charging network is not economically or technically feasible in the short term. These facts show that CNG is not just a temporary tool, but a systemic element in the strategy for the transition to sustainable mobility. Its viability is not only determined by technical parameters, but also by the ability of the state to set up a functioning ecosystem that combines research, innovation, public investment and regulatory instruments. Coupled with the development of biomethane, reverse gasification and hybrid technology options, CNG can form a stable pillar of the transport sector transformation in the coming decades. If climate goals are to be achieved while ensuring affordable and reliable mobility for all segments of the population, CNG should not be ignored but targeted and promoted as part of a multi-level energy mix.

RESEARCH METHODOLOGY

This study used real operational data from the presentation "EPIC – Environmental and Economic Savings Analysis of CNG Vehicles" [5], which summarises the results of a multi-year monitoring of CNG vehicles for the period December 2015 to June 2020. The data included a comprehensive set of information on fuel consumption (in litres and kilograms), kilometres driven, emission production (CO_2, NO_x, SO_2, PM) as well as technical equipment of the refuelling infrastructure. The data obtained were then extracted from the graphical outputs and tables as well as converted into a common calculation format (CSV), while further standardised into units of kg/100 km and kg CO_2.

The sample consisted of 33 vehicles, divided between CNG and Diesel technologies, all operated under real-life conditions in urban and suburban public transport within Slovakia. The vehicle fleet included M3 category buses used for regular passenger service, primarily in scheduled city and regional routes. The vehicles varied in age from 2 to 8 years at the beginning of the study period, ensuring a realistic representation of the operational fleet rather than idealised or laboratory conditions. Both CNG and Diesel buses were comparable in terms of weight class, seating capacity, and daily mileage, which ranged on average between 150 and 300 kilometres per day, depending on route assignment. Fuel consumption was measured under different seasonal and load conditions, capturing variations in heating usage, passenger volume, and topography. The vehicles were also subject to standardised maintenance protocols within the same operating company, ensuring uniform servicing schedules and minimising bias due to technical discrepancies. CNG vehicles operated with factory-installed spark-ignition engines, while Diesel buses used modern compression-ignition engines compliant with EURO V or EURO VI emission standards. By including vehicles of different service durations and operating intensities, the dataset allows for a representative analysis of medium-term environmental and economic performance.

Vehicle testing was carried out under standard urban and suburban transport conditions. Fuel consumption was monitored under different operating modes and seasonal periods to capture dynamic load changes and their impact on emissions. Emission values were converted from fuel volumes according to standardised emission factors according to EEA and IPCC methodologies, distinguishing both direct tailpipe emissions and aggregated carbon footprint values. The key analytical method was linear regression analysis, which modelled the relationship between fuel consumption as well as CO_2 and NO_x emissions production. A separate regression equation was calculated for each type of powertrain, which allowed the prediction of emissions based on the input consumption values, while the R2 values of the coefficient of determination were also identified, confirming the strong dependence between the variables under study. The calculations were performed in the Python programming environment, using the matplotlib and statsmodels libraries to visualise the results. The obtained outputs were processed into graphs and clear tables that compared the environmental impacts of CNG, Diesel, Biomethane and EVs throughout the life cycle of the vehicle. The results showed that CNG is a significantly cleaner alternative to Diesel, and biomethane even achieves the lowest carbon footprint of all the fuels studied. This methodology thus provided an objective basis for comparing the environmental and economic benefits of different technologies under real-world vehicle operating conditions.

The methodology also includes an analysis of trends in projected emission reductions and fuel cost developments for CNG and Diesel vehicles between 2015 and 2030, using normalised indices that allow for meaningful relative comparisons over time. The methodological design is based on trend extrapolation, which allows for the visualisation of both environmental and economic trajectories as well as clearly demonstrates a more significant reduction in emissions and operating costs for CNG compared to Diesel. By using a relative index framework instead of absolute values, the analysis effectively mitigates value distortions and highlights the long-term sustainability and cost-effectiveness of CNG as a viable alternative in the transport sector.

RESULTS AND DISCUSSION

The results of the quantitative analysis are based on a combination of empirical data and regression models obtained from observing real-world operation of CNG and Diesel-powered cars. The following figures present graphically the environmental parameters that allow an objective comparison of the two technologies. The results show a direct relationship between the kilometres driven and the number of emissions produced as well as the fuel costs. The visualised data provides a transparent overview of the benefits of CNG in the urban transport environment and also serves as a basis for sustainability-oriented policy making.

Figure 1 compares the total CO_2 emissions during operation of CNG and Diesel vehicles. The results show that Diesel vehicles emitted approximately 429 390 kg CO_2, while CNG vehicles only 306 886 kg, a saving of more than 122 000 kg CO_2 in favour of CNG. The difference shows the significantly lower carbon footprint of CNG and its environmental advantage in the fight against climate change. These figures confirm that the deployment of CNG technologies is not only sensible from a climate policy perspective, but also a practical step towards reducing the carbon footprint of transport. The study by Jamrozik et al. [16] confirms that increasing the share of CNG leads to a reduction of CO_2 emissions and almost a complete reduction of CO_2 emissions compared to the pure Diesel mode. The significance of this difference is even more urgent in the context of the European Union's commitments under the Fit for 55 climate strategy, which sets a 55% reduction in GHG emissions by 2030 [17]. Given the lower CO_2 emissions and existing infrastructure options, CNG is a viable transitional fuel that can play a key role in decarbonising the transport sector.

Figure 2 shows a comparison of NO_x emissions in kilograms between CNG and Diesel vehicles. The results clearly show that the Diesel vehicles emitted 512 480 kg of NO_x, while the CNG vehicles emitted only 175 680 kg, a reduction of 336 800 kg, i.e. approximately 65%. This difference has a significant environmental and health impact as NO_x contributes to ground-level ozone formation, acid rain and is linked to respiratory

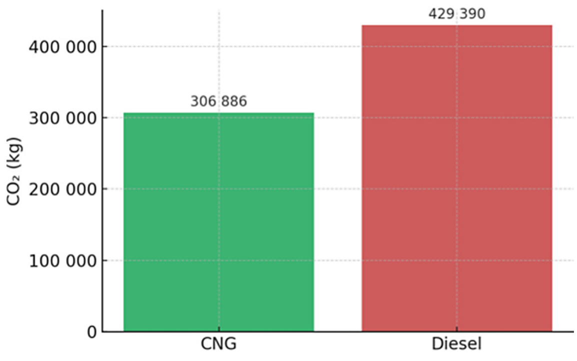

Figure 1. Carbon dioxide emissions (CO_2) in kilograms

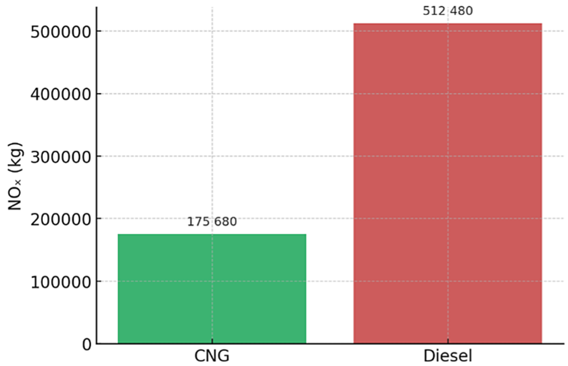

Figure 2. Comparison of nitrogen oxides (NO_x) in kilograms

diseases, especially in vulnerable populations such as children and the elderly. Yasar et al. [18] pointed out that switching from Diesel to CNG leads to significant reductions in HC emissions, NO_x, and tailpipe opacity. A study by Kumar et al. [19] reported that there is a reduction in CO_2, NO_x and smoke emissions when using CNG. The authors conducted an experiment which demonstrated that the use of CNG in dual-fuel combustion with Diesel has a significant effect on engine performance and especially emissions. In the context of European environmental policy, where NO_x emission limits are regulated by the Air Quality Directive (Directive 2008/50/EC), CNG technology represents a real contribution to improving air quality and meeting the objectives of the Green Convention for Europe.

In the case of particulate matter, which is one of the most dangerous pollutants for human health, it was shown (Figure 3) that Diesel vehicles emitted 22.8 g, while CNG emitted only 2.4 g. This corresponds to a 90% reduction, highlighting the crucial role of CNG in improving urban air quality and protecting public health. The study by Lejda et al. [20] showed results that CNG

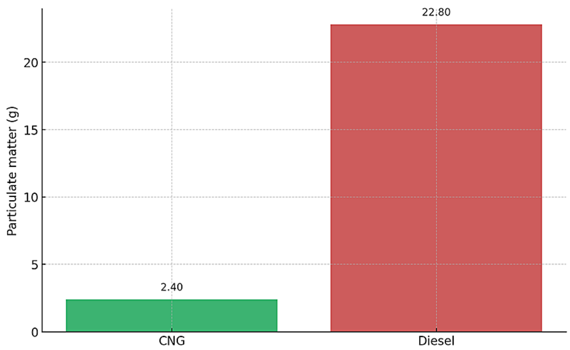

Figure 3. Comparison of PM emissions in grams

vehicle had significantly lower CO_2 and CO emissions, especially in urban conditions. Emissions were measured during New European Driving Cycle (NEDC) testing and in real road tests. High concentrations of $PM_{2.5}$ and PM_{10} are closely associated with increased mortality, incidence of cardiovascular disease, asthma and other chronic respiratory diseases. The World Health Organization therefore recommends strict limits on population exposure to these particles and encourages the deployment of low-emission technologies, including CNG, especially in the areas with heavy traffic and vulnerable populations [21].

In the case of sulphur emissions, CNG vehicles released only 2 400 g into the air, while Diesel vehicles emitted up to 2 468 000 g, a difference of more than 1 000 times. This amount of sulphur contributes to acidification of the atmosphere and water sources, resulting in soil degradation, corrosion of infrastructure and adverse impacts on biodiversity. Under European legislation, the sulphur content of fuels is strictly limited (at 10 mg/kg), making CNG one of the cleanest fuels in terms of sulphur pollution [22].

Together, these results point to the benefits of CNG not only in terms of climate goals, but also in terms of protecting public health, making it an important tool for environmental and transport policy, especially in the transition towards zero-emission mobility.

Figure 4 shows a regression analysis of fuel cost (CNG vs. Diesel) versus mileage. Both fuels have a linear relationship between miles driven and cost, with the increase in cost for Diesel being significantly steeper. This confirms that CNG represents a more economically viable alternative, especially for longer operation. Similar results were also reached by Do et al. [23] in the assertion, which follows from their study, that CNG vehicles can be an efficient substitute for Diesel vehicles, while offering lower operating costs.

The regression analysis shown in Figure 5 clearly documents the linear relationship between the number of kilometres driven and CO_2 emissions for Diesel and CNG vehicles. Diesel vehicles, represented by the red regression line, show a significantly higher increase in CO_2 emissions compared to CNG vehicles, represented by the blue regression line. This difference is due to the lower carbon intensity of CNG, which makes its use more environmentally beneficial. The results are consistent with the findings of the European Environment Agency, which states that

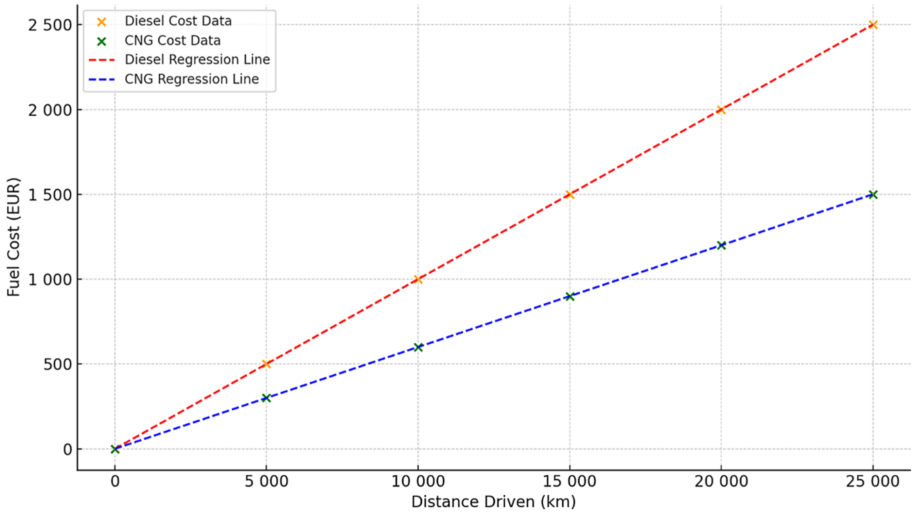

Figure 4. Regression analysis of fuel costs by kilometres travelled

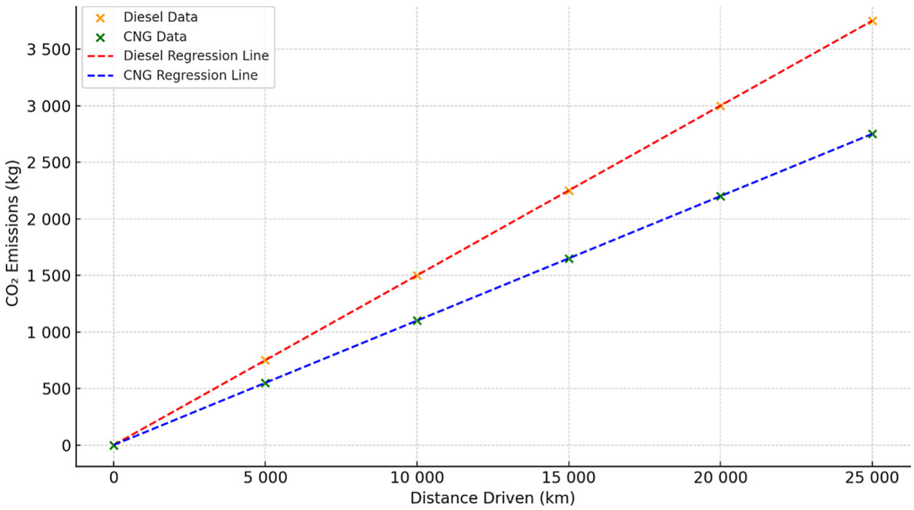

Figure 5. Regression analysis of CO_2 emissions by kilometres travelled

CNG vehicles achieve on average 20–30% lower CO_2 emissions compared to Diesel alternatives [2]. Tong et al. [24] found that CNG vehicles can achieve up to 20% reduction in CO_2 emissions compared to gasoline vehicles based on a regression analysis comparing the life cycle GHG emissions between CNG and gasoline vehicles. By using Monte Carlo analysis, the authors wanted to show that the variability and uncertainty of emissions throughout the life cycle of natural gas is considered. In their study, Pijoan et al. [25] developed regression models to quantify CO_2 emissions from different types of vehicles, including those powered by CNG. Their analysis also shows and confirms claims that CNG vehicles produce lower CO_2 emissions compared to traditional fuels such as Diesel or gasoline.

Similar conclusions are also provided by an experimental study by Sahoo and Srivastava [3], according to which up to 29% lower CO_2 emissions were measured for CNG engines compared to gasoline and also a significant reduction compared to Diesel. Lee et al. [26] show in their study that the vehicles produced approximately 20% less CO_2 emissions and significantly lower NO_x emissions compared to Diesel vehicles. The practical impact was also investigated by Igwe et al. [27], who demonstrated that the conversion of passenger vehicles from gasoline to CNG leads to measurable savings and lower emissions. These findings are consistent with the conducted regression analysis, which confirms a linear relationship between mileage and both cumulative cost and CO_2 savings. In his study, Mądziel [28] applied and implemented the development of an accurate CO_2 prediction model for CNG vehicles in the context of stringent environmental policies. The CO_2 emission models designed for CNG vehicles support global efforts to reduce the carbon footprint of transportation. The study also confirms the obtained findings that CNG-powered vehicles emit less CO_2 than conventional vehicles, thus contributing significantly to GHG reduction.

Figure 6 represents the predicted development of emission for two different fuels (CNG and Diesel) in the years 2015–2030. The vertical axis shows the relative emission index, which starts at 100 for both fuels in 2015 and gradually decreases. This index allows for a comparison of the rate of emission decline between the two technologies, not considering the absolute amounts of emissions, but the change over time. The trend analysis shows that CNG emissions are declining at a faster rate than Diesel emissions. While Diesel shows a modest emission decline of around 7% over 15 years, CNG has seen a more significant reduction of around 22%. This difference underlines the environmental advantage of CNG, which results from its lower carbon footprint and cleaner combustion compared to Diesel. In conclusion, if the predicted trend is fulfilled, CNG will be a significantly cleaner solution than Diesel in terms of emissions in 2030, which supports its application in sustainable mobility policy and ecological transport systems.

Figure 7 shows the projected development of fuel costs per kilometre for CNG and Diesel vehicles between 2015 and 2030. The vertical axis shows relative cost units, which represent the trend development (not absolute prices in euros), while the horizontal axis shows individual years. The operating costs of CNG vehicles have a decreasing trend, being at 1.0 units in 2015 and decreasing to approximately 0.7 units by 2030. This development reflects technological progress, increasing CNG combustion efficiency and the favourable development of Diesel prices in transport. In contrast, Diesel costs are gradually increasing, increasing from 1.2 units in 2015 to more than 1.3 units in 2030. This increase may be related to increasing Diesel prices, stricter emission legislation, increased taxes and maintenance costs of older Diesel engines. Comparing both trends clearly shows that CNG is becoming a more cost-effective solution in transport in the long term. This fact strengthens its application in vehicle transport and logistics services, where long-term costs play a decisive role. The trend analysis in Figure 7 confirms not only the ecological but also the economic advantage of CNG in the period up to 2030.

Despite the clear environmental and economic advantages demonstrated in this study, the use of CNG in public and commercial transport also presents several limitations that merit critical consideration. One of the main challenges remains the limited availability of refuelling infrastructure, especially in rural areas and smaller towns. While some countries, including Slovakia, have made progress in building CNG stations, the network is still insufficient for their widespread deployment. This limits the operational flexibility of CNG vehicles and may discourage private operators or municipalities from converting their

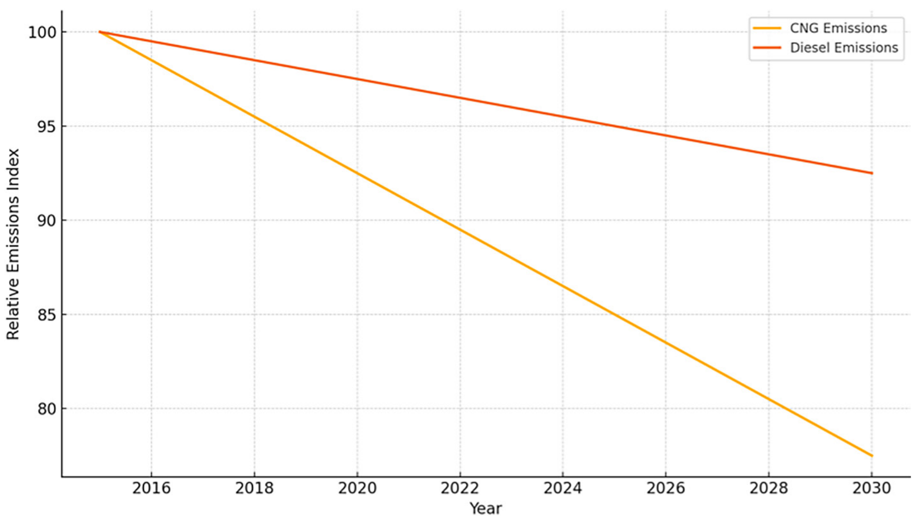

Figure 6. Projected emission trends (2015–2030)

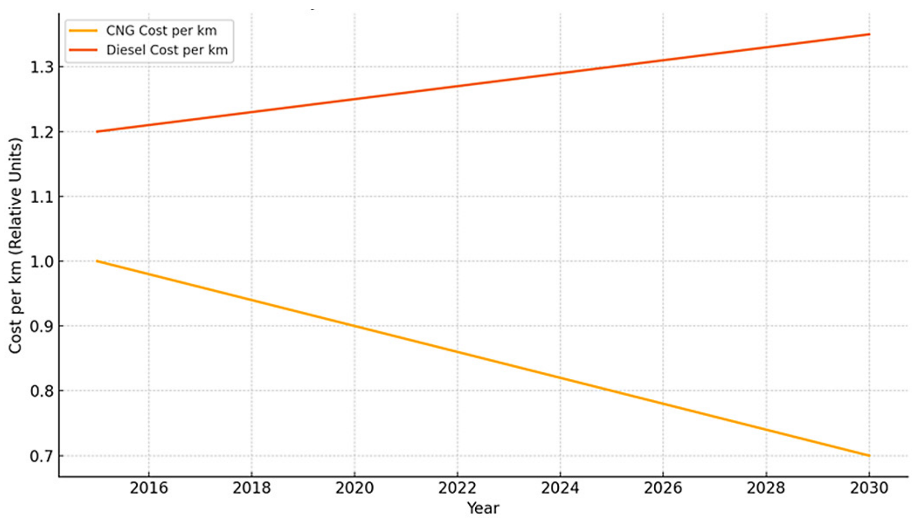

Figure 7. Projected fuel cost trends (2015–2030)

fleets without guaranteed access to fuel. Another obstacle is the initial investment costs, especially in the case of retrofitting existing diesel vehicles or purchasing new CNG-compatible models. Although operating costs are generally lower, the initial expenditure on conversion kits, vehicle replacement and the necessary maintenance training can represent a significant burden, especially for smaller transport operators. Without targeted public subsidies or incentives, the return on investment in CNG technology may not be favourable in all contexts. Safety concerns, although largely mitigated by modern design standards, persist in public perception. CNG is stored under high pressure (typically 200–250 bar), which can pose a risk in the event of accidents or improper handling. The need for strict safety protocols, regular inspections and trained personnel increases operational complexity. Insufficient maintenance or outdated storage systems can further increase vulnerability, especially in retrofitted or older vehicles. In addition, the climatic and performance limitations of CNG technology can affect engine efficiency in cold weather or high-load applications. Unlike diesel, which operates reliably over a wide range of temperatures and altitudes, CNG engines can exhibit reduced performance under harsh conditions, requiring additional technological adaptation. Finally, in the long term, CNG (although cleaner than Diesel) is still a fossil fuel-based fuel, and its deployment must be considered as an interim measure. Without the integration of renewable forms such as biomethane, the decarbonisation potential of CNG in the context of achieving net zero emissions targets remains limited. Therefore, while the results of this study confirm the environmental and economic advantages of CNG compared to Diesel, a balanced assessment must also consider these limitations. Overcoming them will require not only technical innovations, but also supportive policy frameworks, targeted investments and coordinated infrastructure planning at both national and regional levels.

CONCLUSIONS

The results of this study confirm that CNG represents an efficient alternative to traditional fossil fuels in the transport sector, especially in terms of environmental and economic benefits. Data showed that CNG vehicles have significantly lower CO_2 emissions and also bring significant savings in operating costs compared to Diesel vehicles. These findings are in line with international studies showing the environmental benefits of CNG. CNG vehicles emit less greenhouse gases and pollutants compared to traditional fuels, which contributes to improving air quality and reducing the carbon footprint. Moreover, cost-effectiveness analysis shows that CNG can be more economically viable, especially for long-term operation of vehicles in urban environments. From an environmental point of view, CNG represents a fuel with a lower emission factor, which also has the potential to work synergistically with renewable options such as biomethane. A study states that the integration of renewable natural gas into existing CNG infrastructure can further reduce GHG emissions and support the transition to more sustainable transport. In the context of the European Union's climate targets and the need for immediate emission reductions in the transport sector, CNG is a relevant part of the fuel mix.

However, for its potential to be fully developed, targeted support from the state is essential, especially in the form of incentives, investment in infrastructure and flexible subsidy policies. In order to achieve a systematic reduction of carbon emissions in the transport sector, it is also necessary to allocate attention to the introduction of breakthrough technologies or the evaluation of currently available solutions aimed at reducing the number of vehicles. The current era of digitalisation and the use of artificial intelligence is also increasingly being applied for the purpose of GHG removal. The results emphasise the importance of modern technologies in creating sustainable and efficient solutions, such as electric and hybrid vehicles in particular, which contribute significantly to the reduction of GHG emissions, due to the fact that electric vehicles do not produce any emissions (CO_2) and the CO_2 emissions from hybrid vehicles are low, resulting in a reduction of the emissions themselves compared to gasoline and Diesel-powered vehicles. At the same time, research into hybrid solutions should be encouraged to enable the technology to be applied more widely in more demanding transport segments. An analysis of projected emission and fuel cost trends from 2015 to 2030 highlights CNG as a more sustainable and economically viable alternative to Diesel. CNG shows significantly greater emission reductions, reinforcing its environmental benefits and alignment with low-carbon transport policies. The decreasing trend in CNG operating costs compared to the increasing costs of Diesel confirms its long-term cost-effectiveness. These findings support the strategic integration of CNG technologies into transport systems and logistics to support cleaner and more affordable transport solutions.

Acknowledgements

This research paper is a partial output of the project VEGA 1/0713/24 Digital economy as a key challenge for the transformation of enterprises in Slovakia financed by the Ministry of Education, Research, Development and Youth of the Slovak Republic.

REFERENCES

1. European Environment Agency. *Greenhouse gas emissions by country and sector*. 2022. (Accessed: 03.06.2025) https://www.eea.europa.eu/en/analysis/indicators/greenhouse-gas-emissions-by-country-and-sector-2
2. European Environment Agency. Air quality in Europe – 2020 report (EEA Report No. 9/2020). (Accessed: 03.06.2025) https://www.eea.europa.eu/publications/air-quality-in-europe-2020-report
3. Sahoo, S. and Srivastava, D. K. *Environment and economic assessment of CNG and gasoline engines: An experimental analysis* (Paper No: ICEF2021-66772, V001T04A001). ASME. 2021. https://doi.org/10.1115/ICEF2021-66772
4. European Commission. National policy framework on the development of the market for alternative fuels in the transport sector and the deployment of the relevant infrastructure – Slovakia Report. 2019. (Accessed: 03.06.2025) https://transport.ec.europa.eu/document/download/773ed6ef-0667-47f5-8ca9-97b298ef227d_en?filename=Slovakia-NPF-Report-2019.pdf
5. EPIC. Analysis of environmental and economic savings of vehicles CNG (2015–2020). 2020. [Internal document, M.B.M. Group].
6. Divekar, P., Han, X., Zhang, X., Zheng, M. and Tjong, J. Energy efficiency improvements and CO_2 emission reduction by CNG use in medium- and heavy-duty spark-ignition engines. Energy. 2022; 263, 125769. https://doi.org/10.1016/j.energy.2022.125769
7. Ali, Y., Younus, A., Khan, A. U. and Alrefai, A. H. Compressed natural gas (CNG) as a fuel and the associated risks: A quantitative analysis in the scenario of a developing country. Journal of Safety Science and Resilience. 2024; 5, 306–316. https://doi.org/10.1016/j.jnlssr.2024.05.001
8. Al-Mohannadi, A. A., Ertogral, K. and Erkoc, M. Alternative fuels in sustainable logistics—Applications, challenges, and solutions. Sustainability; 2024. 16(8484). https://doi.org/10.3390/su16198484
9. Rose, L., Hussain, M., Ahmed, S., Malek, K., Costanzo, R. and Kjeang, E. A comparative life cycle assessment of diesel and compressed natural gas powered refuse collection vehicles in a Canadian city. Energy Policy. 2012; 52, 453–461. https://doi.org/10.1016/j.enpol.2012.09.064
10. Borgosano, S., Saldarini, A., Longo, M., Zaninelli, D. and Astori, V. Cost analysis and optimization of public bus fleets using genetic algorithm considering different technologies. Proceedings of AEIT Conference 2024. Politecnico di Milano. https://ieeexplore.ieee.org/xpl/conhome/10736529/proceeding

11. Özcan, F. and Kılıç, M. Dynamic modeling of a compressed natural gas refueling station and multi-objective optimization via Gray Relational Analysis method. Applied Sciences. 2025; 15(4908). https://doi.org/10.3390/app15094908
12. Fabianová, J. and Janekova, J. Economic assessment of investment in electric buses and CNG buses – A case study of a public transport company. Advances in Science and Technology Research Journal. 2022; 16(4), 96–105. https://doi.org/10.12913/22998624/151801
13. Majczak, A., Barański, G., Sochaczewski, R. and Siadkowska, K. CNG injector research for dual fuel engine. Advances in Science and Technology Research Journal. 2017; 11(1), 212–219. https://doi.org/10.12913/22998624/68458
14. Hussaini, M., Babagana, M., Jibrin, I., Haliru, M. M., Ugoamadi, C. E., Hamid, A. T., Yauri, A. M. and Aba, M. M. Appraising the prospects and scenario of low carbon energy transition for road transport sector in Maiduguri metropolis. Bayero Journal of Engineering and Technology. 2024; 19(1), 22–40. https://www.academia.edu/120741192/APPRAISNG_THE_PROSPECTS_AND_SCENARIO_OF_LOW_CARBON_ENERGY_TRANSITION_FOR_ROAD_TRANSPORT_SECTOR_IN_MAIDUGURI_METROPOLIS
15. Valavanidis, A. Transport systems and renewable energy sources: Critical role in achieving climate change mitigation. Scientific Reviews. 2024. https://www.researchgate.net/publication/380899466
16. Jamrozik, A., Tutak, W., Pyrc, M., Grab-Rogaliński, K. and Gruca, M. Experimental Comparative Study on the Use of Hydrogen and Ammonia in a Dual-Fuel Diesel Engine. 2025. Available at SSRN: https://ssrn.com/abstract=5200527
17. European Commission. *Fit for 55: Delivering the EU's 2030 Climate Target on the way to climate neutrality*. Brussels: European Commission. (Accessed: 03.06.2025) https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52021DC0550
18. Yasar, A., Haider, R., Tabinda, A., Kausar, F. and Khan, M. A comparison of engine emissions from heavy, medium, and light vehicles for CNG, diesel, and gasoline fuels. Polish Journal of Environmental Studies. 2013; 22(4): 1277–1281. https://www.pjoes.com/pdf-89090-22949?filename=22949.pdf
19. Kumar, N., Arora, B. and Maji, S. Environmental impact evaluation of diesel engine fuelled with CNG. Archives of Environmental Protection. 2023. https://doi.org/10.24425/aep.2023.144740
20. Lejda, K., Jaworski, A., Mądziel, M., Balawender, K., Ustrzycki, A. and Savostin-Kosiak, D. Assessment of petrol and natural gas vehicle carbon oxides emissions in the laboratory and On-Road tests. Energies. 2021; 14(6), 1631. https://doi.org/10.3390/en14061631
21. World Health Organization. *WHO global air quality guidelines: Particulate matter ($PM_{2.5}$ and PM_{10}), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide*. 2021. https://www.who.int/publications/i/item/9789240034228
22. European Commission. *Commission Implementing Regulation (EU) 2022/631 of 13 April 2022*. (Accessed: 03.06.2025) https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32022R0631
23. Do, S., Taa, M. and Far, F. Performance and fuel consumption evaluation of heavy-duty vehicles with CNG engines in real application. SAE Technical Papers on CD-ROM/SAE Technical Paper Series. 2023; https://doi.org/10.4271/2022-36-0116
24. Tong, F., Jaramillo, P. and Azevedo, I. M. L. Comparison of life cycle greenhouse gases from natural gas pathways for medium and heavy-duty vehicles. Environmental Science & Technology. 2015; 49(12), 7123–7133. https://doi.org/10.1021/es5052759
25. Pijoan, A., Oribe-Garcia, I., Kamara-Esteban, O., Genikomsakis, K. N., Borges, C. E. and Alonso-Vicario, A. Regression based emission models for vehicle contribution to climate change. Advances in intelligent systems and computing. 2016; 47–63. https://doi.org/10.1007/978-3-319-43991-4_5
26. Lee, D., Zietsman, J., Farzaneh, M. and Johnson, J.. Characterization of On-Road emissions of compressed natural gas and diesel refuse trucks. Transportation Research Record Journal of the Transportation Research Board. 2011; 2233(1), 80–89. https://doi.org/10.3141/2233-10
27. Igwe, I., Amadichuku, N., Ibanga, V. S. and Alerechi, U. Economic implications of converting petrol based cars to natural gas based cars. International Journal of Science Engineering and Technology. 2024. https://www.ijset.in/wp-content/uploads/IJSET_V12_issue1_567.pdf
28. Mądziel, M. Modelling CO_2 emissions from vehicles fuelled with compressed natural gas based on on-road and chassis dynamometer tests. Energies. 2024; 17(8), 1850. https://doi.org/10.3390/en17081850