IMPACT OF DRIVING STYLE ON THE EXHAUST EMISSION OF A DIESEL MULTIPLE UNIT

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ABSTRACT
This paper considers aspects regarding exhaust emissions from vehicles, the reduction of which is one of the main trends of current worldwide development efforts. These efforts resulted in numerous legal tools being created to tackle the problem of toxic gas emissions and global warming. These tools include emission limits and type approval procedures. Such norms for rail vehicles are simplistic and fail to provide a reliable method of assessing the real exhaust emission from rail vehicles operating on the tracks. Hence, PEMS (portable emission measurement system) type apparatus was used to perform measurements of exhaust emissions of a diesel multiple unit designed for short–mid range passenger transport in real operating conditions. The vehicle tested belonged to a widely and commonly used group of passenger vehicles, and the testing methods were similar to current RDE (real driving emissions) test requirements for road vehicles. The selected vehicle was powered by an internal combustion engine in which ecological and economic properties depend on the operating ranges and parameters used. These types of train lines are characterized by frequent stops at stations, which confirms the need to investigate this subject. The vehicle exhaust emissions were measured for different driving styles, regular driving style typical for the driver and a drive more closely in line with the concepts of eco-driving, with reduced maximum acceleration values. Since most previous studies on the eco-driving principles used road vehicles for testing, this resulted in a gap in knowledge in this field regarding rail vehicles. The aim of the paper is to assess the impact of the choice of driving style on the exhaust emission values of a selected passenger rail vehicle.
Keywords: RDE, eco-driving, railbus, exhaust emissions.

1 INTRODUCTION

The transport sector is responsible for 24% of all CO_2 emissions produced by burning fossil fuels according to IEA (International Energy Agency) [1]. This equates to approximately 8 Gt of CO_2, of which 60% is produced by passenger transport and 40% by freight transport. This poses a significant problem to tackle in lieu of reducing global CO_2 emissions and preventing global warming effects. This article focuses on the environmental impact of passenger rail transport, as in addition to their CO_2 contribution combustion engines also produce a significant amount of other toxic compounds. While freight transport is often used over longer distances and between areas focused on industry or commerce, passenger transport is more often nestled in the most densely populated areas. As a result the exhaust emissions released by passenger transport is one of the primary concerns for the health and wellbeing of the human population [2] as well as having significant impact on the long-term air pollution levels in inhabited areas [3]. Transport related air pollution has long been well known to have a strong impact on human health [4]. A significant aspect of this impact relates to the emission of particulates, mainly measured as PM_{10} and $PM_{2.5}$, which is known to be carcinogenic as well as cause lung damage and upper respiratory infections [5]. As a result of its impact, PM emissions from vehicles have been tested and researched intensively in the last few decades, and other sources can provide fairly comprehensible data with regards to PM emissions from rail transport [6]. The environmental and health impact of rail vehicles can be reduced through multiple means, such as design modifications, engine computer

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modeling [7], combustion process shaping [8], and fuel chemical engineering [9]. This article investigates the effect that can be achieved by using more effective driving styles, known as eco-driving, when performing the vehicle regular operations. Thus it discusses RDE style exhaust emission tests of a passenger rail vehicle, specifically a diesel multiple unit, measuring the emission values of CO_2, CO, HC, and NO_x. A comparison of two test drives performed in a normal driving style and eco-driving was made, to assess the potential impact of what can be considered a simple non-invasive solution to exhaust emissions reduction. The popularity of adopting eco-driving principles in vehicles with combustion engines stems from its known effectiveness in road vehicles [10]. Even though rail vehicles typically contribute much less to the overall emissions compared to rail transport, much of their exhaust emission is still released in urban agglomerations, magnifying its impact on human health. Prokolej estimates the average CO_2 emissions for the passenger rail vehicles to be about 60 g/pkm while for road vehicles this value is over 140 g/pkm [11]. The investigation of its effects in the rail sector, as well as potential applications has been lagging behind, however. This article aims to provide an impact assessment of eco-driving on exhaust emissions measured in real driving conditions.

2 TEST VEHICLE AND METHOD

The tested vehicle belonged to the NRMM (non-road mobile machinery) group – the SA108 rail bus (Fig. 1). It is powered by two MAN D2866 LUH21 diesel engines with a power output of 257 kW (Fig. 2). Other major technical and operational parameters of the SA108 rail bus engine were provided in Table 1.

Figure 1: Rail bus with mounted measuring apparatus for testing in RDE conditions.

Figure 2: Source of propulsion of the test vehicle – the MAN D2866 LUH21 engine.

Table 1: Selected technical and operational parameters of the MAN D2866 LUH21 engine.

Engine design	In-line, 6 cylinders horizontal configuration
Ignition type	Compression
Maximum power output	257 kW (350 KM) at 2,000 rpm
Maximum torque	1500 N·m in the range 1,000–1,500 rpm
Stroke volume	11.96 dm^3
Compression ratio	17:1
Piston diameter	128 mm
Piston stroke	155 mm
Average piston velocity	10.85 m/s
Exhaust emission norm	Euro II

The assessment of pollutant exhaust emissions of the SA108 rail bus engines was carried out in the conditions of its real operation during the inspections carried out on the 36-km section of the railway line from Krzyż Wielkopolski to Trzcianka (Figs 3 and 4, points A and B). This route was chosen as it was almost completely straight and located on flat terrain. For the drive one way the route was covered while maintaining the typical way of controlling rail bus engines, while the drive on the return was performed while taking into account the principles of economic and ecological driving (so-called eco-driving). It mainly boiled down to the use of less "aggressive" engine loadings and frequent coasting. Fig. 5 shows an example of the vehicle speed profile recorded during the tests (standard travel). The test drive max speed was 100 km/h, while the mean travel speed was about 62 km/h.

The tests were performed with the use of mobile analyzers from the PEMS (portable emission measurement system) group to determine the composition of engine exhaust gases, including components of the Semtech-DS device and their software (exhaust flow meter, Figs 6 and 7).

Figure 3: View from the driver's cab during tests in real driving conditions.

Figure 4: The test route between Krzyż Wielkopolski–Trzcianka.

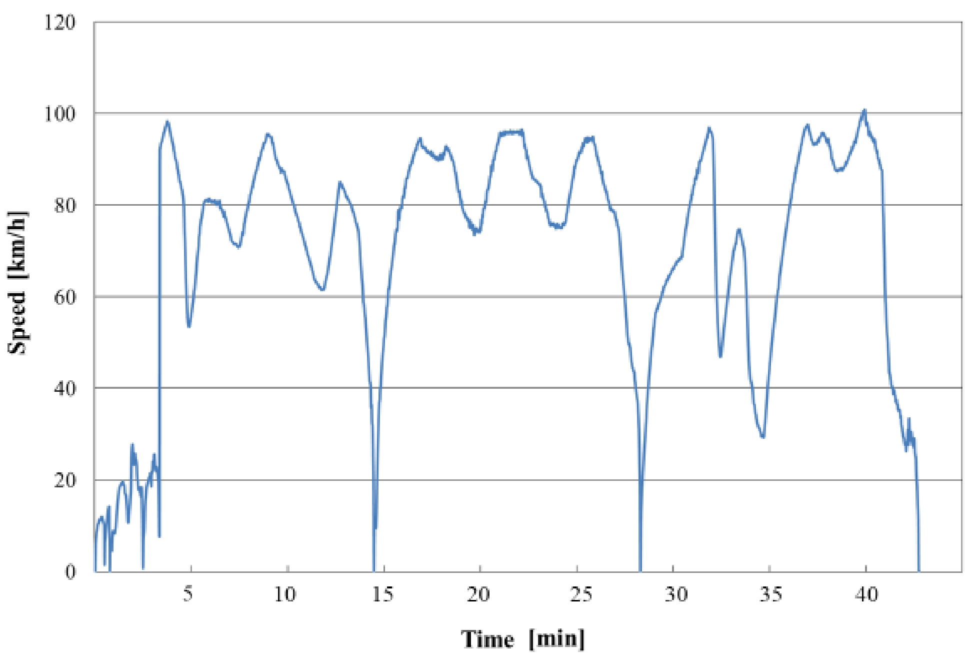


Figure 5: The speed profile of the rail bus SA108 determined for a standard drive.

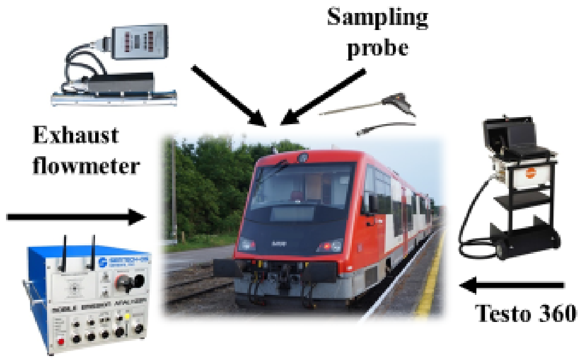


Figure 6: Measuring apparatus mounted on the test vehicle.

Figure 7: The measuring apparatus placed inside the test vehicle.

3 RESULTS AND ANALYSIS

In order to carry out the analyses that are the subject of this study, measurements of exhaust gas flow from the engines of the tested rail bus were performed beforehand (Fig. 8). Due to the fact that the first part of the test route consisted mainly of manoeuvres in the vicinity of the railway station in Krzyż Wielkopolski, the nature of the exhaust gas flow is significantly different (much lower flow rate) from the other recorded data. This also had an impact on the exhaust gas temperature (Fig. 9).

A significant drop in exhaust gas temperature can be observed when using eco-driving as opposed to the standard drive. Lower temperature in the combustion engine reduces the formation of nitrogen oxides species, which are among the most toxic exhaust components. When using mobile apparatus for exhaust emissions testing, the concentration of individual gaseous compounds in exhaust gas can be determined. The measurement results were used to calculate the emission intensity of these compounds (Figs 10–13). In all cases, higher emission levels were observed for the standard drive. This is primarily due to the much more dynamic and liberal application of engine loads.

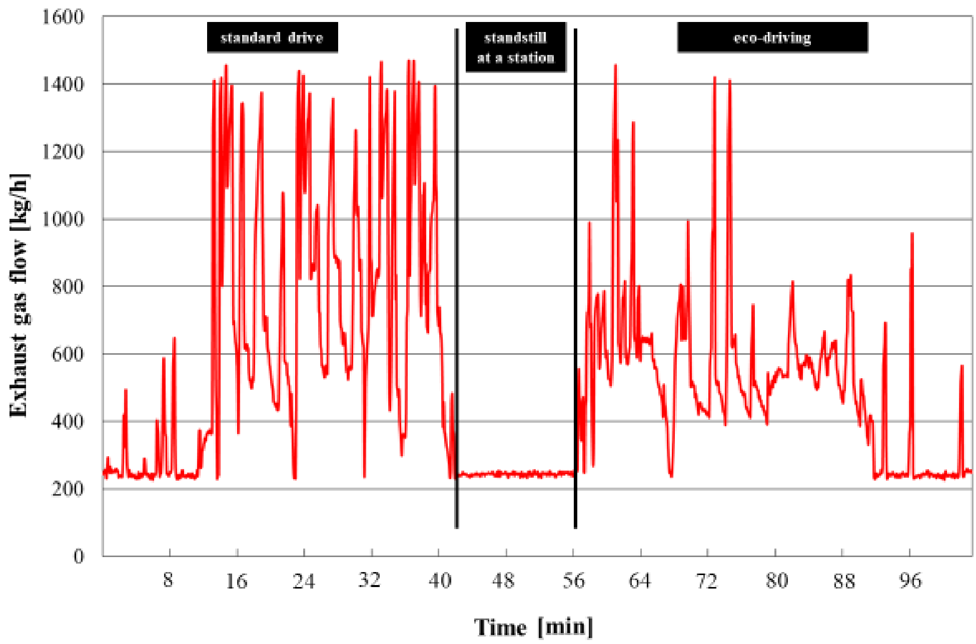


Figure 8: Exhaust mass flow rate recorded during testing – one vehicle engine.

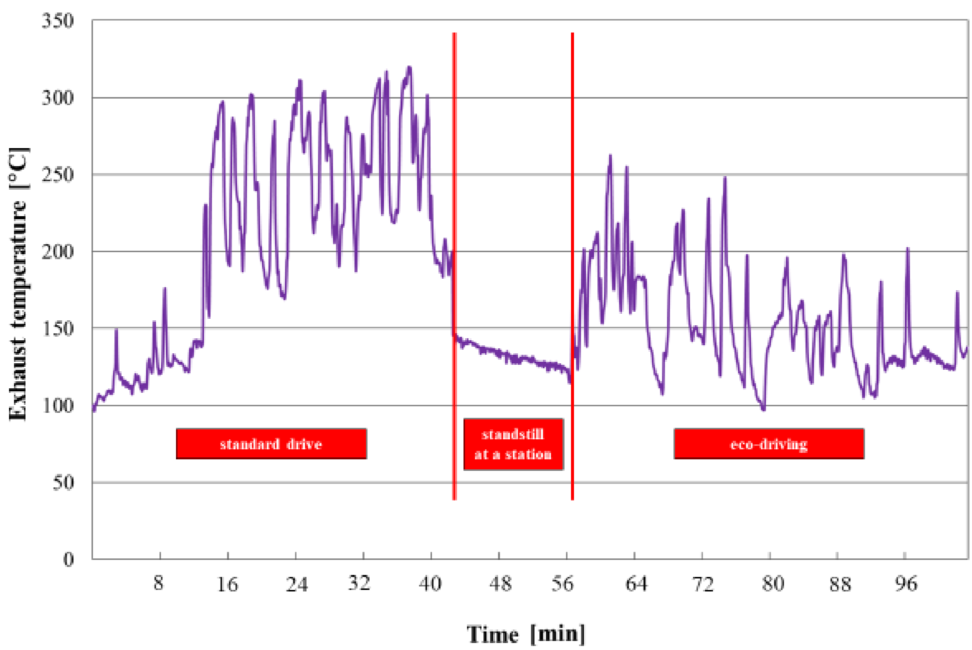


Figure 9: Exhaust gas temperature recorded during tests – one vehicle engine.

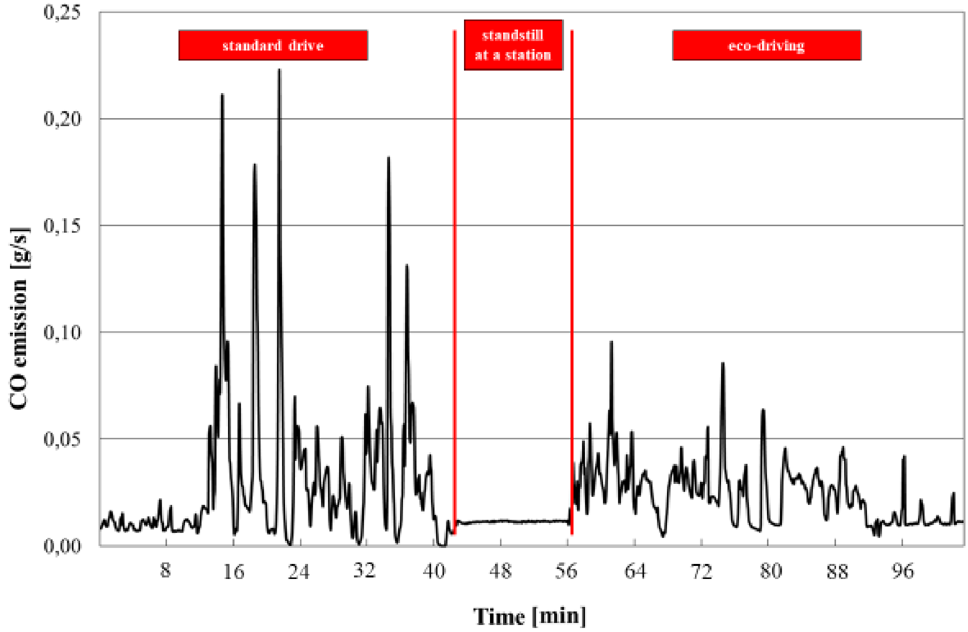


Figure 10: Carbon monoxide exhaust emission rate from the SA108 rail bus exhaust system – one vehicle engine.

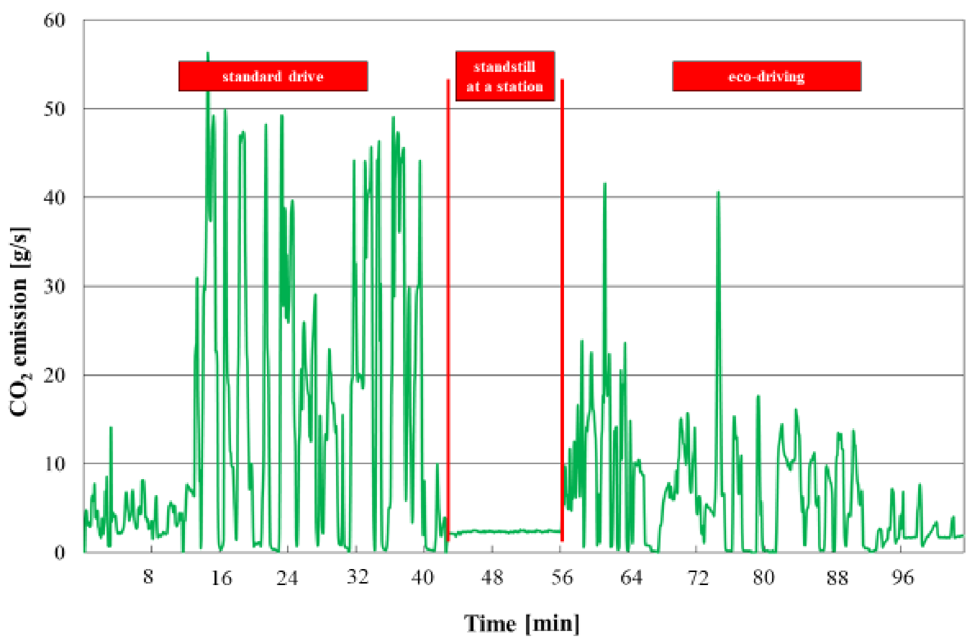


Figure 11: Carbon dioxide exhaust emission rate from the SA108 rail bus exhaust system – one vehicle engine.

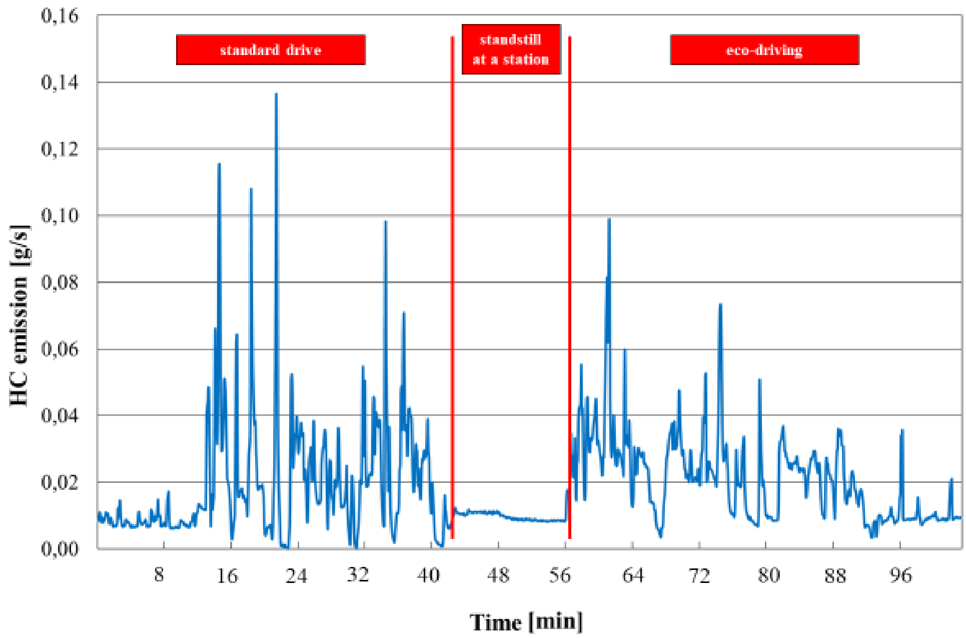


Figure 12: Hydrocarbons exhaust emission rate from the SA108 rail bus exhaust system – one vehicle engine.

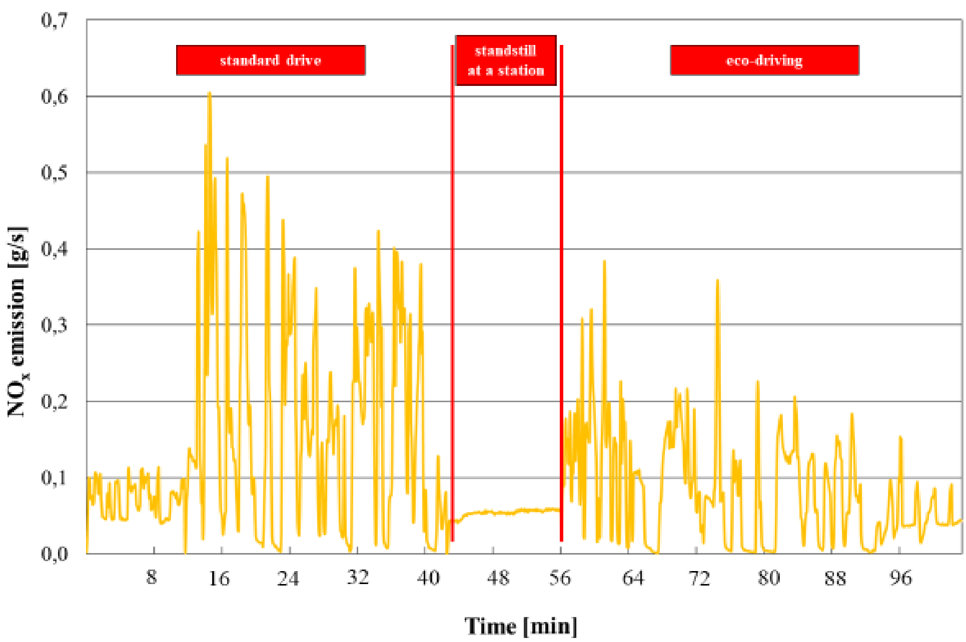


Figure 13: Nitrogen oxides exhaust emission rate from the SA108 rail bus exhaust system – one vehicle engine.

A noticeable reduction in the exhaust emissions of each of the measured compounds (CO, CO_2, HC, NO_x) has been observed. This indicates that the reduction of acceleration and deceleration values in the eco-driving test portion had a positive impact on the exhaust emissions of the vehicle. The observed changes in exhaust emissions are in line with what is often found for tests on road vehicles when applying the eco-driving style. Through the performed analyses, the exhaust emission of each harmful exhaust component for each entire drive was then calculated (Fig. 14). As in the previous case of exhaust emission intensity, a significant diversification of values was observed (Fig. 15).

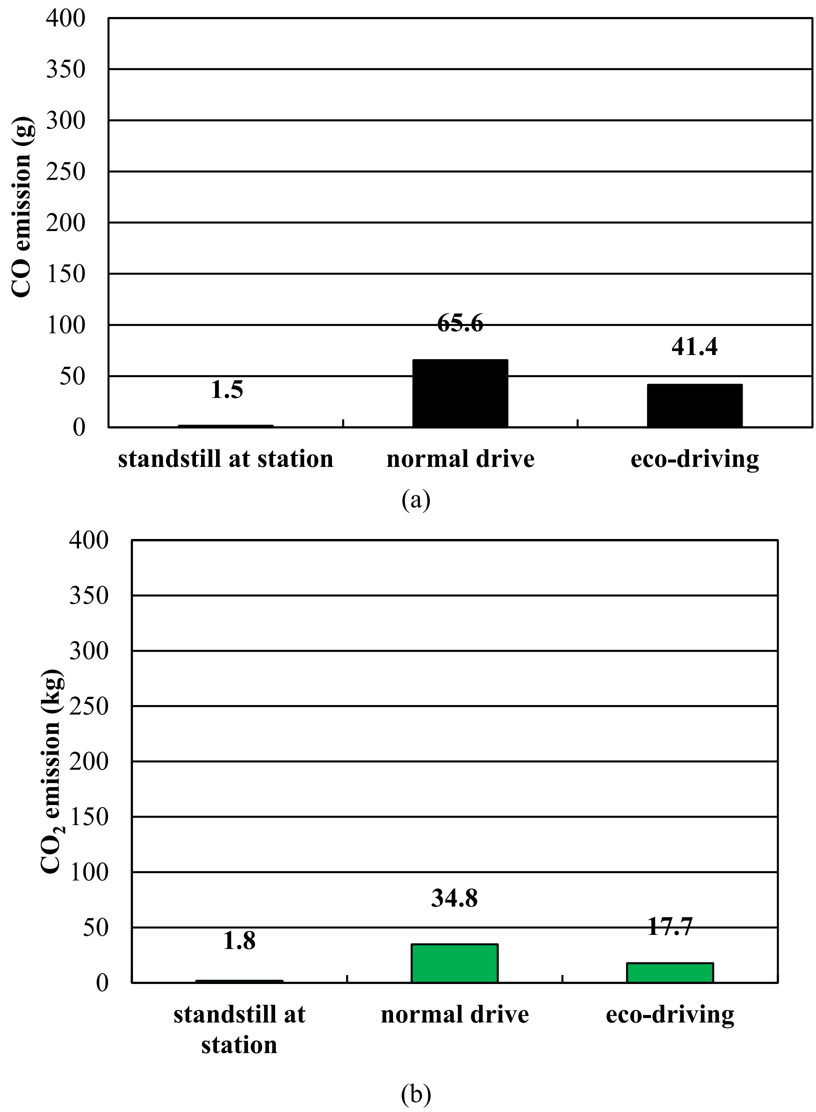
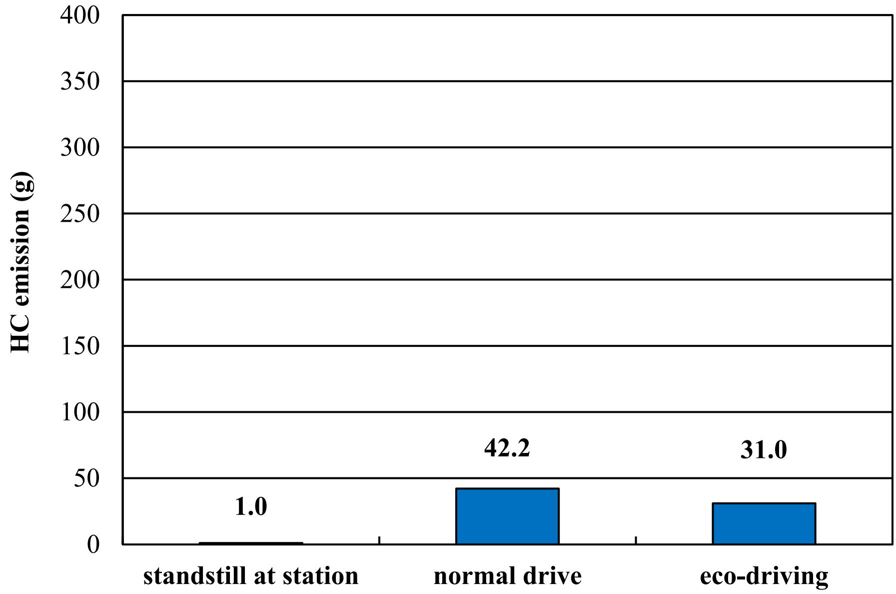
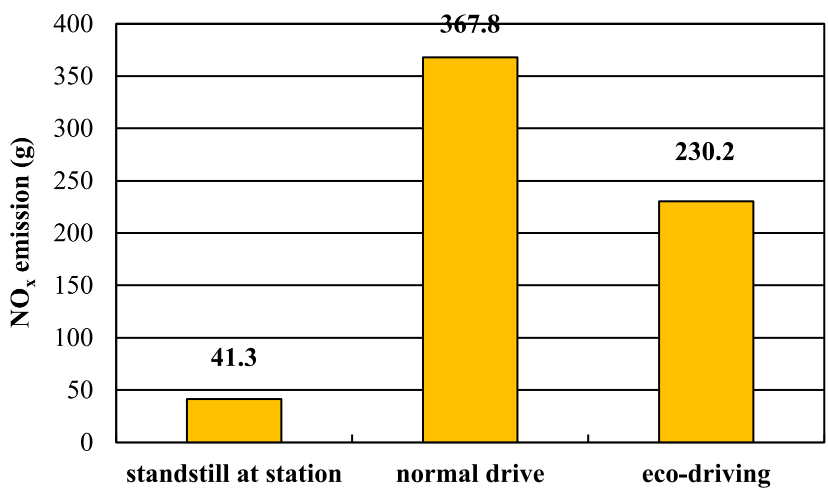


Figure 14: Exhaust emission value at standstill and in the two individual drives (one vehicle engine) for: (a) carbon monoxide; (b) carbon dioxide; (c) hydrocarbons; and (d) nitrogen oxides.



(c)



(d)

Figure 14: Continued.

Using eco-driving had the largest impact (49% reduction) on exhaust emissions of CO_2, which could be explained by the fact that this driving style is mostly used to maximize fuel efficiency, which is proportional to CO_2 emitted. The least affected was the emission of HC, with a relative change of less than 27%. This may be due to the fact that with lower

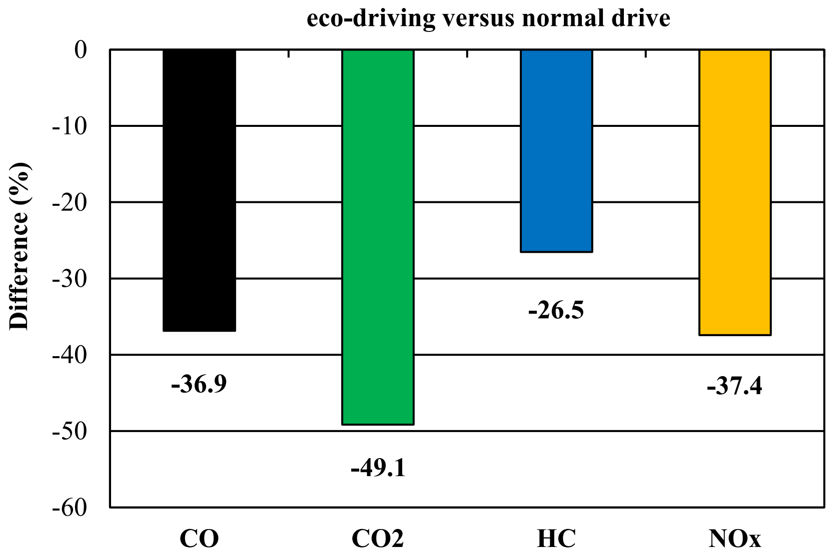


Figure 15: The relative change in exhaust emissions of individual exhaust components when using the eco-driving principles.

acceleration and deceleration values, the engine operates at a lower average rpm, and lower loads over increased periods of time. This results in lower temperature in the combustion engine which in turn reduces the rate of oxidation of hydrocarbons.

4 CONCLUSIONS

The performed exhaust emissions tests and analysis for the standard drive and eco-driving indicate a significant change in exhaust emission values of each of the measured exhaust components. The most significant impact was observed in the case of CO_2 emissions, which is directly correlated with fuel consumption. This should be expected, as eco-driving principles have been developed primarily to help improve the fuel efficiency of vehicles with combustion engines. The overall change reached up to about 50% of CO_2 emission reduction for the second drive. In addition the ecological impact of eco-driving for the rail bus was as follows:

- 37% exhaust emission reduction of carbon monoxide;
- 26% exhaust emission reduction of hydrocarbons;
- 37% exhaust emission reduction of nitrogen oxides.

This result indicates an average exhaust emission reduction of toxic exhaust components by about a third. This result will vary depending on the vehicle type, engine type and age, and the type of work performed (route, stops, slope, speeds etc.). Despite these variables, the obtained results indicate an opportunity to significantly reduce exhaust emissions from rail vehicles through the use of driver training, instead of invasive repairs and modifications, such as retrofitting or engine unit replacement.

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