JEE Journal of Ecological Engineering

Journal of Ecological Engineering, 2025, 26(9), 229–238
https://doi.org/10.12911/22998993/204172
ISSN 2299–8993, License CC-BY 4.0

Received: 2025.04.10
Accepted: 2025.06.13
Published: 2025.06.23

The method for ecological assessment of a diesel-electric multiple unit

Krystian Woźniak[1,2], Natalia Szymlet[3*], Jakub Sobczak[3], Łukasz Rymaniak[3], Piotr Pielecha[2]

[1] Institute of Technology, Electrotechnical Testing Laboratory, Łukasiewicz Research Network, Poznan, Warszawska 181, PL-61055 Poznan, Poland
[2] Faculty of Civil and Transport Engineering, Doctoral School of Poznan University of Technology, Piotrowo 3, PL-60965 Poznan, Poland
[3] Institute of Powetrains and Aviation, Faculty of Civil Engineering and Transport, Poznan University of Technology, Piotrowo 3, PL-60965, Poland
* Corresponding author's e-mail: natalia.szymlet@put.poznan.pl

ABSTRACT

The article presents a proprietary method for assessing the environmental impact of a hybrid rail vehicle utilizing both electric traction and an internal combustion engine for propulsion. Current efforts aimed at decarbonizing transportation have led to an increase in the production of electric vehicles and the adoption of such powertrains. However, the energy required to power these vehicles still predominantly comes from fossil fuels, which contribute to global emissions of toxic compounds. The lack of regulatory standards for measuring energy consumption hinders an accurate evaluation of the environmental impact of such vehicles. The proposed testing cycle consisted of several repeated runs of the vehicle on a specialized test track. During the actual runs, measurements were taken of the emissions of toxic compounds from the exhaust systems, as well as the vehicle's electrical energy consumption. The real-world energy consumption was then compared to data on emissions of toxic compounds from the largest power plants operating in Poland. The results of the analysis suggest that current internal combustion engines, which comply with the latest emission standards, contribute less to global air pollution than vehicles powered by electricity generated from fossil fuels. There is a need for continued research into the energy consumption of electric vehicles to accurately assess their real environmental impact. Additionally, further research should be conducted on real operating conditions of exhaust emissions.

Keywords: diesel powertrain, electric powertrain, energy consumption, exhaust emission, rail transportation, real operating conditions.

INTRODUCTION

In recent years, rail transport has been playing an increasingly important role in global transportation systems. Railways are characterized by high energy efficiency and the ability to transport larger quantities of goods in unit transport compared to other transport sectors. The development and investment in rail transport align with current European Union trends regarding environmental protection challenges and the decarbonization of the economy. The total length of the European railway network exceeds 220,000 kilometers, with 19,000 kilometers running through Poland. However, this extensive infrastructure does not translate into a significant share of freight and passenger transport compared to other modes of transportation. In 2023, the rail sector accounted for only 6% of passenger transport and 25% of freight transport. The relatively low share compared to competing modes of transport can be attributed to the low electrification rate, which stands at 62.9%, covering over 12,000 kilometers of railway lines [28].

As a result, locomotives or multiple units equipped with diesel engines are still in use. These vehicles, especially on regional routes, emit harmful compounds such as nitrogen oxides (NO_x), carbon oxides (CO_x), and particulate matter (PM) into the atmosphere. However, the harmfulness of these emissions depends on the operational characteristics of the diesel engine. According to the authors of [10], diesel locomotives operate in idle mode for 51.6% of the time, while they use their rated power for only 10% of the time, primarily during acceleration. Additionally, diesel locomotives are characterized by a high quantitative emission of particulate matter (PN) with a diameter of 350 nm, which negatively affects the human respiratory and circulatory systems [4].

In response to growing public environmental awareness and the implementation of increasingly stringent emission standards in rail transport, appropriate measures have been taken to reduce the negative environmental impact of diesel engines. Exhaust gas treatment systems have been progressively improved to become more efficient. The commercial use of biofuels, hybrid drives, and alternative fuel-powered systems has been introduced. Significant investments have been made in the modernization and electrification of railway lines in the area of infrastructure. Furthermore, efforts have been undertaken to optimize dosing, flow, and energy usage in rolling stock equipped with electric engines. The benefits of these developments have been extensively described in publications [1, 3, 7, 15].

Locomotives or multiple units equipped with conventional engines pollute the environment at the location of emission, acting as mobile point sources. On the other hand, rail vehicles equipped with electric motors contribute to emissions indirectly, shifting them to the location of power plants. In Poland, many power plants are still powered by conventional fuels. Therefore, it can be assumed that despite the lack of harmful emissions at the point of operation, electrically powered rail vehicles also contribute to emissions indirectly. These emissions will vary depending on the energy structure in a given region and the efficiency of the transmission network, where losses can reach up to 16% [6, 18].

Therefore, research on various rail propulsion technologies, their optimization, and their environmental impact is crucial for the sustainable development of rail transport. In the case of rail vehicles powered by electricity, studies focus on the total amount of energy consumed and returned to the transmission network, considering various factors such as route length, gradient, curve radius, total stop time, maximum speed on a given section, the voltage characteristics of traction network, and maximum acceleration [20].

Emission standards for all non-road mobile machinery vehicles, including rail vehicles, are expressed as a unit of mass relative to the work performed by the powertrain. As demonstrated in studies [11, 13], during real operating conditions tests, this can lead to underestimation of the obtained indicators due to the inclusion of the engine's internal losses. This means that the calculations account for indicated work rather than effective work. The reason for this is that the torque values are read from the onboard diagnostic system, which calculates them based on fuel injection time and pressure.

Non-road mobile machinery vehicles, due to their diverse purposes, cannot be evaluated environmentally in terms of distance traveled [19, 21, 22]. This conclusion applies to the entire group of these machines in a general sense. However, certain subgroups of these machines, such as passenger rail vehicles, can be expressed in such coefficients. This facilitates comparing the environmental impact of this mode of transport with that of passenger cars, motorcycles, or suburban and intercity buses. For many years, density characteristics of operational time have been used for vehicle powertrains [2, 9]. This mathematical tool provides information on phenomena occurring within specific speed and acceleration ranges, while also considering the variability of these parameters within the indicated range.

The article presents research on a hybrid rail vehicle designed for passenger transport. The applied solutions allow the vehicle to operate using either electric or diesel power, utilizing two compression ignition engines. Energy consumption and emission measurements were conducted to assess the environmental impact of this means of transportation.

RESEARCH METHODOLOGY

The research object was a railbus equipped with a dual diesel-electric propulsion system. The vehicle can operate on diesel power – two compression ignition engines with a power output of 450 kW each – or on electric power supplied by overhead lines, using six electric motors with a power output of 300 kW each (Table 1, Figure 1). The maximum speed of the vehicle in electric

Table 1. Technical data of research object

Number of cabs	2
Number of carriages	3
Number of standing places	224
Number of seating places	156
Maximum speed in electric drive mode [km/h]	160
Maximum speed in diesel drive mode [km/h]	120
Power of the diesel powertrain system [kW]	2 x 450
Emission standard	Stage V
Power of the electric powertrain system [kW]	6 x 300
Weight [kg]	171,000

mode is 160 km/h, while in diesel mode it is 120 km/h. In the emission assessment research, a mobile device from the PEMS (Portable Emissions Measurement System) group – Axion RS+ – was used. Its application allowed the determination of emissions of harmful compounds: hydrocarbons (HC), carbon monoxide (CO), carbon dioxide (CO_2), NO_x, and PM. The technical data is presented in Table 2. The concentrations of HC, CO, and CO_2 were measured using a nondispersive infrared sensor (NDIR). The concentrations of NO and O_2 were determined using electrochemical analyzers. The measurement equipment also included a weather station, a GPS positioning system, and a module allowing data recording from the onboard diagnostic system.

The energy evaluation of the electric propulsion system was conducted using a current-voltage transducer mounted on the roof of the vehicle, behind the pantograph, as well as traction voltage measurements using a voltage transducer on the rectifier. A digital recorder, model SIRIUSie-8xLV+ manufactured by DEWEsoft, was used to record the aforementioned parameters (Figure 2, Table 3). SIRIUS is a data acquisition system that allows for the reading of voltage signals from almost any sensor available on the market. The data acquisition module is connected to a computer via a USB or EtherCAT interface [23]. Using the DEWEsoft software installed on the computer, it is possible to record the measured parameters and perform further analysis.

The tests of the hybrid multiple unit consisted of five repeatable runs using diesel traction and five runs using electric traction. Each test involved accelerating to maximum speed and braking. The

Figure 1. View of the research object – hybrid multiple unit

Table 2. Technical data on the Axion R/S+ device used for emission measurement [5]

Gas	Mesaurement range	Accuracy	Resolution	Type of mesaurement
CO	0–10%	± 0.02% abs. or ±3% rel.	0.001 vol. %	NDIR
CO_2	0–16%	± 0.3% abs. or ±4% rel.	0.01 vol. %	NDIR
NO*	0–4000 ppm	± 25 ppm abs. or ±3% rel.	1 ppm	E-chem
O_2	0–25%	± 0.1% ppm abs. or ±3% rel.	0.01 vol. %	E-chem

Note: * the NOx emissions value was estimated based on the assumption that the amount of NO_2 in exhaust gases is approximately 5% of the measured NO value for gasoline and approximately 10% for diesel oil.

Table 3. Technical parameters of SIRIUSie-8xLV+ data acquisition system [23]

Inputs	
Input types	Voltage Full bridge strain Current
ADC type	24-biet delta-sigma dual core with anti-aliasing filter
Sampling rate [kS/s]	Simultaneous 200
Voltage mode	
Dual core range (Low range) [V]	±200
Offset accuracy (Dual Core) [mV]	±40
Offset accuracy after balance amplifier[mV]	2
Gain drift [ppm/K]	Typical 10, max. 30
Gain linearity	<0.02%
Input Coupling [Hz]	OC, AC 1 (3, 10 per SW)
Input Impedance [MΩ]	1
Max. common mode voltage [V]	Isolated version ±500 Differantial version ±200
Overvoltage protection [V]	300
Gain accuracy [%]	±0.05% of reading

runs were conducted on a test track. The vehicle's motion parameters were selected based on the characteristics of the infrastructure in Wielkopolska Voivodeship (Poland). The distances between stations indicate that the proposed test parameters align very well with these distances, as the average distance is 3.35 km (Table 4, Figure 3). Over this distance, the railbus can reach its maximum speed, maintain it for a few to several seconds, and then begin the braking process.

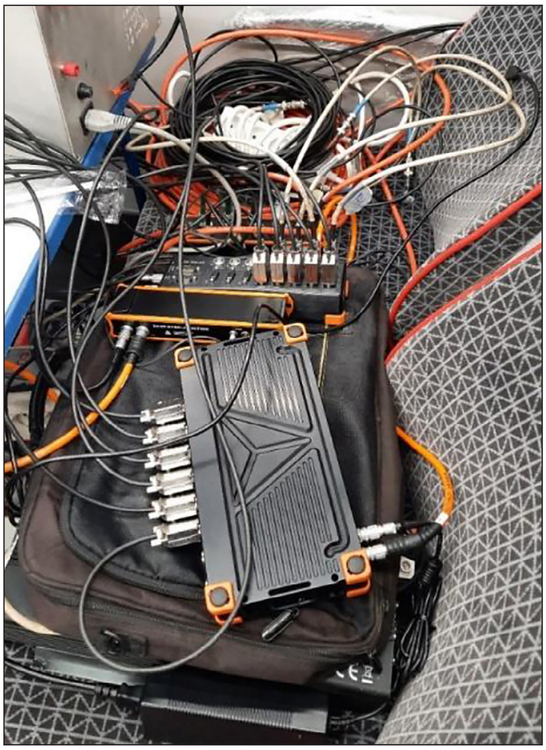

Figure 2. SIRIUSie-8xLV+ data acquisition system

ANALYSIS OF RESEARCH RESULTS

Energy assessment in the acceleration process

During tests on real operating conditions of the rail vehicle, an energy consumption assessment was conducted during the acceleration process. Figure 4 shows the change in speed as well as the power generated by the combustion engine for a sample run. The rail vehicle accelerated to its maximum operational speed (120 km/h), after which the engine driver brought the train to a stop at 0 km/h. During acceleration, the control stand was set to maximum (100% power), which resulted in a linear increase in the total work generated by the propulsion unit.

Table 4. Example of a selected railway connection operated by a railway carrier in Wielkopolska Voivodeship (Poland)

Total distance [km]	57
Average distance between stops [km]	3.35
Number of stops	18
Average travel time between stops [s]	270

Figure 5 illustrates the speed variation and total work performed by the vehicle while drawing energy from the traction network for one of

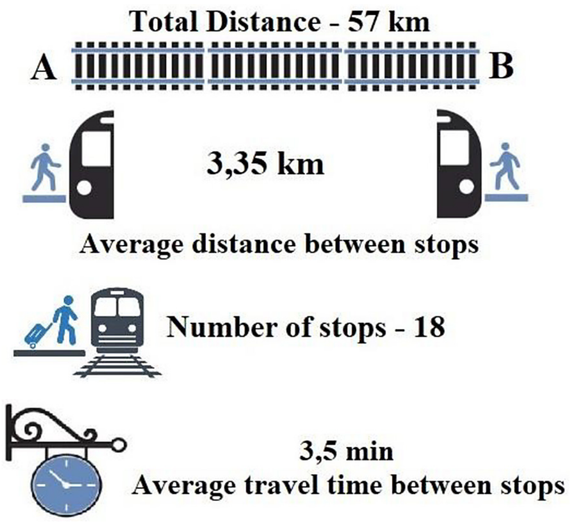

Figure 3. Characteristics of the selected railway connection in Wielkopolska Voivodeship (Poland)

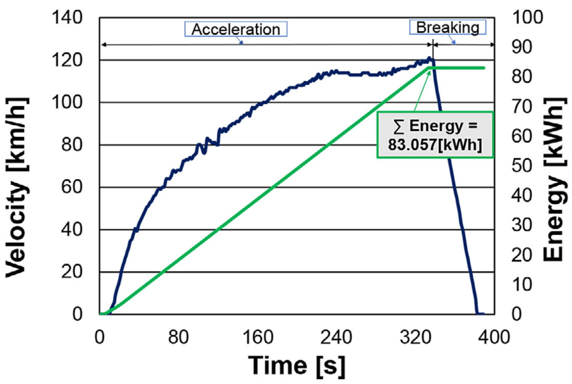

Figure 4. Speed profile and total work for the tested vehicle using diesel traction

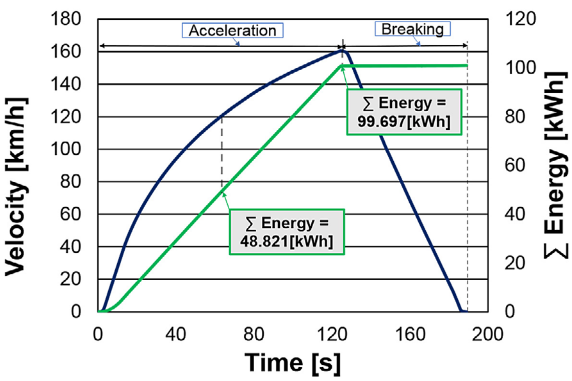

Figure 5. Speed profile and total energy for the tested vehicle using electric traction

the test runs. The electric train was accelerated to the vehicle's maximum operational speed under electric traction – 160 km/h. For comparison between both power sources, Figure x also marks the reference point at 120 km/h, as this is the maximum speed for diesel traction. The acceleration time was approximately 60 seconds to reach 120 km/h when powered by electricity. For the diesel system, this time was nearly five times longer. The work performed by the vehicle also increased linearly, as the control stand was also set to maximum for the electric drive test.

The presented relationships demonstrate that the energy required to accelerate a vehicle using electric power is lower than when using combustion engines. For acceleration to 120 km/h, the total energy consumption amounted to 83 kWh for combustion engines and 48.8 kWh for diesel powertrain. When accelerating the vehicle with electric power to 160 km/h, the total energy used was 99.7 kWh. The lower energy consumption of the electric drive is due to the reduced losses in the applied electric machines. The combustion drive, which consists of thermal engines and electric machines, is characterized by lower efficiencies. Additionally, for the vehicle acceleration process, electric motors exhibit superior traction parameters, which stem from the design advantages of these solutions.

Analysis of the environmental indicators of a diesel powertrain system

During the testing of a rail vehicle powered by a diesel engine, measurements were taken of harmful compound emissions from the exhaust system of the tested object. Based on the concentrations of harmful compounds obtained and the exhaust gas flow parameters, specific emissions for CO, CO_2, and NO_x were determined, as shown in Figure 6. The specific emission values from each run were compared to the maximum permissible limits specified in the Stage V NRE-v-6 standard, under which the vehicle's diesel engine was certified (Figure 6).

For CO specific emissions, the highest value (1.212 g/kWh) was recorded during the third test run. This value is nearly three times lower than the maximum permissible value specified in the certification limit. In the case of NO_x, the maximum value was also obtained during the third test run, amounting to 0.096 g/kWh, which is four times lower than the allowable specific emission limit for this toxic compound. The low NO_x emissions from the tested vehicle are due to the selective catalytic reduction (SCR) system installed on the vehicle, which reduces nitrogen oxides to nitrogen and water. The highest specific CO_2

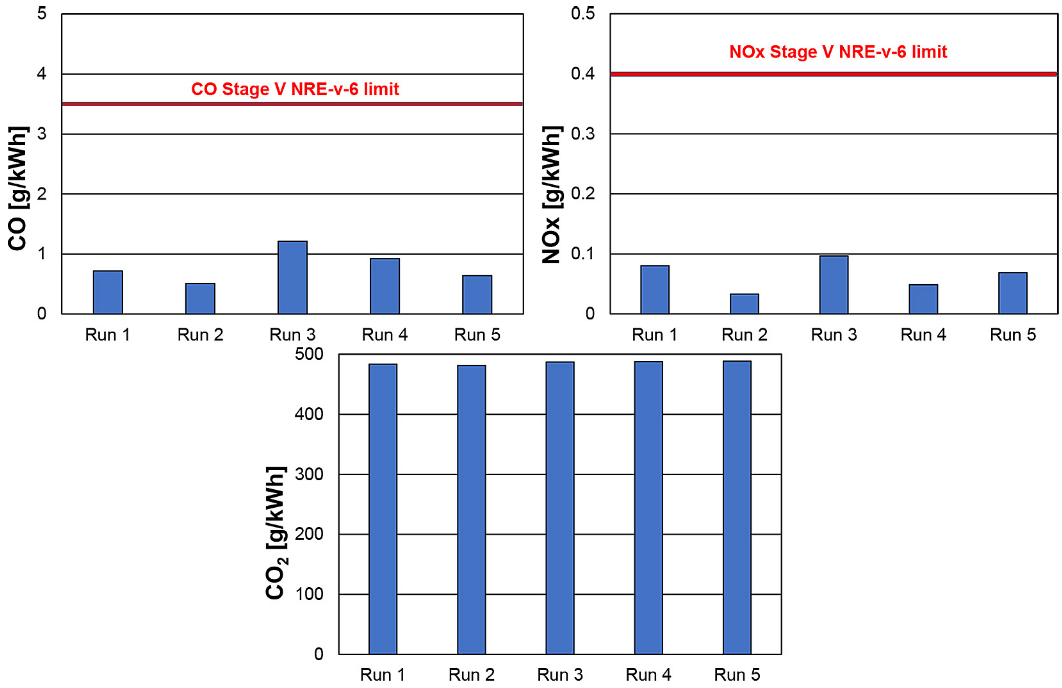

Figure 6. Unit emission of harmful gaseous compound (diesel traction)

emission value (488.475 g/kWh) was recorded during the fifth test run. However, CO_2 emissions are not subject to any emission limits for off-road engines. Among the three primary gaseous compounds covered by the Stage limits for combustion engines, alongside NO_x and CO, are HC. In this study, HC analysis was not conducted due to its proportional correlation with carbon monoxide emissions, which is characteristic of modern propulsion units [16].

Analysis of electric drive energy consumption

During the test runs of the hybrid railbus using electric traction, measurements of electric energy consumption were conducted. Figure 7 presents the results from five runs at speeds of 120 km/h and 160 km/h. The energy consumption values were compared for these two speeds, in order to evaluate the two propulsion sources (diesel engine and electric traction). The maximum speed of the vehicle using the diesel engine is 120 km/h, while the maximum speed on electric traction is 160 km/h. At the maximum speed of 120 km/h, energy consumption values ranged between 48.8 kWh and 49.6 kWh. In the case of the maximum speed of 160 km/h, energy consumption values were nearly double, ranging from 98.4 kWh to 100.9 kWh.

The comparison of energy consumption for the vehicle powered by electric energy at two speeds and by a diesel engine is presented in Figure 8. For each trial, the mean deviation was

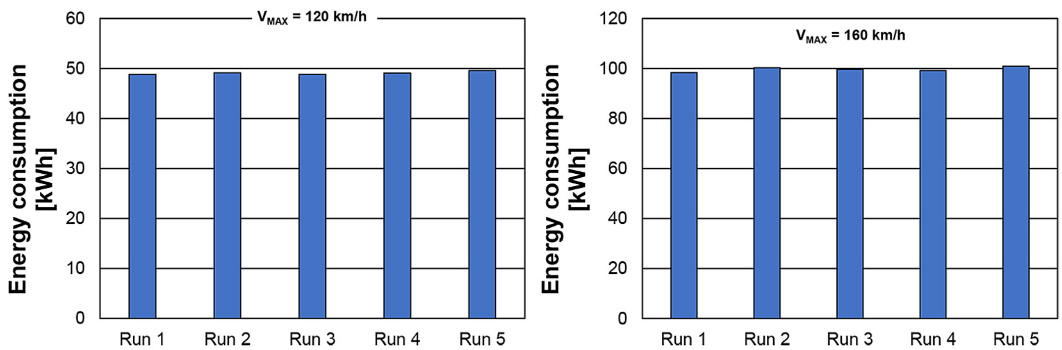

Figure 7. Electric energy consumption for the rail vehicle during acceleration to speed of 120 km/h and 160 km/h

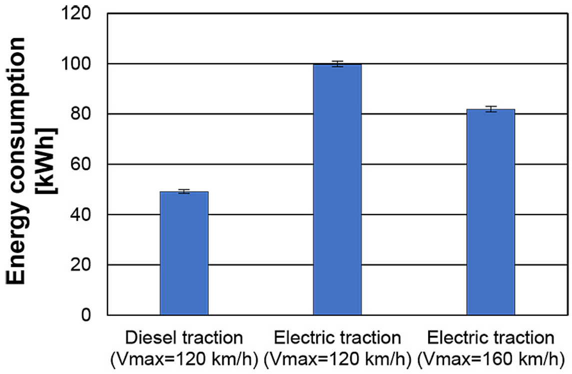

Figure 8. Energy consumption of the tested object in different propulsion source variants

calculated, which amounted to the following for the vehicle:
- Powered by electric energy at 120 km/h – 49.10 ± 0.22 kWh
- Powered by electric energy at 160 km/h – 99.68 ± 0.74 kWh
- Powered by diesel engine at 120 km/h – 81.85 ± 0.82 kWh

Environmental assessment of electric and diesel powertrain

Based on research published in the report [27], it was assumed that energy transmission losses between power plants and the vehicle's supply from the traction network amount to 9.97%. To assess the environmental impact of the electric vehicle, data regarding the average emissions of harmful compounds generated by the four largest coal-fired power plants operating in Poland were used. Table 5 presents the averaged emission values of harmful compounds from the Bełchatów, Kozienice, Opole, and Połaniec power plants, which are necessary to deliver 1 kWh of energy to the rail vehicle. The data in the table takes into account energy transmission losses, making them approximately 10% higher than the figures reported by the power plants in their official reports.

To determine the environmental impact of the tested vehicle, the unit emissions of harmful compounds for diesel traction and electric traction were presented (Figure 9). For electric traction, the unit emission values are those shown in Table 5, which are the average emission values of harmful compounds from coal-fired power plants operating in Poland. The CO_2 emissions from the energy needed to power the vehicle from the power plants are twice as high as those from the vehicle using diesel traction. NO_x emissions are nearly ten times higher from the power plants than from the diesel vehicle. This is a key factor in considering the use of additional exhaust gas cleaning systems, such as SCR, which effectively reduces NOx emissions. Only in the case of CO emissions were the emissions from power plants lower than those from the diesel vehicle. It should also be noted that power plants emit many other harmful compounds that modern rail vehicles do not, such as SO_2 and mercury (Hg).

Further environmental analysis regarding the use of electric and diesel propulsion focused on determining road emissions. The tested vehicle belongs to the non-road category, but due to its purpose, it is possible to assess its emissions in relation to distance traveled. Figure 10 presents the road emissions of NO_x for diesel and electric traction. At a speed of 120 km/h, road emissions were nearly 40 times higher for electric traction compared to diesel traction. At a speed of 160 km/h, road emissions were nearly 20 times higher. A significant factor in road emissions was the fact that the vehicle with electric traction reached its maximum speed faster than the vehicle with diesel traction. In the case of diesel traction, road CO_2 emissions were 8 times lower than for electric traction at speeds up to 120

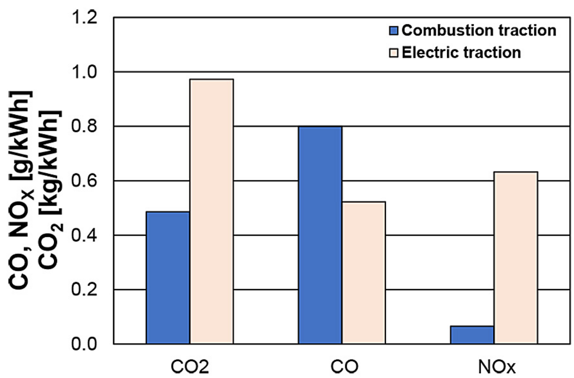

Figure 9. Comparison of unit emissions of harmful compounds for the tested object using diesel and electric traction

Table 5. Average unit emission values of harmful compounds [24–26]

Harmful compound	SO_2	NO_x	CO_2	CO	PM
Avarage emssion [g/kWh]	0.639	0.632	972.448	0.522	0.025

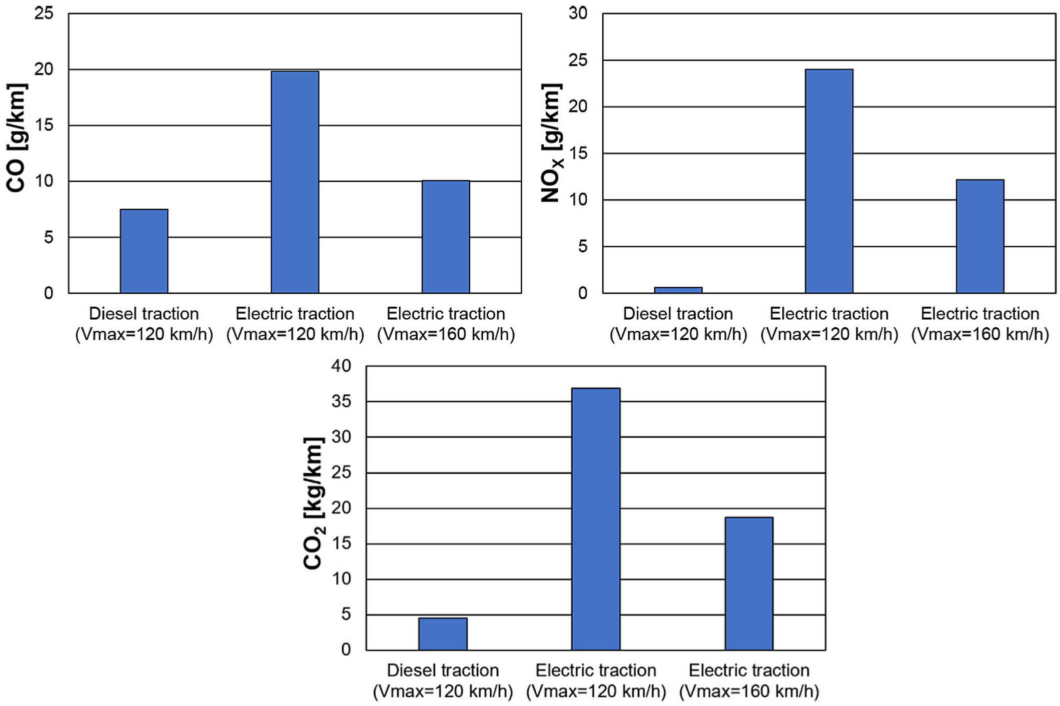

Figure 10. Road emissions of CO, NO_x and CO_2 for diesel and electric traction

km/h, and 4 times lower at a maximum speed of 160 km/h. Figure 10 also shows road emissions of CO. For electric traction, CO emissions were 2.5 times higher at a maximum speed of 120 km/h and 1.3 times higher at a maximum speed of 160 km/h compared to diesel traction.

CONCLUSIONS

Pollution and energy consumption measurements in the transport sector currently play a key role. They help, among other things, to understand environmental impact issues, contribute to understanding the scale of the problem, and enable the execution of research and development work [8, 12, 14, 17]. At the same time, they serve as a valuable source of information when designing transportation systems on both local and global scales. Significant progress in such studies is visible in the field of road vehicles. However, for the group of off-road vehicles and machinery, these issues require continuous improvement, particularly in studies conducted under real operating conditions.

This article presents an environmental assessment of a vehicle equipped with both diesel and electric powertrain systems. The obtained traction characteristics indicate that electric powertrain is less energy-intensive, which is due to the high efficiency of electric machines and the favorable torque curves of electric motors. The diesel propulsion system demonstrated worse parameters. It is crucial to compare the environmental indicators obtained through direct measurement from the diesel engine with those calculated based on data from Poland's largest power plants for the electric drive. The conventional engine achieved much more favorable indicators, as coal-fired power plants are characterized by unfavorable emission parameters. Additionally, the transmission of electrical energy involves losses, which also affects the overall environmental balance. The presented results and conclusions clearly demonstrate that every effort should be made to introduce alternative energy sources into the energy economy, preferably those belonging to the group of renewable energy sources.

Acknowledgments

The study presented in this article was performed within statutory research (No. 0415/SBAD/0351).

REFERENCES

1. Andersen, M.H.G.; Johannesson, S.; Fonseca, A.S.; Clausen, P.A.; Saber, A.T.; Roursgaard, M.; Loeschner, K.; Koponen, I.K.; Loft, S.; Vogel, U.

(2019). Exposure to air pollution inside electric and diesel-powered passenger trains. *Environmental science & technology*, *53*, 4579–4587, https://doi.org/10.1021/acs.est.8b06980.
2. Bajerlein, M.; Karpiuk, W.; Smolec, R. (2022). Application of gas dissolved in fuel in the aspect of a hypocycloidal pump design. *Energies 15*, 9163, https://doi.org/10.3390/en15239163.
3. Din, T.; Hillmansen, S. (2018). Energy consumption and carbon dioxide emissions analysis for a concept design of a hydrogen hybrid railway vehicle. *IET Electrical Systems in Transportation 8*, 112–121, https://doi.org/10.1049/iet-est.2017.0049
4. Fruhwirt, D.; Sturm, P.; Nöst, T.; Leonhardt, P.; Bode, G.; Michael, S.; Rodler, J. (2023). PM emissions from railways–results of tests on a wheel-rail test bench. *Transportation Research Part D: Transport and Environment 122*, 103858, https://doi.org/10.1049/iet-est.2017.0049
5. GlobalMRV Axion R/S+ PEMS.
6. González-Gil, A.; Palacin, R.; Batty, P.; Powell, J. (2014). A systems approach to reduce urban rail energy consumption. *Energy Conversion and Management 80*, 509–524, https://doi.org/10.1016/j.enconman.2014.01.060
7. Kapetanović, M.; Núñez, A.; van Oort, N.; Goverde, R.M. (2021). Reducing fuel consumption and related emissions through optimal sizing of energy storage systems for diesel-electric trains. *Applied Energy 294*, 117018, https://doi.org/10.1016/j.apenergy.2021.117018
8. Merkisz, J.; Bajerlein, M.; Dobrzynski, M.; Michalak, D. (2013). A comparison of the exhaust emission from city buses fuelled with diesel oil and CNG. *WIT Transactions on The Built Environment 130*, 495–505, https://doi.org/10.2495/UT130401.
9. Merkisz, J.; Gallas, D.; Siedlecki, M.; Szymlet, N.; Sokolnicka, B. (2019). Exhaust emissions of an LPG powered vehicle in real operating conditions.; *EDP Sciences, 100*, 00053
10. Merkisz, J.; Lijewski, P.; Pielecha, J. (2016). PEMS-based investigations into exhaust emissions from non-road and rail vehicles. *Combustion Engines 55*, 46–53, https://doi.org/10.19206/CE-2016-339
11. Merkisz, J.; Pielecha, J.; Jasiński, R. (2016). The impact of operating parameters of tractor's engine on exhaust emissions. *Journal of KONES 23*, 339–350, https://doi.org/10.5604/12314005.1217245
12. Pielecha, I.; Cieślik, W.; Szałek, A. (2017). Operation of hybrid propulsion systems in conditions of increased supply voltage. *International Journal of Precision Engineering and Manufacturing 18*, 1633–1639, https://doi.org/10.1007/s12541-017-0192-3
13. Rymaniak, Ł.; Lijewski, P.; Kamińska, M.; Fuć, P.; Kurc, B.; Siedlecki, M.; Kalociński, T.; Jagielski, A. (2020). The role of real power output from farm tractor engines in determining their environmental performance in actual operating conditions. *Computers and Electronics in Agriculture 173*, 105405, https://doi.org/10.1016/j.compag.2020.105405
14. Sawczuk, W.; Merkisz-Guranowska, A.; Rilo Cañás, A.-M. (2021). assessment of disc brake vibration in rail vehicle operation on the basis of brake stand. *Eksploatacja i Niezawodność 23*, http://dx.doi.org/10.17531/ein.2021.2.2
15. Stawecki, W.; Merkisz-Guranowska, A.; Andrzejewski, M.; Daszkiewicz, P. (2017). The use of alternative fuels in railway vehicles. *Rail Vehicles/Pojazdy Szynowe*, 10–19.
16. Szymlet, N.; Kamińska, M.; Ziółkowski, A.; Sobczak, J. (2024). Analysis of non-road mobile machinery homologation standards in relation to actual exhaust emissions. *Energies 17*, 3624, https://doi.org/10.3390/en17153624
17. Urbański, P.; Huang, Y.; Gallas, D.; Zhou, J.L.; Merkisz, J. (2024). Real-world assessment of the energy consumption and emissions performance of a novel diesel-electric dual-drive locomotive. *Sustainable Energy Technologies and Assessments 71*, 104017, http://dx.doi.org/10.1016/j.seta.2024.104017
18. Wang, Y.-Z.; Zhou, S.; Ou, X.-M. (2021). Development and application of a life cycle energy consumption and co2 emissions analysis model for high-speed railway transport in China. *Advances in Climate Change Research 12*, 270–280, https://doi.org/10.1016/j.accre.2021.02.001
19. Warguła, Ł.; Adamiec, J.M.; Waluś, K.J.; Krawiec, P. (2018). The characteristics analysis of torque and rotation speed of working unit of branch grinder-introductory research.; *EDP Sciences 157*, 01021.
20. Woźniak, K.; Andrzejewski, M.; Daszkiewicz, P.; Rymaniak, Ł. (2019). Badania zużycia energii przez pojazdy w warunkach rzeczywistych. *Maszyny Elektryczne: zeszyty problemowe*.
21. Ziółkowski, A.; Fuć, P.; Jagielski, A.; Bednarek, M.; Konieczka, S. (2023). Comparison of the energy consumption and exhaust emissions between hybrid and conventional vehicles, as well as electric vehicles fitted with a range extender. *Energies 16*, 4669, https://doi.org/10.3390/en16124669
22. Ziółkowski, A.; Fuć, P.; Lijewski, P.; Jagielski, A.; Bednarek, M.; Kusiak, W. (2022). Analysis of exhaust emissions from heavy-duty vehicles on different applications. *Energies 15*, 7886, https://doi.org/10.3390/en15217886
23. www.dewesoft.com. Available online: https://downloads.dewesoft.com/manuals/dewesoft-sirius-manual-en.pdf (accessed on 22 October 2024).
24. www.elbelchatow.pgegiek.pl. Available online:

https://elbelchatow.pgegiek.pl/Ochrona-srodowiska/Wskazniki-emisji (accessed on 01 October 2024).
25. www.elopole.pgegiek.pl. Available online: https://elopole.pgegiek.pl/Ochrona-srodowiska/Deklaracja-srodowiskowa (accessed on 15 October 2024).
26. www.enea.pl. Available online: https://raport2022.esg.enea.pl/srodowisko/ograniczanie zanieczyszczen-gazowych-i-pylowych/ (accessed on 10 October 2024).
27. www.prokolej.org. Available online: https://prokolej.org/wp-content/uploads/2022/10/Raport-3-25kV.pdf (accessed on 21 October 2024).
28. www.stat.gov.pl. Available online: https://stat.gov.pl/obszary-tematyczne/transport-i-lacznosc/transport/przewozy-ladunkow-i-pasazerow-w-2023-roku,11,12.html (accessed on 20 October 2024).