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Analysis of the Impact of Static and Dynamic Driving Factors on the Consumption Difference Between LNG-and Diesel-Powered Heavy-Duty Trucks in Test Track Environment

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Abstract

The present study builds upon the authors' previous research, which highlighted the fuel consumption advantage of LNG-powered (liquefied natural gas) trucks over conventional diesel vehicles. Expanding on this topic, the aim of this research is to analyze the influence of static and dynamic driving factors on the consumption advantage of LNG vehicles. The study was conducted in a test-track environment, ensuring optimal reproducibility with minimal external influencing factors, allowing for various types of measurements. In this research, fuel consumption values were recorded indirectly through the fleet management system (FMS) using controller area network (CAN) messages. Data distribution analysis, the Shapiro-Wilk test, and ANOVA were employed to validate the research hypotheses. Our study is unique in the field of heavy-duty vehicles (HDVs) as the measurements were performed at the test-track level, providing precise data for emission differences. The results indicate that the static driving environment (represented by different test track modules) has a stronger influence on the consumption advantage of LNG vehicles. In contrast, driving mode has a lesser effect on the consumption difference between LNG and diesel trucks.

Keywords

liquefied natural gas vs. diesel, heavy-duty trucks, consumption advantage analysis, test-track measurements

1 Introduction

Sustainability, environmental protection, and digitalization are megatrends that continuously shape the balance in transportation and logistics. Carbon-dioxide (CO_2) is the primary greenhouse gas (GHG) emitted by human activity and is naturally present in environments where human activities can easily disrupt the balance, such as in the production and use of fossil fuels (Nunes, 2023). Heavy-duty vehicles (HDVs) are a key concern, with the International Energy Agency's 2023 report stating that more than 60,000 medium- and heavy-duty vehicles were put into service globally in the previous year, accounting for 1–2% of total world sales. However, despite this small percentage, the truck sector is a significant contributor to greenhouse gas emissions, releasing nearly 2,300 Mt of CO_2 annually (International Energy Agency (IEA), 2023). The transport sector is a major greenhouse gas emitter, responsible for 6% of global emissions and over 25% of CO_2 emissions (Krause et al., 2023). The European Commission confirms this emission rate in its 2023 report "The European Green Deal" (European Commission, 2023) and also states that almost 96% of the European Union's (EU) vehicle fleet is currently powered by internal combustion engines (ICE), which rely mainly on imported fossil fuels. This further heightens the European Union's energy dependence on a global scale. The report emphasizes that more stringent European regulations mandate the medium- and heavy-duty vehicle sectors to play a role in reducing GHG and CO_2 emissions, while promoting a shift towards low or zero-emission alternatives in the market (European Commission, 2023). Globally, China (with over 9,500 million tons) and the United States (with over 5,000 million tons) remain the largest contributors to emissions. In Europe, Germany (with over 900 million tons) leads as a significant GHG emitter, followed by the United Kingdom (470 million tons) and France (460 million tons), with the energy, industry, and transport sectors being the primary contributors (Anderhofstadt and Spinler, 2020). According to a study by Gunawan and Monaghan, the HDV segment is one of the most challenging areas to regulate in

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the effort to reduce GHG emissions within the transport sector (Gunawan and Monaghan, 2022). In 2019, the European Parliament and the Council introduced new regulations under the 2019/1242 directive for HDVs in the European Union. For instance, manufacturers are required to cut their CO_2 emissions by 15% by the end of 2025 compared to 2019 levels. If this target is not met, adjustments to the regulation will be implemented to incentivize the transition from diesel vehicles to lower-emission alternatives, with various benefits offered for adopting alternative vehicles in the EU transportation sector (European Parliament, Council of the European Union, 2019).

In order to achieve the goals and targets set by the European Parliament and Council, the adoption of alternative powertrains and e-fuels with lower emissions compared to diesel technology is necessary. However, the widespread implementation of these alternative technologies faces several challenges from financial, environmental, political, functional, and social perspectives. The EU and national governments are working to promote the adoption of alternative technologies through various incentives, such as tax breaks, free access to road networks, route permits, and extended operational hours (European Parliament, Council of the European Union 2019; Jahaniaghdam et al., 2023).

Currently, there are numerous alternatives available for HDV powertrains that either reduce tailpipe emissions or eliminate greenhouse gas emissions during operation entirely. The latter is achieved through hydrogen propulsion, an area with significant development potential, and battery technology (Aryanpur and Rogan, 2024). Both powertrains share common features, including the ability to power an electric motor, the absence of greenhouse gas emissions, and the use of regenerative braking (Cunanan et al., 2021). Each technology has its own advantages and disadvantages that must be carefully considered. For instance, while hydrogen technology has the potential to significantly reduce emissions, its high current cost, non-green production methods, and low fuel energy density make it less than ideal for replacing the entire diesel HDV market. Substantial investment, further technological advancements, and safe management practices are essential to ensure efficient and sustainable operation for this type of HDVs (Osorio-Tejada et al. 2017; van Kranenburg et al., 2020). The efficiency of battery technology is significantly influenced by factors such as the energy source, charging times, storage costs, mass, energy density, and lifespan. Although battery-powered systems offer simpler designs and lower maintenance costs compared to conventional diesel engines, their current lifespan falls short of being competitive across all HDV transport segments (Cunanan et al., 2021; Giuliano et al., 2021). The challenge is further aggravated by insufficient infrastructure and the limited deployment of charging systems, which are critical for supporting low storage capacity types in both electric and hydrogen propulsion systems. At present, the practical application of electric technology is constrained, with short-distance transport being the most viable option (Ribberink et al., 2021; Sugihara et al., 2023).

As an alternative for reducing emissions, it is important to emphasize natural gas-based technology, which can result in lower fuel consumption. Compared to diesel propulsion, it significantly reduces the presence of harmful chemical elements, including CO_2, NOx (mono-nitrogen oxide), SOx (sulphur-oxide), and PM (particulate matter) concentrations, which are detrimental to both the environment and human health (Askin et al., 2015). Natural gas systems easily comply with EURO VI emission standards and can maintain an optimal stoichiometric air-fuel ratio, thereby eliminating the need for complex aftertreatment and regeneration systems. Natural gas propulsion has been used in mobility for many years, initially through compressed natural gas (CNG). However, due to CNG's low energy density, liquefied natural gas (LNG) has gained prominence, offering up to 2.5 times the energy content of CNG (Thiruvengadam et al., 2018). The liquefaction process compresses the gas volume to approximately 1/600th of its original size, facilitating economical transport, and resulting in a density of 430–480 kg m^3 at −162°C under atmospheric pressure. The LNG is a colorless, odorless, non-toxic, and non-corrosive substance composed of up to 98% pure methane (CH_4). Due to its high methane content, LNG undergoes efficient oxidation, resulting in nearly complete combustion with minimal ash production. This process leads to the emission of up to 10% fewer greenhouse gases compared to conventional fuels, making LNG a promising alternative for long-distance transportation (Pfoser et al., 2018; Teixeira et al., 2020). However, LNG's primary drawback lies in its relatively low density compared to diesel fuel (diesel density ranges from 840 to 860 kg m^3). LNG has approximately half this density, meaning that achieving the same driving range requires nearly twice the fuel tank capacity. This limitation poses a significant challenge in applications where fuel storage space is constrained (Smajla et al., 2019).

Recent studies have explored the emissions from diesel versus LNG-powered heavy-duty vehicles (HDVs). In 2017, Quiros et al. compared greenhouse gas emissions from diesel, diesel-hybrid, and LNG-fueled HDVs. In this study, seven different tractors were tested (five diesel-powered and two LNG-powered), revealing that LNG-powered vehicles produced 5–15% lower CO_2-equivalent emissions and fuel consumption on average over various routes compared to diesel (Quiros et al., 2017). On highways, this reduction exceeded 10%. Similarly, in 2019, Di Maio et al. reported a 6–8% reduction in urban settings and a 10% reduction on highways, once again favoring LNG over diesel in terms of CO_2-equivalent emissions and fuel consumption (Di Maio et al., 2019). In Europe, several studies have further investigated diesel and LNG HDV emissions in freight and long-distance transport. In 2010, Arteconi et al. conducted a well-to-wheel analysis (accounting for all life cycle phases, from raw material extraction to fuel use) and found that LNG reduces greenhouse gas emissions by approximately 10% compared to diesel (Arteconi et al., 2010). In 2021 Gnap and Dočkalik corroborated these findings in their study, which measured fuel consumption and CO_2 emissions along Slovakia-Germany and Slovakia-Hungary routes. Their results showed an 8% CO_2-equivalent and 6–8% fuel consumption reduction in favor of LNG tractors across various terrains and environmental conditions (Gnap and Dočkalik, 2021). Beyond Europe, for example in China, the conventional diesel HDVs are responsible for 16.8% of CO, 6.9% of THC (Total Hydrocarbon), 57.8% of NOx and 66.3% of PM emissions from the total vehicle fleet, while the HDV fleet accounts for 3.1% of total vehicle emissions (Wang et al., 2021). In 2013, Ou and Zhang examined primary energy consumption and CO_2 emissions from natural gas-based alternative fuels in China. Their results indicated a 5–10% reduction in greenhouse gas emissions (as well as the fuel consumption) when using CNG and LNG compared to conventional diesel technology (Ou and Zhang, 2013). More recent data from the United States, as reported by Toumasatos et al. in 2024, found a significant CO_2-equivalent difference between conventional diesel and LNG-powered HDVs across various road types, including highways, urban roads, rural areas, and uphill sections. Their study demonstrated a 10–15% reduction in CO_2-equivalents and lower fuel consumption for LNG-powered HDVs (Toumasatos et al., 2024).

In our previous research, we investigated the differences in CO_2 emissions between conventional diesel and LNG-powered HDVs, specifically analyzing the impact of speed on emissions. Our findings indicated that, unlike conventional diesel HDVs, the fuel consumption of LNG-powered vehicles does not increase significantly during sudden acceleration or aggressive driving. Preliminary test results showed that LNG-fueled HDVs were less sensitive to rapid changes in acceleration (such as full-throttle operation) and deceleration, compared to diesel HDVs, with regard to both fuel consumption and emission levels. The preliminary research supported the conclusion that driving behavior is a key factor influencing emissions. The difference in CO_2 emissions between the two propulsion systems typically remains around 10%, with LNG showing a consistent advantage. Our findings demonstrate that LNG offers a reliable alternative, resulting in an approximately 11% reduction in CO_2 emissions compared to diesel under controlled conditions (in test track environment) (Sütheö and Háry, 2024).

2 Research goal

The current analysis builds on an earlier research of the authors, which pointed out the consumption advantage of an LNG-powered truck compared to the classic Diesel vehicle. As a continuation of this topic, the purpose of this research is to analyze the impact of static and dynamic driving factors on the LNG vehicles' consumption advantage. In this paper, static factors are meant as follows: shape of the driving environment including angle of road surface, and dynamic factors are meant as follows: driving mode varying from economy style to dynamic. The objective of the research is to analyze the strength of relationships between static and dynamic conditions versus the LNG consumption advantage of the given truck.

Hypotheses of the research are:

- H1: There is a statistically proven relationship between the static factors and the LNG consumption advantage of the analyzed truck.
- H2: There is a statistically proven relationship between the dynamic factors and the LNG consumption advantage of the analyzed truck.

3 Materials and methods

In this research, a diesel tractor and a trailer, as well as an LNG tractor and trailer combination were used and tested for five days over 600 kilometers. Both vehicles were made by the same OEM (Original Equipment Manufacturer) in 2023, equipped with engines of nearly 13,000 cm^3, 12-speed automatic gearboxes and similar-sized tires as shown in Table 1.

The trailers in the vehicle combination were box body semi-trailers and the weight differences were compensated by adjusting the personnel distribution during the tests.

The data required for the analysis was obtained from the vehicles' controller area network (CAN) system, utilizing continuous real-time readout and post-processing

Table 1 Technical data of the Diesel and LNG tractors

Type	Diesel fueled	LNG fueled
Model	AS440S49T/P – AF4T	AS440S46T-P 2LNG – AG4T
Weight	8,465 kg	8,279 kg
Gearbox	12TX 2210 TD	12TX 2010 TO
Tire	315/70R22,5 Pirelli FH01/TH01	315/70R22,5 Michelin X Multi Energy Z/D
Performance	357 kW / 1,900 rpm	338 kW/ 1,900 rpm
Torque	2400 Nm / 950 rpm	2000 Nm / 1,100 rpm
Cylinder capacity	12,882 cm^3	12,900 cm^3
Compression ratio	20,5 ± 0,5:1	12 ± 0,5:1
Injection type	Direct	Indirect

through the Kvaser CanKing software (version V6.24.510) (Kvaser, 2023). The fleet management system (FMS) gateway served as the connection point for extracting CAN data at a bus speed of 250 kbit/sec, which represents the standard access point and bus speed for such systems. Data decoding was based on the standardized FMS system (version 04, dated 17/09/2021) (ACEA, 2021), with a focus on filtering consumption-specific and influencing values. The CAN message decoding file was generated using CANdb++ software (version 3.1) (Vector, 2022). The data read and process was performed with the Kvaser Memorator R-SemiPro CAN bus interface as shown in Fig. 1, which had CAN-Low, CAN-High, +12V power supply and protective grounding integrated into D-SUB 9-pin connector. Therefore, only one USB connection was needed for the measurements between the interface and the laptop.

As the outcome of the data collection, a pre-defined data structure was used to arrange the data records, using the following features as shown in Table 2.

During our measurements in the ZalaZONE Proving Ground (www.zalazone.hu), we employed five distinct

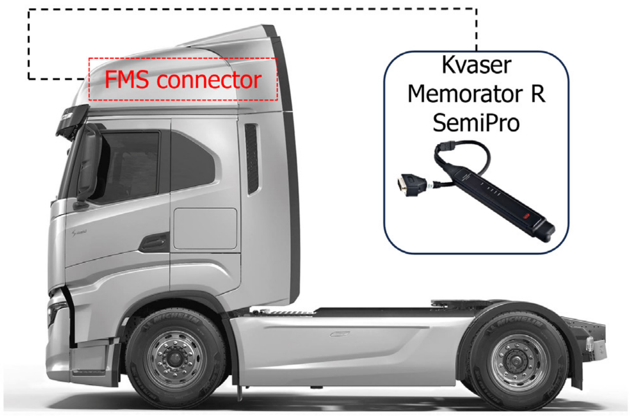

Fig. 1 Application of CAN bus interface to read and process CAN messages via FMS gateway

Table 2 Dynamic and static factor variables in the test rack measurements

Dynamic factor variables	Static factor variables
City driving mode	City environment (SCZ)
Economy driving mode	Highway (MW)
Normal driving	High-speed handling track (HS-HC)
Dynamic driving	Rural road conditions (RR)
Slope driving	Slopes (HILL)

driving styles. Predominantly, we conducted normal, economy, and dynamic test cases, supplemented by urban driving and hill climb scenarios to represent typical operating conditions for HDVs engaged in long-distance transport. In the normal and economy test cases, a connected road network (Motorway & Rural Road section) was used to compare the performance of two tractors under varying speeds and loads. For the dynamic driving test, the high-speed handling section of the test track was utilized, enabling both normal and dynamic accelerations and decelerations. To simulate urban driving conditions, we designed a driving plan in an urban environment, incorporating multi-lane roads, intersections, roundabouts, and a depot. To replicate uphill driving conditions, we conducted tests on a track featuring climbs and descents in different gradients (5%, 12% and 18%). The overall test cycle was environmentally diverse, with a primary focus on highway driving, and included simulations of rural road traffic, combined with hills, slopes, and urban environments as shown in Fig. 2. Additionally, this setup enabled the testing of complex, interconnected systems to maximize the distance travelled while utilizing a more extensive environment (such as Motorway track connection with Rural Road section).

Data records were generated based on the collected data as per elementary time slots, which were around the one-minute range. This allowed the calculation of the LNG consumption advantage for each and every time slot in a comparable way in Eq. (1). In a given time slot, the consumption of

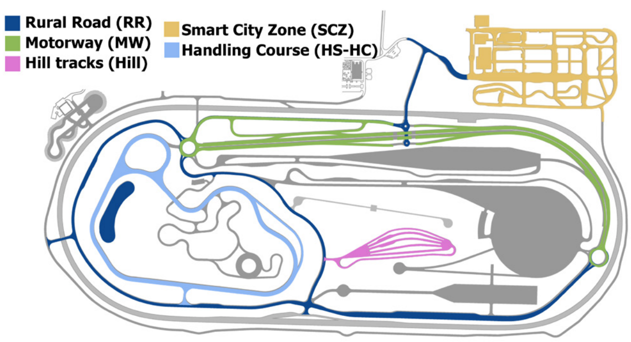

Fig. 2 The map of the ZalaZONE test track

the LNG truck and the Diesel truck were measured with the same (static and dynamic factor) conditions. Consumption was measured in liters for diesel tractors and in kilograms for LNG. To determine the difference, the consumption of the diesel tractor was converted from liters to kilograms, with 1 liter of diesel equaling approximately 0.85 kilograms (the density of diesel 840–860 kg/m^3) (Speight, 2011).

$$\text{LNG consumption advantage } [\text{kg}] = \text{Consumption Diesel} - \text{Consumption LNG} \quad (1)$$

A total of 587 data points have been evaluated. The data assessment was done using two-factor ANOVA analysis method. The first factor was the static factor, including the surface features of the driving and the second factor was the dynamic factor including the driving modes. The LNG consumption value was left as calculated absolute value according to the Eq. (1). The assessment was made using JAMOVI statistical software (Version 2.4) (The jamovi project 2023).

4 Results and discussion

Table 3 shows the main descriptive statistics of the measured LNG consumption advantage in comparison to the normal Diesel truck.

In order to establish ANOVA analysis pre-conditions, normality of the consumption data (as dependent variable) was determined. As it can be seen in Fig. 3 and Fig. 4, normal distribution of the data is confirmed.

The Shapiro-Wilk test outcome ($p < 0.001$) also confirms the firm assumption on the normality of the dependent value distribution, as shown in Table 4.

As per the other pre-condition of the feasibility of ANOVA analysis, homogeneity check was performed using Levene's formula. As it is shown by Table 5, the test value with $p < 0.001$ confirmed the required homogeneity nature of the data.

Table 3 Descriptive statistics of the measured LNG consumption advantage

Descriptive	LNG consumption advantage
N	587
Missing	1
Mean	464
Median	463
Standard deviation	784
Variance	614
Range	13
Minimum	−5
Maximum	8

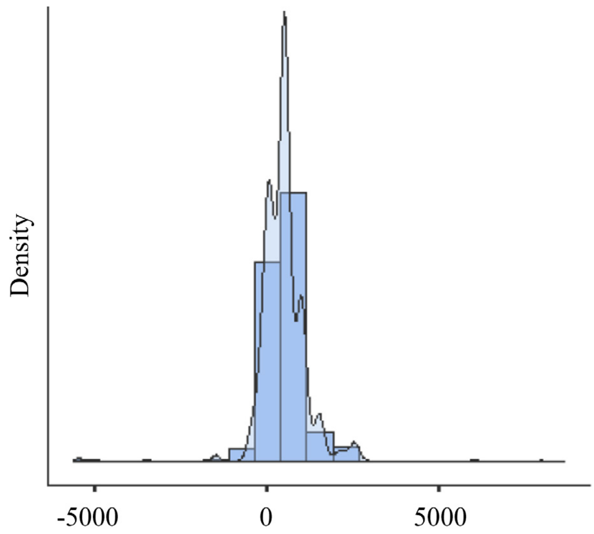

Fig. 3 Check of distribution of LNG consumption advantage values

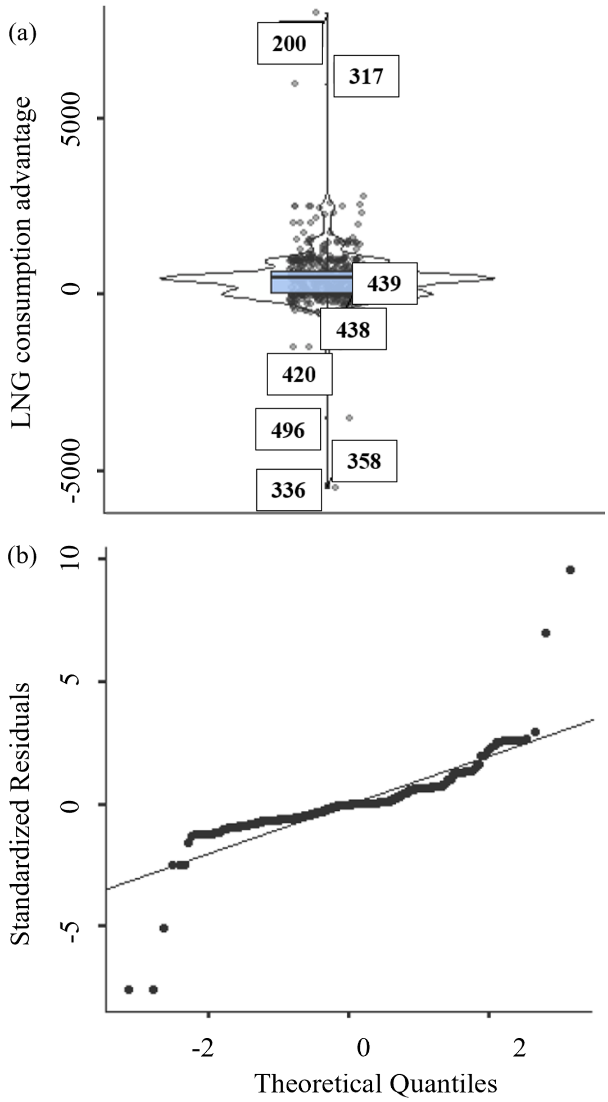

Fig. 4 Check of distribution of LNG consumption advantage values (a) frequency distribution; (b) Q-Q plot

Table 4 Normality test (Shapiro-Wilk) outcome of LNG consumption advantage values

Statistics	p
0.722	< 0.001

Table 5 Data homogeneity of variances test (Levene's formula) outcome of LNG consumption advantage values

F	df_1	df_2	p
3.38	7	579	0.001

After ensuring the completion of the pre-conditions, the ANOVA analysis has been run in three ways: only with driving mode (as dynamic) factors, then only with test track module (as static) factors, and also for the general model, including both static and dynamic factors. The summary of the results is shown in Table 6.

As it can be seen, the overall model line dynamic × static reflect statistically strong conclusions with $p < 0.001$ value on relationship. Still, the single model analysis (either the static or dynamic side) shows rather strong relations among the influencing factors and the LNG consumption advantage values. It is also apparent that the static driving environment (represented by the various test track modules) has stronger impact on the consumption advantage of LNG vehicles. Contrary, the driving mode has less influence on the consumption difference between LNG and Diesel trucks.

Fig. 5 represents the ANOVA analysis results through scatter charts. As it can be seen, the patterns of economy and normal mode are rather similar in data center, but show broader range of data scattering at city driving. Contrary, the usual driving modes (economy, normal, dynamic) has less, but statistically still significant impact on advantage of LNG drive.

Looking at the static factors, the highway environment shows the most moderate data distribution, while the rest modules demonstrated wider data scattering.

As an outcome of the data analysis, H1 is accepted, statistically proven relationship was found between the static factors and the LNG consumption advantage. H2 is not confirmed as there was not found a statistically proven

Table 6 Results of the ANOVA analysis

	Sum of Squares	df	Mean Square	F	p
Overall model	2.03e+7	7	2.90e+6	4.94	<0.001
Dynamic factor	5.24e+6	4	1.31e+6	2.23	0.065
Static factor	4.72e+6	2	2.36e+6	4.02	0.018
Dynamic factors × Static factors	1.03e+7	1	1.03e+7	17.59	<0.001
Residuals	3.40e+8	579	587359		

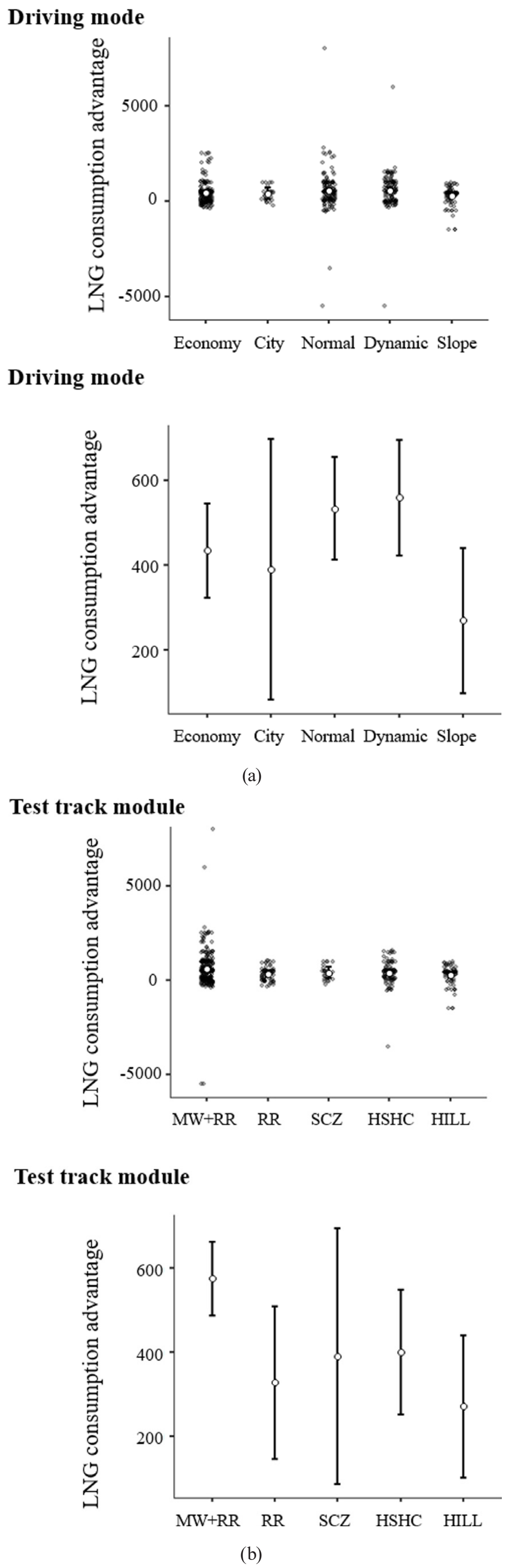

Fig. 5 Scatter charts of the ANOVA analysis results (a) dynamic factor variables; (b) static factor variables

relationship between the dynamic factors and the LNG consumption advantage, but the relationship is still significant, indicating practically relevant consequences.

5 Conclusion

The research compared two heavy-duty vehicle propulsion technologies suitable for long-distance haulage, primarily in terms of differences in fuel consumption, which were tested for static and dynamic influencing factors using ANOVA statistical analysis. The statistic factor variables were the test track environments such as urban area, highway, rural road conditions, slopes and handling track. The dynamic factor variables were the driving modes, such as normal, economy, dynamic, city and slope driving modes.

The model analysis reveals apparent relations between the influencing factors and the LNG consumption advantage values.

The static driving environment has a greater impact on consumption advantages of the LNG vehicles.

Driving mode has lower but still firm effect on the consumption difference between LNG and diesel trucks.

The advantage of the LNG powered truck is more characteristic in highway mode, which is the mostly relevant environment for long-distance freight logistics.

As a summary, the research and the data analysis proved the advantage of LNG trucks in certain traffic circumstances.

The research was limited to and the findings are based on the tests explained above, and as such, having certain limitations due to scope and length of the tests performed. Based on the conclusions, further extended tests can be prepared to identify additional observations on consumption features of LNG versus diesel trucks.

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References

Anderhofstadt, B., Spinler, S. (2020) "Preferences for autonomous and alternative fuel-powered heavy-duty trucks in Germany", Transportation Research Part D: Transport and Environment, 79, 102232. https://doi.org/10.1016/j.trd.2020.102232

ACEA (2021) "Fleet Management System (FMS) Standard (Version 04), 17/09/2021", [pdf] HDEI. Available at: https://www.fms-standard.com/Bus/down_load/fms%20document_v_04_vers.17.09.2021.pdf [Accessed: 23 Sept 2024]

Arteconi, A., Brandoni, C., Evangellista, D., Polonara, F. (2010) "Life-cycle greenhouse gas analysis of LNG as a heavy vehicle fuel in Europe", Applied Energy, 87(6), pp. 2005–2013. https://doi.org/10.1016/j.apenergy.2009.11.012

Aryanpur, V., Rogan, F. (2024) "Decarbonising road freight transport: The role of zero-emission trucks and intangible costs", Scientific Reports, 14, 2113. https://doi.org/10.1038/s41598-024-52682-4

Askin, A. C., Barter, G. E., West, T. H., Manley, D. K. (2015) "The heavy-duty vehicle future in the United States: A parametric analysis of technology and policy tradeoffs", Energy Policy, 81, pp. 1–13. https://doi.org/10.1016/j.enpol.2015.02.005

Cunanan, C., Tran, M. K., Lee, Y., Kwok, S., Leung, V., Fowler, M. (2021) "A Review of Heavy-Duty Vehicle Powertrain Technologies: Diesel Engine Vehicles, Battery Electric Vehicles, and Hydrogen Fuel Cell Electric Vehicles", Clean Technologies, 3(2), pp. 474–489. https://doi.org/10.3390/cleantechnol3020028

Di Maio, D., Beatrice, C., Fraioli, V., Napolitano, P., Golini, S., Rutigliano, F. G. (2019) "Modeling of Three-Way Catalyst Dynamics for a Compressed Natural Gas Engine during Lean-Rich Transitions", Applied Sciences, 9(21), 4610. https://doi.org/10.3390/app9214610

European Commission (2023) "European Green Deal: Commission proposes 2030 zero-emissions target for new city buses and 90% emissions reductions for new trucks by 2040". [online] Available at: https://ec.europa.eu/commission/presscorner/detail/en/ip_23_762 (Accessed: 26 March 2024)

European Parliament, Council of the European Union (2019) "Regulation (EU) 2019/1242 of the European Parliament and of the Council of 20 June 2019 setting CO_2 emission performance standards for new heavy-duty vehicles and amending Regulations", Brussels, Belgium. [online] Available at: https://eur-lex.europa.eu/eli/reg/2019/1242/oj (Accessed: 26 March 2024)

Giuliano, G., Dessouky, M., Dexter, S., Fang, J., Hu, S., Miller, M.(2021) "Heavy-duty trucks: The challenge of getting to zero", Transportation Research Part D: Transport and Environment, 93, 102742. https://doi.org/10.1016/j.trd.2021.102742

Gnap, J. Dočkalik, M. (2021) "Impact of the operation of LNG trucks on the environment", Open Engineering, 11(1), pp. 937–947. https://doi.org/10.1515/eng-2021-0096

Gunawan, T. A. Monaghan, R. F. D. (2022) "Techno-econo-environmental comparisons of zero- and low-emission heavy-duty trucks", Applied Energy, 308, 118327. https://doi.org/10.1016/j.apenergy.2021.118327

International Energy Agency (IEA) (2023) "Global CO_2 emissions from trucks and buses in the Net Zero Scenario, 2000-2030". [online] Available at: https://www.iea.org/data-and-statistics/charts/global-co2-emissions-from-trucks-and-buses-in-the-net-zero-scenario-2000-2030 (Accessed: 26 March 2024)

Jahaniaghdam, T., Mamdoohi, A. R., Kheyrabadi, S. A., Mehryar, M., Ciari, F.(2023) "Preferences for Alternative Fuel Trucks among International Transport Companies", World, 4(4), pp. 795–815. https://doi.org/10.3390/world4040050

The jamovi project (2023) "jamovi, (Version 2.4)", [Computer software]. Available at: https://www.jamovi.org [Accessed: 14 Aug 2024]

van Kranenburg, K., van Delft, Y., Gavrilova, A., de Kler, R., Schipper, C., Smoker, R., Verbeek, M., Verbeek, R. (2020) "E-FUELS: Towards a more sustainable future for truck transport, shipping and aviation", [pdf] TNO. Available at: https://www.tno.nl/publish/pages/3735/vankranenburg-2020-efuels.pdf (Accessed: 5 June 2024)

Krause, J., Arcidiacono, V., Maineri, L., Broekaert, S., Fontaras, G. (2023) "Calculating heavy-duty vehicle CO_2 emission reduction costs for Green Deal scenarios: Extension of the DIONE model", Transportation Research Procedia, 72, pp. 2597–2603. https://doi.org/10.1016/j.trpro.2023.11.788

Kvaser (2023) "CanKing, (version 6.24.510)", [Computer software]. Available at: https://kvaser.com/ [Accessed: 5 Aug 2024]

Nunes, L. J. R. (2023) "The Rising Threat of Atmospheric CO_2: A Review on the Causes, Impacts, and Mitigation Strategies", Environments, 10(4), 66. https://doi.org/10.3390/environments10040066

Osorio-Tejada, J. L., Llera-Sastresa, E. Scarpellini, S. (2017) "Liquefied natural gas: Could it be a reliable option for road freight transport in the EU?", Renewable and Sustainable Energy Reviews, 71, pp. 785–795. https://doi.org/10.1016/j.rser.2016.12.104

Ou, X. Zhang, X. (2013) "Life-Cycle Analyses of Energy Consumption and GHG Emissions of Natural Gas-Based Alternative Vehicle Fuels in China", Journal of Energy, 2013(1), 268263. https://doi.org/10.1155/2013/268263

Pfoser, S., Schauer, O. Costa, Y. (2018) "Acceptance of LNG as an alternative fuel: Determinants and policy implications", Energy Policy, 120, pp. 259–267. https://doi.org/10.1016/j.enpol.2018.05.046

Quiros, D. C., Smith, J., Thiruvengadam, A., Huai, T., Hu, S. (2017) "Greenhouse gas emissions from heavy-duty natural gas, hybrid, and conventional diesel on-road trucks during freight transport", Atmospheric Environment, 168, pp. 36–45. https://doi.org/10.1016/j.atmosenv.2017.08.066

Ribberink, H., Wu, Y., Lombardi, K., Yang, L. (2021) "Electrification Opportunities in the Medium- and Heavy-Duty Vehicle Segment in Canada", World Electric Vehicle Journal, 12(2), 86. https://doi.org/10.3390/wevj12020086

Teixeira, A. C. R., Borges, R. R., Machado, P. G., Mouette, D., Ribeiro, F. N. D. (2020) "PM emissions from heavy-duty trucks and their impacts on human health", Atmospheric Environment, 241, 117814. https://doi.org/10.1016/j.atmosenv.2020.117814

Smajla, I., Sedlar, D. K., Drljača, B., Jukić, L. (2019) "Fuel Switch to LNG in Heavy Truck Traffic", Energies, 12(3), 515. https://doi.org/10.3390/en12030515

Speight, J. G. (2011) "2 - Production, properties and environmental impact of hydrocarbon fuel conversion", In: Advances in Clean Hydrocarbon Fuel Processing, Woodhead Publishing, pp. 54–82. ISBN 9781845697273 https://doi.org/10.1533/9780857093783.1.54

Sugihara, C., Hardman, S., Kurani, K. (2023) "Social, technological, and economic barriers to heavy-duty truck electrification", Research in Transportation Business & Management, 51, 101064. https://doi.org/10.1016/j.rtbm.2023.101064

Sütheö, G., Háry, A. (2024) "Comparison of Carbon-Dioxide Emissions of Diesel and LNG Heavy-Duty Trucks in Test Track Environment", Clean Technologies, 6(4), pp. 1465–1479. https://doi.org/10.3390/cleantechnol6040070

Thiruvengadam, A., Besch, M., Padmanaban, V., Pradhan, S., Demirgok, B. (2018) "Natural gas vehicles in heavy-duty transportation - A review", Energy Policy, 122, pp. 253–259. https://doi.org/10.1016/j.enpol.2018.07.052

Toumasatos, Z., Zhu, H., Durbin, T. D., Johnson, K. C., Cao, S., Karavalakis, G. (2024) "Real-world particulate, GHG, and gaseous toxic emissions from heavy-duty diesel and natural gas vehicles", Atmospheric Environment, 327, 120512. https://doi.org/10.1016/j.atmosenv.2024.120512

Vector (2022) "Candb++, (version 3.1)", [Computer software]. Available at: https://www.vector.com/int/en/ [Accessed: 16 Aug 2024]

Wang, X., Song, G., Zhai, Z., Wu, Y., Yin, H., Yu, L. (2021) "Effects of Vehicle Load on Emissions of Heavy-Duty Diesel Trucks: A Study Based on Real-World Data", International Journal of Environmental Research and Public Health, 18(8), 3877. https://doi.org/10.3390/ijerph18083877