Regular Article

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Impact of the operation of LNG trucks on the environment

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Abstract: The significance and importance of road freight transport in society are certainly unquestionable. As in most sectors of the economy, road freight transport has an impact on the environment. The EU seeks to eliminate, as far as possible, the negative environmental impacts of various sectors. For these reasons, several EU commitments have been made in the future to reduce emissions so that road haulage vehicles are also more environmentally friendly. Trucks that use alternative fuels, such as natural gas, are already in use today. The EU attaches importance to reducing CO₂ production, and this contribution also pays particular attention to the production of CO₂ vehicles using liquefied natural gas (LNG) fuel compared to vehicles using standard diesel. The results show that when operating vehicles using LNG, it is possible to achieve lower CO₂ production and at the same time lower vehicle noise, which is an advantage when operating vehicles in cities.

Keywords: road transport, CO₂, LNG, environment, trucks

1 Introduction

Road transport by its activity also contributes to the production of greenhouse gases. The EU seeks to reduce the production of greenhouse gas emissions, especially CO₂, in all areas of the economy. Protecting human health and the environment as a whole should be an extremely important goal. It is important to reduce pollutant emissions, to adopt and implement effective measures to reduce emissions at the local, national as well as EU level

on the basis of more accurate data verified on the basis of the same measurement methodology and in real practice, e.g., on the same transport routes with the same load. It will definitely not be easy to achieve the EU objectives for reducing the production of emissions and it will certainly require innovative and environmentally friendly technologies. At present, the construction of a vehicle is of great importance, especially for its ecological operation, or rather the reduction of the ecological burden on the environment. The production of emissions in the exhaust gases is checked before it is put into service and during the operation of the vehicle. One of the possibilities may be the use of alternative fuels instead of standard ones, which are currently commonly used in practice. Alternative fuels, such as compressed natural gas CNG or liquefied natural gas (LNG), are also gradually being used in road freight transport in the EU. Like any technology, the use of these fuels has its environmental and economic consequences, which need to be compared to some extent with standard fuels. The use of natural gas in road freight transport has the potential to reduce CO₂ production. For this reason, in some EU countries, these vehicles are supported through various benefits in the form of subsidies or taxes and fees. At present, there are also requirements from some customers for carriers to use these vehicles. From an ecological point of view, as well as from a commercial and marketing point of view, these vehicles can have the potential to gain a foothold in the market now and in the future. Some EU countries that have different incentive schemes to encourage the purchase of LNG vehicles have also decided to help increase the use of LNG vehicles.

This article examines the benefits of using LNG vehicles on the basis of data obtained from the selected transport company and real practice and experience with the use of LNG vehicles. Based on these data, the article expresses the impact of LNG vehicles on the environment compared to diesel vehicles in terms of CO₂ production. The main research question is to find out the differences in the impact of the real operation of semi-trailers with tractors powered by LNG fuel and diesel fuel on specific routes of international road freight transport on CO₂ emissions.

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The results of the research fit into the issue of the targets of sustainable development [1,2].

2 Literature review

At present, the combustion engine is an almost exclusive source of propulsion for road transport vehicles. Deterioration of the environment causes that the requirements for improving the operation of motor vehicles equipped with a combustion engine are associated with increasingly stringent emission limits [3]. One-third of all final energy in the EU is consumed for transport. Most of this energy comes from oil. This means that transport is responsible for a large share of the EU's greenhouse gas emissions and significantly contributes to climate change [4]. Transport produces almost 30% of all EU carbon dioxide emissions whereby road transport accounts for 72% [5].

Road freight transport is a very important part of the trade in the European continent. According to the ACEA (European Automobile Manufacturers Association), trucks transport 76.7% of all cargo transported by land [6]. Exhaust gases of motor vehicles contain chemicals in different concentrations, with different effects on human health and the environment [7]. Although carbon dioxide is a nontoxic product of combustion, the increase in carbon dioxide content in the atmosphere is one of the major causes of the greenhouse effect [8]. According to the European Environment Agency, heavy-duty vehicle emissions have increased by 25% since 1990, mainly due to an increase in the volume of transportations of road freight transport [9].

Air pollution damages human health and the environment. In some places, there are problems with air quality. A certain part of Europe's population lives in areas, especially in cities, where air quality standards are exceeded. The EU's long-term objective is to achieve such levels of air quality that do not lead to unacceptable effects on human health and the environment and do not endanger them. In order to reduce exposure to air pollution, the EU is taking action at many levels. This is not only through legislation but also through cooperation with the sectors responsible for air pollution [10].

The EU has therefore set itself the objective of reducing CO₂ emissions from transport by at least 40% by 2030 and by 60% by 2050 compared to the level of emissions in 1990. Emission limits should fall by 37.5% by 2030 for new passenger cars and by 31% for vans. Members of the European Parliament also approved a proposal to reduce CO₂ emissions from new trucks. These should fall by 30% by 2030 compared to 2019 [5].

Regulation (EU) 2019/1242 of the European Parliament and of the Council, which sets CO₂ emission standards for new heavy-duty vehicles, is also in force in order to limit growing emissions from road transport. CO₂ emissions from heavy-duty vehicles such as tractors trucks are required to be reduced by 30% by 2030, with the aim of a medium reduction by 15% by 2025. By 2025, manufacturers will be required to ensure that at least 2% share of the market from sales of new vehicles will consist of zero and low emission vehicles in order to counteract the steady increase in road transport emissions, of which about one-quarter is emitted by heavy-duty vehicles. In 2022, the European Commission will also have to propose new targets after 2030 in line with the Paris agreement [9].

The authors of the article [11] focused on the EU's goal of reducing global greenhouse gas emissions in the transport sector by 20% by 2020 compared to 1990 levels, and subsequently identify the costs needed to achieve the 2020 emission reduction targets in a selected area.

The purpose of the study in ref. [12] is to present the current situation of road freight transport in the European Union and the directions for change in this area. The statistics presented in the paper demonstrate the changes that are taking place in road freight transport. The European Union's transport policy is also described in the article. The authors paid special attention to the presentation of European Union projects that make it possible to reduce the negative impact of freight transport on the urban environment.

ACEA takes note of the legislation that sets standards for CO₂ emissions from heavy-duty vehicles. In practice, this will mean that already in 2030, almost one-third of all trucks and buses in the market should have alternative propulsion - with electric motors, compressed or LNG or biogas engines. It also implies the need to build the infrastructure in the EU Member States needed to recharge and refuel vehicles with alternative propulsion. In order to meet the set reduction in CO₂ emissions, trucks and buses with alternative propulsion will have to be sold in large quantities [13].

According to expectations and past development of growth of a gross domestic product that generates demand for freight transport, without the measures taken, the share of CO₂ emissions from heavy-duty vehicles would increase by around 9% between the years 2010 and 2030 [14].

In recent years, there has been an increased awareness of the negative externalities of freight transport. Operational research, especially in recent years, has continued to contribute to mitigating negative impacts through the use of various optimization models and solutions. The basic principles and an overview of a set of models and

solutions for the greening of freight transport are presented in ref. [15].

LNG is becoming progressively attractive as a sustainable alternative fuel for heavy-duty vehicles and its share is expected to grow in the near future. In ref. [16], the authors present their patented innovative system aimed at recovering the cryogenic energy from the LNG vaporization upstream of the engine injection. The calculations showed the very interesting potential of engine power boost in the range of 10–15%. Also, a modest reduction in specific energy consumption of the engine was calculated.

Studies [17–19] deal in detail with the issue of transport and distribution of CNG or LNG that can be used in transport. A similar issue of methane emissions from LNG was addressed by the authors in a study that investigated six methods used to offload LNG from a tanker truck to an LNG refuelling station and their contribution to methane emissions [20].

A simulation of the composition of the vehicle fleet by vehicles with an alternative type of propulsion taking into account operational and economic factors was addressed in the study [21], with the expression of 25% lower CO₂ production.

The issue of greenhouse gas emissions produced by the road haulage sector is addressed in ref. [22]. These emissions affect the structure of the ozone layer and contribute to the greenhouse effect, which causes global warming problems that are closely linked to changing weather conditions and extreme weather events. According to the authors, it is necessary to pay attention to the discrepancies related to biofuels, specifically the fact that even though their use generates almost zero greenhouse gas emissions, their production requires a high level of energy consumption. The paper deals with the theoretical basis of the negative impacts of transport on the environment and the subsequent measurement of the extent of harmful emissions produced by the road freight transport sector. Calculation procedures and declared energy consumption and greenhouse gas emissions generated by transport services analysed according to EN 16258, are also provided. The article also focuses on the application of the methodology to specific transport on a designated transport route, where the total energy consumption and the production of greenhouse gas emissions are determined. These calculations are based on comprehensive studies performed for a specific transport company, which assigned the authors the task of determining the extent to which the declared energy consumption and greenhouse gas emissions change when the type of fuel used changes.

The incorporation of clean-fuel technologies has become essential for the sustainability of the transportation sector. Natural gas technology, especially the use of LNG, has become a possible alternative to diesel oil in freight transport because of its acceptable autonomy and low fuel prices. The study [23] introduces a multicriteria-based methodology that integrates the key factors involved in the transport system: vehicles, infrastructure and fuels, and consideration of the three pillars of sustainability, as well as the reliability of technology, legislation and market issues. The results indicate that LNG trucks would be an attractive option compared to diesel oil and HVO, provided that decision-makers give significant weight to social and environmental criteria and that the government guarantees legislative security to maintain the low taxes on natural gas [23].

The next article conducts a life-cycle analysis on LNG and compressed natural gas in heavy-duty trucks and takes the methane leakage of natural gas supply chains into account. The results indicate that natural gas production and transportation dominate as the major contributor to the total methane emissions of the natural gas supply chains, accounting for approximately 68.7–86.7% of the total methane emissions estimated. Life-cycle analysis on LNG, CNG and diesel heavy-duty trucks shows that LNG and CNG heavy-duty trucks will reduce the life-cycle greenhouse gas emissions by 11.17 and 5.18%, respectively, compared to that of diesel [24]. A similar issue is addressed in the article that was solved in China [25].

The environmental and economic impacts of the use of LNG and bio-LNG have been addressed by the authors in ref. [26], which points to the environmental benefits of using natural gas in transport.

What factors affect the purchasing decision and operation of low-emission heavy-duty trucks and which ones are the most relevant are solved in ref. [27]. According to the experts, a truck's reliability, and available fuelling/charging infrastructure, the possibility to enter low-emission zones as well as current and future fuel costs are key factors when purchasing and operating alternative fuel-powered heavy-duty trucks [27].

The next article reviews the key environmental, technical and socio-economic aspects of LNG deployment as an alternative fuel for road freight transport, and some projections for the LNG implementation in the Spanish road freight transport that are introduced, concluding that the fuel switch in long-haul trucks could reduce GHG emissions by 12% and diesel fuel consumption by 42% in the long term [28].

The comparison of LNG, CNG and diesel fuels was also conducted in refs [29,30] where the exhaust emissions of urban public transport buses were compared.

The issue of filling stations and the optimization of the European network of filling stations for trucks running on natural gas are dealt in ref. [31].

In order to promote the development of LNG trucks in the Shenzhen road freight industry, the article aimed at forecasting the LNG filling demand and planning the construction of stations. As a result, the required number of LNG filling stations can be calculated [32].

The use of other alternative fuels in combination with conventional fuels is also dealt in ref. [33]. The use of alternative fuels in transport can also influence the decision-making when choosing the mode of transport from the point of view of enterprise logistics [34,35].

Transport operations are one of the sources of the current pollution problems in urban areas. One of the many reasons for such a situation is the growing need for freight transport using different modes of transport, especially road transport. The impact on the environment should be one of the most important criteria to be taken into account when choosing a mode of transport. The aim of the study in ref. [36] was to assess the level of pollution generated from gaseous emissions depending on the vehicle type, category and size of the load. Urban areas were also taken into account. Based on the obtained results, the potential of the level of pollution in cities was determined and it was found out which mode of transport contributes the most to air pollution. The main target of the next study was to analyse the use of LNG as a fuel for heavy trucks. Different aspects of the LNG chain were analysed along with the economic and ecological benefits of LNG application. Filling stations network for LNG were described for the purpose of comparative analysis of diesel and LNG heavy trucks. Results have shown that using LNG as propellant fuel has numerous advantages over the use of conventional fuels. In addition to cost-effectiveness, LNG road vehicles reduce CO₂ emissions. Therefore, the environmental targets in transport, not only of the member states but worldwide, could not be met without LNG in heavy truck traffic [37].

The authors in ref. [38] dealt with the implementation of new EU regulations to reduce CO₂ emissions where the energy and economic framework of legislative measures was simulated. The analysis reveals a reduction in road transport CO₂ emissions and diesel consumption as a result of the uptake of more efficient truck technologies. In particular, LNG trucks are favoured because of the lower emission factor of natural gas relative to that of diesel [38].

The need to pay attention to green solutions in road freight transport through different policy measures and their impacts on transport and the environment, as a shift

of freight transport from road to other modes of transport may not mean a better environmental impact on the environment are dealt in ref. [39].

The issue of the application of alternative fuels into the real operation of road freight transport is therefore very current and the research outputs mentioned in this article follow some published results.

3 Emissions of LNG-powered trucks

According to the Regulation (EU) 2019/1242 of the European Parliament and of the Council, LNG is an available fuel alternative to diesel for heavy-duty vehicles. The introduction of existing and new innovative LNG technologies will contribute to meeting the objectives for the reduction of CO₂ emissions in the short and medium-term, as the use of LNG technologies reduces CO₂ emissions compared to diesel vehicles [14].

LNG is a natural gas cooled to a temperature of −162°C when it turns into a liquid without colour and odour. In this state, it has a volume 600 times smaller than natural gas in the gaseous state. LNG is stored in well-insulated tanks (cryogenic tanks). For comparison, CNG (compressed natural gas) is compressed natural gas and it has a volume approximately 200 times smaller than natural gas. Liquefaction reduces the volume of natural gas three times more than when compressed, and the LNG vehicle thus has a range of approximately three times more than a CNG vehicle with a CNG tank of the same size [40].

Manufacturers of LNG-powered trucks, namely Scania, Volvo and Iveco, state that operating LNG trucks can reduce CO₂ emissions by 15–20% compared to Euro VI, and up to 95% when using biogas; 95% less solid particles, 25–70% less nitrous oxide and, of course, a significant reduction in noise pollution. The percentage reduction in emissions is declared by the manufacturers for in-service emissions from cars, known as “tank-to-wheel” [41–43].

According to Danish transport research, in which the authors looked at the perspectives for gas in transport in Denmark, it is possible to reduce greenhouse gas emissions by at least 15% per km with the use of LNG if it is a well-to-wheel expression, so a comprehensive expression taking into account the production of greenhouse gases from the extraction of the raw material to its final consumption. This effect can be several times higher with the use of renewable components [44].

A study by the Oxford Institute for Energy Studies from 2014 sees the greatest potential for natural gas in

transport in heavy freight transport. It notes that in comparison with heavy-duty vehicles and buses powered by diesel, emissions taking into account also other greenhouse gases expressed in the form of CO_{2e} (carbon dioxide equivalent) per km maybe 15% lower in a well-to-wheel mode by 2030. This is confirmed by a recent study by the Oxford Institute for Energy Studies from 2019. CO_{2e} emissions can be even lower when using bio-LNG. Values are given in g CO_{2e}/km [45] (Table 1).

According to the research published in ref. [27], truck reliability, availability of refuelling, access to city centres and fuel costs are key factors for the purchase and operation of alternative fuel trucks.

4 Impact of LNG and diesel trucks of the selected carrier on the environment

In the case of vehicles with alternative propulsion, in solved issues dealing with vehicles with LNG propulsion, an assessment of the impact of their operating activities on the environment is given. Manufacturers of LNG-powered trucks, as already mentioned, state that the operation of LNG trucks can reduce CO₂ emissions by 15–20% compared to diesel vehicles of emission class Euro VI, and up to 95% when using biogas. Some customers of transport and logistics companies require an accurate calculation of CO₂ production for specific transport routes related to the transport of goods, components for assembly, which are included in their calculations of CO₂ production in the production of their products.

The proposed methodology, which was used in the research, uses data on the production of CO₂ are obtained from the vehicle manufacturer's software that offers the carrier an overview of CO₂ production based on the amount of fuel consumed. The software acquires and stores data on the real fuel consumption of the vehicle. Subsequently, based on the standard STN EN 16258 Methodology for cal-

culation and declaration of energy consumption and GHG emissions of transport services (freight and passengers), the software considers a constant value of CO₂ produced when consuming 1 l of fuel. Knowing the amount of fuel consumed, the software provides information on the amount of CO₂ produced at weekly intervals. This value of CO₂ produced is then analysed and compared between vehicles that use diesel or LNG as fuel.

The data in this article are expressed for tractors that are part of semi-trailers and trucks (T) that are part of trailers. For this reason, the data are also divided according to this terminology for tractors and trucks. The proposed methodology is sufficient for its calculation of CO₂ production for customers of transport and logistics companies and is supplemented by a comparison of production arising from the use of LNG fuel and diesel fuel on the same transport routes with the same cost.

4.1 Comparison of CO₂ emissions

The software provided to the carrier states in its outputs, the so-called monitoring reports, in the weekly interval, in addition to the distance travelled, the specific fuel consumption and other data; also the data on the amount of carbon dioxide CO₂ produced for each vehicle. In order to be able to relativize the data, it is appropriate to express the absolute values of CO₂ production also in the form of CO₂ produced per km or tkm (tonne-kilometre). The data of LNG tractors and LNG trucks are compared with diesel vehicles that were used on the same regular lines in the past and how LNG vehicles are used currently. In Table 2, data exist on tractors from the regular freight line where the goods with an average weight of 11.88 t for both directions of transport are transported.

The vehicles carry out transport on the route Ivanka pri Dunaji (SK) – Schwarzenbruck (DE). In both directions, the vehicle is loaded with goods. From the altitude profile of the route, data on the lowest, highest altitude, subsequent elevation and the nature of the transport route are available, which can also have an impact on fuel consumption and the amount of CO₂ greenhouse gases produced. On the given route, the total ascent is 2,939 m and the total descent is 2,698 m, which represents 0.50% of the total transport route and a 0.46% decrease. The rest of the transport route has a flat character (Figure 1).

These vehicles also carry services on the route Ivanka pri Dunaji (SK) – Budapest (HU). In both directions, the vehicle is loaded with goods. On the given route, the total

Table 1: Well-to-wheel CO_{2e} (g/km) [authors based on ref. [45]]

HDV	Diesel	CNG	LNG	80% CNG + 20% biocomponent	80% LNG + 20% biocomponent
CO _{2e} (g/km)	1,074	908	912	738	749

HDV: heavy-duty vehicles.

Table 2: CO₂ production from tractors with a semi-trailer on regular freight lines

	Transport distance (km)	Fuel consumption (l/100 km); (kg/100 km)	CO ₂ production (t)	CO ₂ production (kg/l); (kg/kg)	CO ₂ production (kg/km)	CO ₂ production (kg/tkm)
Tractor 1	2,977	22.5	1.8	2.69	0.605	0.051
diesel	2,973	22.5	1.8	2.69	0.605	0.051
Tractor 2	1,755	23.4	1.1	2.67	0.627	0.053
diesel	1,395	22.7	0.9	2.84	0.645	0.054
Tractor	3,922	21.2	2.3	2.77	0.586	0.049
3 LNG	3,879	20.4	2.2	2.78	0.567	0.047
Tractor	2,769	21.4	1.6	2.70	0.577	0.049
4 LNG	3,882	21.0	2.2	2.70	0.566	0.048

ascent is 730 m and the total descent is 752 m, which represents 0.34% of the ascent and 0.35% of the descent from the total transport route. The rest of the transport route is flat. From these data, it is possible to conclude that it is a relatively flat surface without significant elevations (Figure 2).

Data on the production of CO₂ from tractor units, which are operated on the described routes, are given in detail in Table 2.

From the data on the production of CO₂ emissions per km, it can be seen that the values are higher for diesel tractors compared to LNG tractors. This difference

Figure 1: Transport route and route altitude profile Ivanka pri Dunaji – Schwarzenbruck [46]. **Figure 2:** Transport route and route altitude profile Ivanka pri Dunaji – Budapest [46].

Figure 3: CO₂ production per 1 km for tractors with semi-trailers.

represents 8% lower CO₂ production for LNG tractors. It is clear that CO₂ production is to some extent dependent on specific fuel consumption that can be influenced by several factors and to a large extent one of the factors is also the driver and driving style of the driver. These are the results of research that really show how much it is possible to reduce CO₂ production on specific transport routes.

The average values of the amount of CO₂ produced from one tractor per km can be seen in Figure 3. Individual values are slightly different when compared, so it is appropriate to calculate the arithmetic mean for diesel tractors and LNG tractors. The diesel tractors that performed the transports produced carbon dioxide on average 0.621 kg/km of the route realized by one tractor and in terms of the unit of transport performance the CO₂ production is on average at a level of 0.052 kg/tkm. At present, LNG tractors produce an average of 0.574 kg of CO₂ per km realized by one tractor, and in terms of the unit of transport performance, the production of CO₂ is on average at the level of 0.048 kg/tkm.

Knowing the value by which LNG tractors produce less CO₂ per kilometre than diesel-powered tractors during the operation of a regular line, it is appropriate to express how much lower the production of this greenhouse gas would be at different standard annual driving performances of tractors (Figure 4).

There are also data on the CO₂ production of diesel trucks with a trailer that performed transport on another regular line in the past, as well as data on LNG trucks that

perform transport on the same line in the current period where the goods with an average weight of 14.85 t for both directions of transport are transported.

Vehicles perform regular transports on the route Dolný Hričov (SK) - Eindhoven (NL). On the given route, the total ascent is 3,520 m and the total descent is 3,824 m, which represents 0.28% of the ascent and 0.30% of the descent from the total transport route (Figure 5).

The sequence of calculation of CO₂ production expressed per unit of fuel consumption in kg or l and calculation of CO₂ production per km, or tkm on the basis of available data is maintained as in the previous case (Table 3).

Data on the production of CO₂ emissions per km show that the values are higher for diesel trucks compared to LNG trucks. This difference represents a 10% lower CO₂ production for LNG trucks. Even in this case, it is clear that CO₂ production is to some extent dependent on the specific fuel consumption for a given vehicle, which can be affected by several factors and to a large extent one of the factors is also the driver and driving style of the driver, the weight of the freight transported (here it was higher compared to semi-trailers sets), or the nature and profile of the transport route (Figure 6).

Diesel trucks produced CO₂ on average 0.721 kg/km of the route realized by one truck, and in terms of the unit of transport performance, the CO₂ production is on average at the level of 0.048 kg/tkm. At present, LNG trucks produce an average of 0.649 kg of CO₂ per km realized by one truck, and in terms of a unit of transport

Figure 4: Difference in CO₂ production between the compared tractors with semi-trailers depending on the annual driving performance in km.

ascent and 0.30% of the descent from the total transport route.

Figure 5: Transport route and route altitude profile Dolný Hričov (SK) – Eindhoven (NL) [44].

performance, CO₂ production is on average at the level of 0.044 kg/tkm. The difference between diesel and LNG trucks is on average 0.072 kg/km of CO₂ produced.

The value by which LNG trucks produce less CO₂ per kilometre than diesel trucks is calculated in the same way as for tractors. It is therefore appropriate to express how much lower the production of this greenhouse gas would be at the different standard annual driving performances of trucks.

In Figure 7, it can be seen that with increasing driving performance much lower amounts of the greenhouse gas CO₂ produced can be achieved when operating an LNG truck.

Data on CO₂ production are expressed for individual vehicles in kg/km. It is clear and understandable that CO₂ production is linked to fuel consumption and with higher specific fuel consumption there is also higher CO₂ production. Both diesel and LNG trucks have a higher specific consumption compared to tractors but the goods transported on the line have also a higher average weight than the goods transported on the lines with tractors. For this reason, it was appropriate to express CO₂ production in addition to kg/km also per unit of transport performance, i.e. in kg/tkm. A summary evaluation of the average CO₂ production for vehicles by type of fuel used is given in Table 4.

Table 3: CO₂ production from trucks with trailers on regular freight lines

	Distance (km)	Fuel consumption (l/100 km); (kg/100 km)	CO ₂ production (t)	CO ₂ production (kg/l); (kg/kg)	CO ₂ production (kg/km)	CO ₂ production (kg/tkm)
Truck 1	5,185	26.5	3.7	2.69	0.714	0.048
diesel	7,665	27.2	5.6	2.69	0.731	0.049
Truck 2	7,571	25.2	5.1	2.67	0.674	0.045
diesel	5,244	28.4	4.0	2.69	0.763	0.051
Truck	7,727	24.0	5.1	2.75	0.660	0.044
3 LNG						
Truck	5,331	23.4	3.4	2.73	0.638	0.043
4 LNG

Figure 6: CO₂ production per 1 km for trucks with trailers.

Figure 7: Difference in CO₂ production between the compared trucks with trailers depending on the annual driving performance in km.

Table 4: Overall evaluation of calculations of average CO₂ production

		Consumption (l/100 km); (kg/100 km)	CO ₂ production (kg/km)	Difference (%)	CO ₂ production (kg/tkm)	Difference (%)
Tractor	Diesel	22.8	0.621	7.56	0.052	7.69
	LNG	21.0	0.574		0.048	
Truck (T)	Diesel	26.8	0.721	9.98	0.048	8.33
	LNG	23.7	0.649		0.044	

According to the calculated data, the CO₂ production is lower for LNG-powered vehicles in case of expression per 1 km, but also in the expression on the unit of transport performance tkm. The difference in CO₂ production for specific operating conditions between diesel and LNG vehicles of the same emission class does not reach the percentage level specified by vehicle manufacturers. But also based on the results already mentioned, the deployment of LNG tractors with semi-trailers has reduced CO₂ production by 7.69% and LNG trucks with trailers by up to 8.33% in real operation on regular freight lines compared to the use of diesel trucks.

5 Discussion and conclusion

In order to achieve the EU's ambitious objectives in the field of CO₂ reduction, it is important to pay close attention to the tools, thanks to which it would be possible to finally meet them. One option is also the use of alternative fuels that can generally be considered greener and more environmentally friendly. Gradually, vehicles with alternative propulsion are also being used in road freight transport, e.g., powered by LNG or CNG.

Based on the data obtained, the article shows how these vehicles affect the environment through their operating activities, especially compared to standard diesel vehicles. The main focus was on CO₂ production because the EU pays close attention to this area. Of course, from

the point of view of the development of LNG vehicles in road freight transport, the economic aspect is also important, as the costs associated with procuring LNG vehicles are higher compared to standard vehicles using conventional propulsion and this affects the transport company's costs.

The environmental impact of LNG vehicles was compared with diesel vehicles that performed the same transports on the same transport routes. The data obtained and calculated show that LNG vehicles produce, on average, a lower amount of greenhouse gas CO₂ than diesel vehicles. Their operating activity can be considered from the point of view of CO₂ production as more environmentally friendly.

As mentioned, the aim of this research was to find out, in particular, the production of CO₂ from operating activities, so that this expression could be considered in a tank-to-wheel mode. The subject of further research could be the identification of a complex environmental impact, which takes into account the production of all greenhouse gases or pollutants and throughout the process from raw material sourcing through distribution to consumption and taking into account all factors affecting the environment throughout this process, which is called a well-to-wheel. In order to achieve the EU's overall emission reduction objectives in road freight transport, the greatest annual savings in CO₂ production in the deployment of LNG trucks will be achieved if they are operated on long-distance lines in international transport with the two-member crew so that the annual driving performance

in km is as high as possible. Also on the basis of the achieved and above-mentioned research results, it can be stated that the higher the annual driving performance with LNG vehicles, the higher the CO₂ savings. Research results may be limited to selected transport routes and possible deviation of measurements and calculations. This could be eliminated if the sample examined contained a larger number of shipments over a longer period, taking into account winter and summer operations, etc.

Research in this area could be supplemented in the future by the question of whether electric trucks are suitable for the transport of goods over long distances and what influences their greater use in real operation on the investigated routes. Here, it is possible to build in part on the results of research on electric light commercial vehicles [47] and on research into the factors influencing the expansion of electric vans and trucks in the EU Member States [48].

For these reasons, some Member States provide schemes and incentives to encourage the purchase of LNG-powered N3 trucks, e.g. Slovakia – 50% motor vehicle tax, Germany – aid € 12,000 and zero toll, Spain – aid € 15,000, France – over-depreciation 40%, the Netherlands – over-depreciation 13.5%, Italy – aid € 20,000. Support schemes for the purchase of LNG trucks may vary but will certainly help to increase the market share of these vehicles.

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