Journal of Mechatronics, Electrical Power, and Vehicular Technology 14 (2023) 87-93

Journal of Mechatronics, Electrical Power, and Vehicular Technology

CrossMark

e-ISSN: 2088-6985
p-ISSN: 2087-3379

mev.lipi.go.id

Impact of road load parameters on vehicle CO_2 emissions and fuel economy: A case study in Indonesia

Kurnia Fajar Adhi Sukra [a, *], Heru Priyanto [a], Dedy Indriatmono [b], Muhamad Agus Wijayanto [c], Irfan Yahya Ikhsanudin [c], Yoga Akbar Ermansyah [d]

[a] *Research Center for Transportation Technology, National Research and Innovation Agency, South Tangerang, 15310, Indonesia*

[b] *Research Center for Energy Conversion and Conservation, National Research and Innovation Agency, South Tangerang, 15310, Indonesia.*

[c] *Directorate of Laboratory Management, National Research and Innovation Agency, South Tangerang, 15310, Indonesia*

[d] *Faculty of Transportation Engineering and Vehicle Engineering, Budapest University of Technology and Economics, Budapest, 1111, Hungary*

Received 4 April 2023; 1st revision 5 June 2023; 2nd revision 14 June 2023; Accepted 19 June 2023; Published online 31 July 2023

Abstract

Carbon dioxide (CO_2) contributes to the greenhouse effect and global warming. The Indonesian government has introduced a reduction in vehicle taxes based on the number of CO_2 emissions, meaning that lower CO_2 emissions result in lower tax rates. To measure the CO_2 emissions, vehicle testing can be conducted on a chassis dynamometer using road load (R/L) parameters to assess the vehicle's loading during the test. The United Nations Economic Commission for Europe (UN ECE) Regulation no. 101 (R101) provides predefined table values for testing, but vehicle manufacturers can also provide their own R/L values, known as actual R/L. In this study, the vehicle underwent two tests: one using the R/L values from the standard table R101 and another using the actual R/L values provided by the manufacturer through coast-down results. By employing the actual R/L values, CO_2 emissions can be reduced by up to 7.3 %. This reduction is achieved by lowering the vehicle's load by up to 17 % to enable optimal vehicle performance. Additionally, there is a potential improvement in fuel economy of up to 7.9 % for vehicles. These findings can serve as a reference for establishing future standard testing procedures.

Keywords: road load (R/L); UN ECE R101; carbon dioxide emission; fuel economy.

I. Introduction

Global warming is a problem experienced by the whole world [1]. Experts suggest that carbon dioxide (CO_2) is the leading cause of the recent occurrence of global warming [2][3]. As much as 25 % of the world's CO_2 emissions are generated from the transportation sector, resulting from the combustion of exhaust gases [3][4][5]. Urban transport produces high CO_2 emissions in urban areas [6].

To overcome this condition, the Indonesian government has enacted PP 73 of 2019, which is revised with PP 74 of 2021 concerning changes to government regulation number 73 of 2019 concerning taxable goods that are classified as a luxury in the form of motor vehicles that are subject to sales tax on luxury goods where the amount of tax for new vehicles is determined based on the CO_2 emissions produced [7][8]. With the enactment of this regulation, it is hoped that vehicle manufacturers, especially in Indonesia, will compete to develop more environmentally friendly technology by reducing CO_2 emissions in vehicle exhaust gases.

Various studies have been carried out to be able to reduce CO_2 emissions from motor vehicles. Modification of the exhaust line can be an option to lower these emissions. Mishra *et al.* explained that using a chamber-shaped exhaust without holes can reduce CO_2 emissions by up to 50 % compared to using chamber types with holes or turbo types,

* Corresponding Author. Tel: *+62-857-2409-9065*
E-mail address: *kurnia.fajar.adhi.sukra@brin.go.id*

doi: https://dx.doi.org/10.14203/j.mev.2023.v14.87-93
2088-6985 / 2087-3379 ©2023 National Research and Innovation Agency

How to Cite: K. F. A. Sukra *et al.*, "Impact of road load parameters on vehicle CO_2 emissions and fuel economy: A case study in Indonesia," *Journal of Mechatronics, Electrical Power, and Vehicular Technology*, vol. 14, no. 1, pp. 87-93, July. 2023.

either with holes or without holes [9]. Zhang *et al.* also explained that the strategy to reduce CO_2 emissions could be done by converting the CO_2 into methanol using a thermal catalytic with an hydrogen (H_2) obtained from the renewable energy process is a promising step in the future [10]. Meanwhile, we can also apply hybrid technology vehicles to reduce CO_2 emissions on the engine side. By using this hybrid technology, the vehicle will operate more efficiently, reducing CO_2 emissions [11].

For vehicle development in Indonesia, the Laboratory for Thermodynamics Motor and Propulsion Technology under National Research and Innovation Agency in Indonesia is one of the government agencies mandated to conduct motor vehicle emission tests. Since 2005 this lab has been testing motor vehicle emissions that will be traded in Indonesia nationally. The vehicle was tested using a test cycle and run-on chassis dynamometer. This dynamometer simulated the vehicle's condition as if it were running on the road. The vehicle's loading adjusted to the vehicle or used the table predetermined by the Euro standard in the United Nations Economic Commission for Europe (UN ECE) Regulation no. 101 (R101). The loading parameter of this vehicle is called road load (R/L). R/L is a vehicle speed loading that accommodates the effects of rolling resistance, aerodynamic resistance, acceleration, and road slope level [12]. For test conditions, the slope level of the road can be assumed to be flat or 0. Meanwhile, the other three parameters will affect the load of the driving resistance.

Kuhlwein [13] reported that there was a difference in the value of CO_2 emissions when using different R/L values. There was an increase in CO_2 emissions when using the actual R/L compared to the R/L data used for the approval type test. On average, there was an increase in CO_2 emissions of up to 7.2 % for type tests in Europe and 1.8 % for type tests in the U.S. Jaworski [14] reported that an increase in the energy consumption of the vehicle will increase the CO_2 emission and lower the fuel economy. There was an increase of 35 % in CO_2 emissions with an increase of 32 % in energy consumption.

The purpose of this research is to compare the CO_2 emissions and fuel economy of vehicles in Indonesia using the R/L data provided by vehicle manufacturers and the UN ECE R101 standard. The study aims to determine the impact of vehicle R/L on chassis dynamometer tests. These results can be used as a reference to determine the standard testing procedures that will be applied in the future.

II. Materials and Methods

This study tested the CO_2 emissions of passenger vehicles below 3.5 tons. This test was carried out following the UN ECE R101 test method, in which the vehicle was tested on a chassis dynamometer and driven to follow the new european driving cycle (NEDC) test cycle [15][16]. Figure 1 is an NEDC cycle that depicts the vehicle running in the actual condition of the vehicle while driving. The NEDC cycle has two main parts: Part I urban driving cycle (UDC), or the driving cycle in the city, and Part II Extra urban driving cycle (EUD), or the driving cycle between cities.

Part I in NEDC simulates a car driven in urban locations such as cities. Part I consist of four times UDC. There were three steps of car velocity: low, medium, and high. The maximum velocity of each section was 15 km/h, 30 km/h, and 50 km/h for low, medium, and high, respectively. Part II simulates a car driven at a higher velocity, such as a toll road or intercity highway, with a maximum velocity of 120 km/h. During the test, the chassis dynamometer will be responsible for loading according to the car's condition while on the road. This loading is a trait possessed for each vehicle and will differ in each car. Even in similar models, it will be a difference, even though it is not too much. This loading value is based on the R/L formulation.

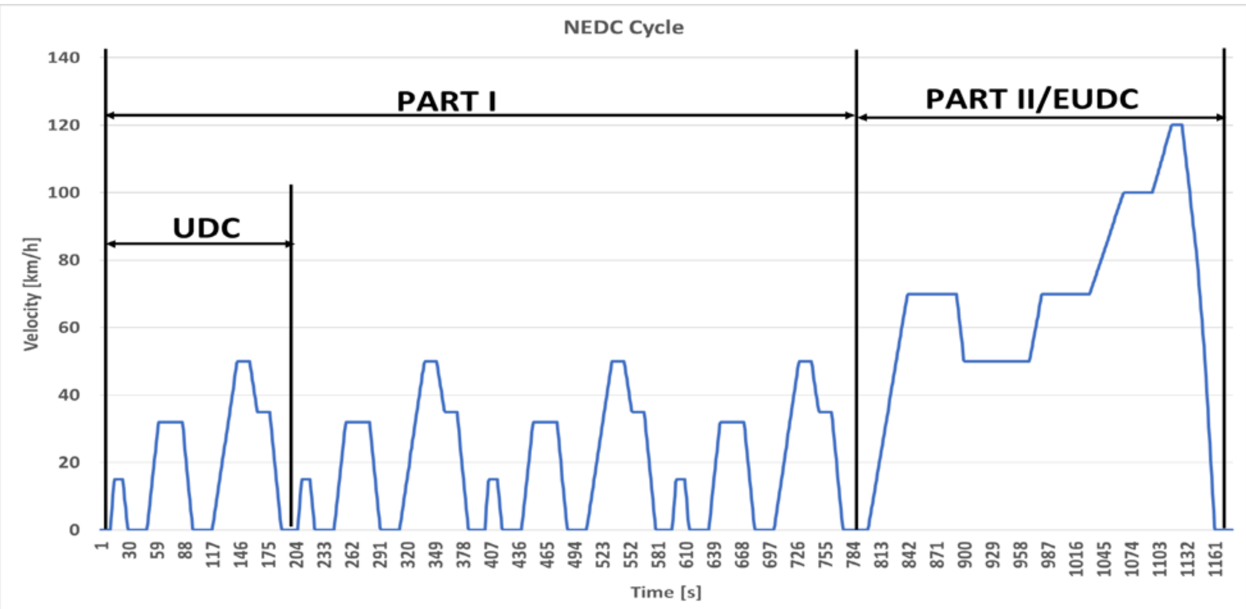


Figure 1. New European driving cycle (NEDC)

Table 1.
R/L reference value based on UN ECE R101 [21]

Car weight [kg]	Inertia [kg]	Standard table		Actual R/L example		
		F0[N]	F2 [N/(km/h)^2]	F0 [N]	F1 [N/(km/h)]	F2 [N/(km/h)^2]
850 – 965	910	5.7	0.0385	96.12	0	0.0400
965 – 1080	1020	6.1	0.0412	156.59	-0.4819	0.0388
1190 – 1305	1250	6.8	0.0460	104.23	0	0.0334
1305 – 1420	1360	7.1	0.0481	145.00	0	0.0470
1420 – 1530	1470	7.4	0.0502	115.10	0.3436	0.0386
1530 – 1640	1590	7.6	0.0515	194.63	-1.0771	0.0485
1640 – 1760	1700	7.9	0.0536	207.56	-1.1337	0.0488

There are two types of chassis dynamometers that can be used for testing: roller and hub type. The main difference between each type is the location of the motor for the dynamometer. The hub type is where the wheel directly connects to the motor without the tires. The roller type uses the tire of the vehicle and the motor connected with the drum roller. The hub type is not included in the current vehicle regulation [17]. By using the chassis dynamometer, we could measure the emission and work generated by the vehicle with an uncertainty factor. Russo *et al.* specified two sources of uncertainty: vehicle experimental setup and experimental equipment. The vehicle experimental setup uncertainties are such as the driver and environmental conditions, and the initial condition of the vehicle. The experimental equipment examples are carry-over conditions, accuracy, and precision of the equipment [18]. Lourenço *et al.* specified that rolling resistance was the most influential factor for fuel consumption measurement [19].

The R/L is the load the vehicle receives when drove on the road [20]. This parameter is formulated in equation (1).

$$F_{total} = F_{rr} + F_{aero} + F_{acc} + F_{grad} \quad (1)$$

where, F_{total} is the total force as resistance in vehicles in N that consist of 4 components; F_{rr} is the resistance of rolling force; F_{aero} is aerodynamic force resistance; F_{acc} is the resistance of acceleration; and F_{grad} is the force from the slope of the road [12]. However, for testing on the chassis dynamometer, the road slope factor can be ignored, so using equation (2)

$$F_{tractive} = F_0 + F_1 \times V + F_2 \times V^2 \quad (2)$$

The R/Ls use three main parameters in the speed function: F_0, F_1, and F_2. F_0 is a coefficient parameter for a wheel rolling resistance, test lines, and drag of braking and bearings in N. F_1 is a coefficient parameter for rolling resistance and pump losses in N/(km/h). F_2 is a coefficient related to the aerodynamic force of the vehicle in N/(km/h)^2. The summation of all component form a tractive force as resistance for the vehicle in N as $F_{tractive}$. V is vehicle speed in (km/h).

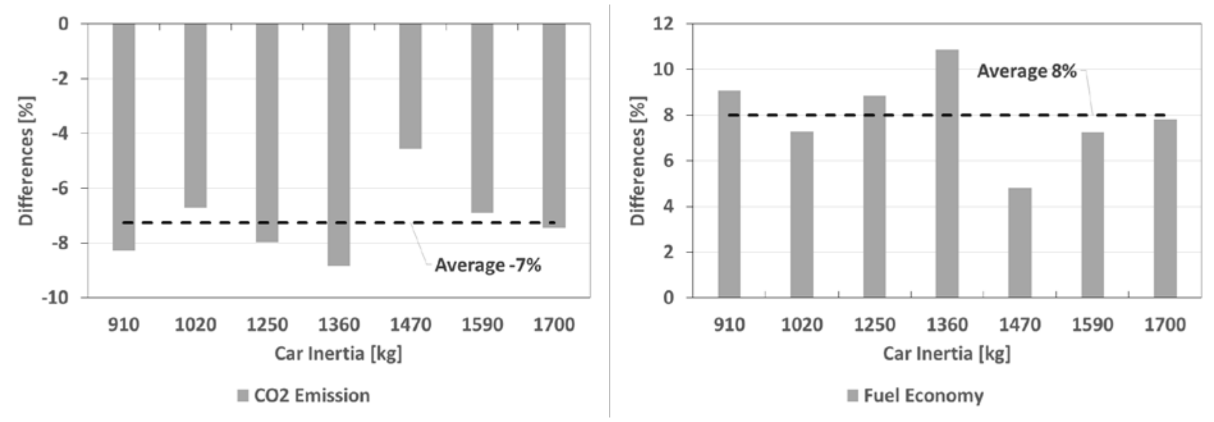
The R/L for each vehicle was obtained by conducting a coast-down test. This test was carried out by driving the vehicle to maximum speed, and then the vehicle slides into the neutral transmission gear position so that gradually the vehicle slows down to a certain speed and then calculates the time needed from high speed to low speed. The test could be performed on tracks, roller chassis, and dynamometers. The speed and time of vehicles were recorded, and the time distance between the speeds was calculated to obtain the coast-down parameter. In addition, the weight of the test vehicle was used for the results of this test [13].

Table 1 shows an example of the R/L chassis dynamometer setting for a car in each inertia. A car was tested twice using different R/Ls, standard table and actual R/L, using R101 to get the emission and fuel economy. All cars were tested in chassis dynamometer at the Laboratory of Thermodynamics, Engine, and Propulsion in Serpong, South Tangerang. The chassis dynamometer provided by AVL can withstand 4x4 or 4x2 cars below 3500 kg. It uses AMA i60 for the gas analyzer and CVS for sampling the exhaust gas. There were 21 sample cars consisting of eight cars belonging to 910 kg inertia, four cars belonging to 1020 kg inertia, one car belonging to 1250 kg inertia, four cars belonging to 1360 kg inertia, two cars belonging to 1470 kg inertia, one car belonging to 1590 kg inertia, and one car belonging to 1700 kg inertia.

The coefficient of R/L will be obtained from the coast-down test. R/L is the vehicle's deceleration force during the coast-down test. R/L is a combination of rolling resistance and aerodynamic force and is calculated at several speeds from the travel time and weight of the vehicle, including rotational inertia sourced from the wheels. This R/L value, when plotted on the graph between time and the traction force, will form a quadratic equation [13].

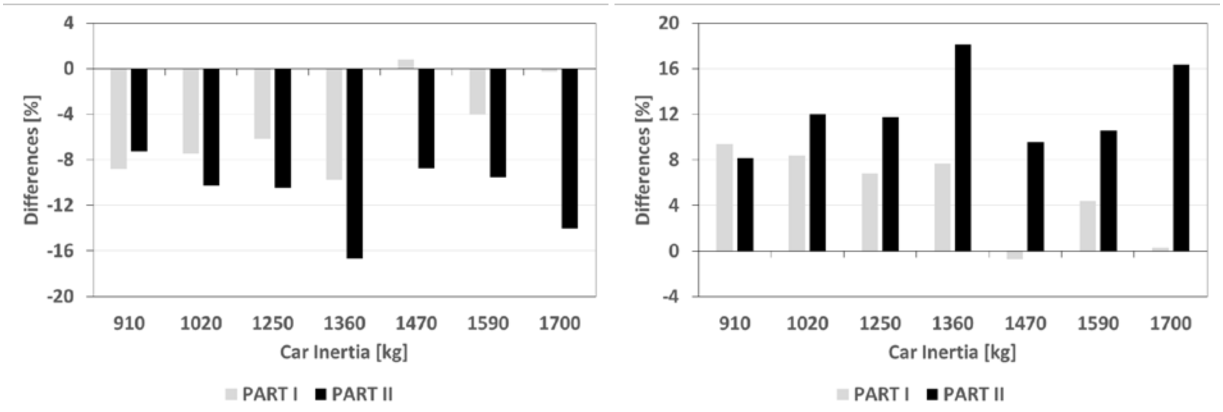
In addition to conducting a coast-down test, the R/L value can be used from the table provided in the UN ECE R101 standard. For each inertial vehicle, there is a coefficient R/L value, which is used as a reference on the dynamometer chassis. This value can be used when there is no data on the coast-down test results. The values in this table do not describe the actual condition of the vehicle when it is driven but can be used as a reference for official testing.

From this R101 test, CO_2 emissions will be obtained produced by vehicles. The amount of CO_2 emissions is used for calculating vehicle fuel



(a) (b)

Figure 2. Differences between the actual to the R/L table in emissions: (a) and fuel economy; (b) for each vehicle



(a) (b)

Figure 3. Differences between the actual to the R/L table in CO_2 emissions: (a) and vehicle fuel economy; (b) in parts I and II

economy during testing by the carbon balance method described in equation (3),

$$FE = \frac{100}{\left(\frac{0.1154}{D}\right)\cdot[(0.866\cdot HC)+(0.429\cdot CO)+(0.273\cdot CO_2)]} \quad (3)$$

where, FE for fuel economy in km/l; D for density of fuel at 15 °C in kg/m3; HC for the measured emission of hydrocarbon in g/km; CO for the measured emission of carbon monoxide in g/km; CO_2 for measured emission of carbon dioxide in g/km [21].

This study conducted a comparative analysis of the carbon dioxide (CO_2) emissions and fuel efficiency of vehicles. To achieve this objective, R/L data obtained from test results were compared with R/L data in the UN ECE R101 standard table. The study identified notable variations in the test results that could be attributed to differences in the loading conditions experienced by the vehicles

III. Results and Discussions

Figure 2 shows the effect of using R/L using the actual to the standard table on CO_2 and fuel economy. Using the actual R/L for each car lowers CO_2 emissions by 5 – 9 % and increases fuel economy between 5 – 11 % for various vehicles. On average from all vehicles, there is a decrease in CO_2 emissions and fuel economy by 7 %, as shown in Figure 2. The highest decrease occurred in cars with inertial 1360 and the lowest decrease occurred in inertial 1470. This emission value is the total emission in the test cycle consisting of 2 parts. Figure 2 also shows the trend of increasing the difference in CO_2 and fuel economy up to car inertia of 1360. The difference decreases in the inertia of 1470 kg, and then the difference increases again at 1700 kg with a slightly smaller difference at 1020 kg. This condition shows that the difference in R/L for large inertia for vehicles in Indonesia has a smaller effect than inertial vehicles of 910 - 1360 kg.

Figure 3 shows the difference in vehicle CO_2 emissions in parts I and II of the NEDC test. In general, the biggest decrease occurred in part II, the Extra urban driving cycle, up to 17 %. While in the part I cycle or UDC, there was the highest decrease up to 10 %. This is due to the difference in the value of the R/L, which is a function of the speed, where in part II, the vehicle velocity is up to 120 km/h with an average speed of around 60 km/h. In part I, the vehicle only travels at a speed of 50 km/h, and the average speed of this cycle is 20 km/h. Figure 3 also shows that urban cycles with low speeds and many accelerations result in a small R/L difference for inertia, especially above 1360 kg. Therefore, the R/L factor for urban conditions can be considered small for inertia above 1360 kg because the cycle is mostly influenced by the kinetic and dynamic friction of the vehicle.

This decrease in CO_2 emissions in vehicles is inseparable from the reduction in energy produced

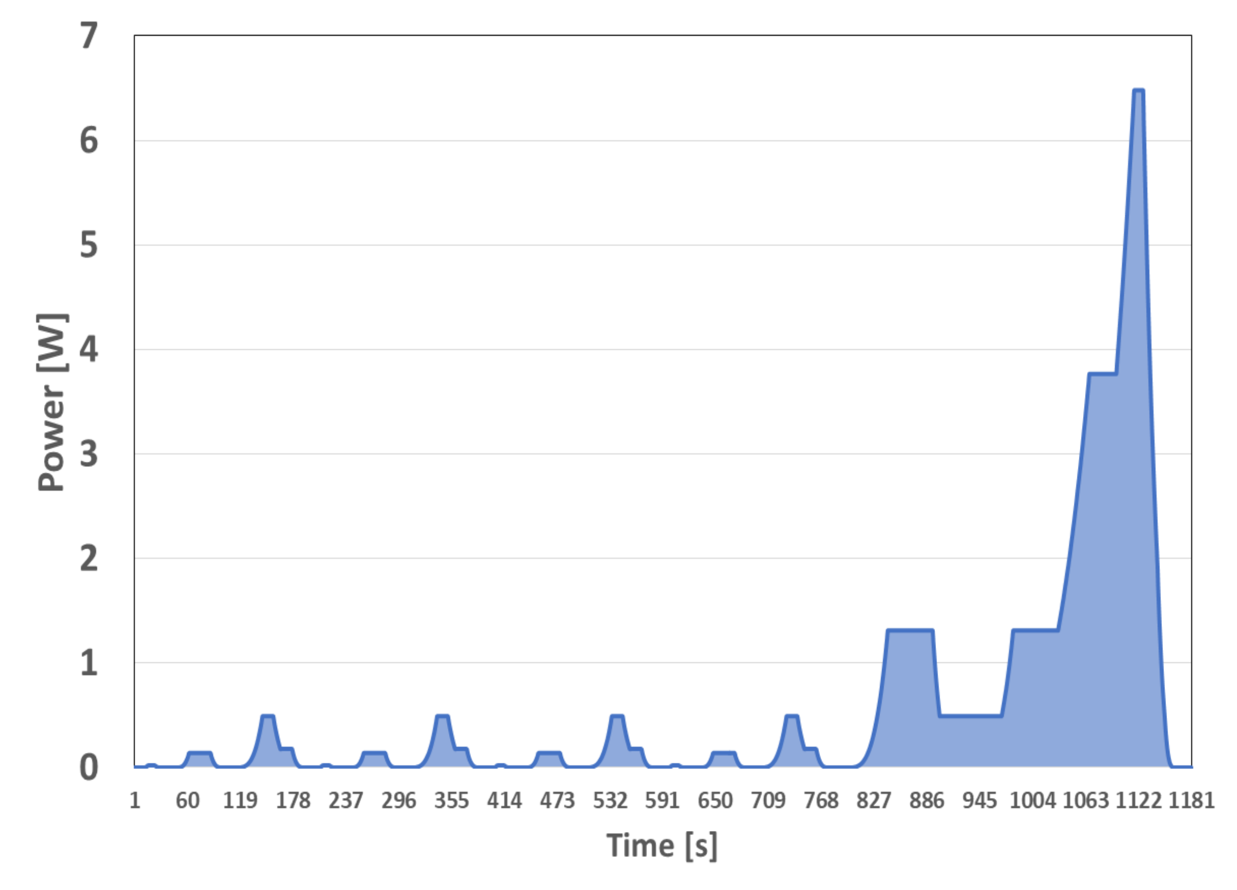


Figure 4. Work generated by the vehicle using R/L calculations

during testing. The energy calculation uses equation (4),

$$P = F \cdot V \quad (4)$$

where, P is the power generated by the vehicle in W, F is the traction force of the R/L in N, and V is vehicle speed in m/s. F is the result of calculating the R/L for each vehicle, either using values from the table or the actual data of the vehicle. The result of this power calculation is made in a graph between power and time that shows the power that must be generated by the vehicle during the test at a certain speed, as shown in Figure 4.

In Figure 4, the area under the power curve over time represents the amount of work generated by the vehicle during the test. The R/L data listed on the test standard is the worst possible condition for a vehicle for each inertia. So, the value of the R/L does not represent the vehicle's actual condition. For this reason, each manufacturer conducts coast-down testing in advance so that the vehicle can operate on a dynamometer chassis.

Figure 5 shows the difference in energy generated by the vehicle during the test. In general, there is a decrease in the power generated by the vehicle during continuous testing. On average, there is a decrease in the power of up to 17 %, leading to a reduction in CO_2 emissions from these vehicles. In some vehicles using actual coast-down data, it increases the power generated by the vehicle, especially in part I in the NEDC testing stage, while in phase II, most of the power decreased by the vehicle. Compared to the power generated by the vehicle, it will be more in part II. This causes part II to have more influence on the emissions of the test results so that if there is a decrease in emissions in part II, it will reduce emissions in total.

The amount of energy produced by the vehicle will have a direct impact on the fuel economy of the vehicle. Using the actual R/L, the power generated by the vehicle is not as large as when using the R/L from the standard table. The real condition of this vehicle will be able to be used by the actual data because it is a condition where the vehicle typically operates on the road.

There was an increase in energy delivered from cars when using actual R/L than the official one. The energy increased by 15 % and 4.2 % in Europe and the U.S., respectively. Due to the increase in energy delivered from the engine, there was an increase in

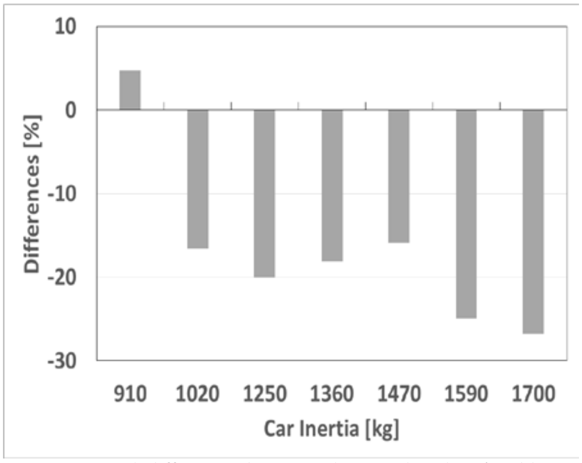


Figure 5. Work differences between the actual to the R/L table

CO_2 emission of about 7 % and 1.8 % for Europe and the U.S., respectively [13]. In Indonesia, there was a decrease in energy produced by vehicles and CO_2 emissions of about 17 % and 7.3 %, respectively. The differences in these results are due to the differences in R/L. Kuhlwein [13] used official R/L provided by the manufacturer for emission testing and realistic R/L. However, this study used actual R/L from the manufacturer and a standard table from UN ECE R101.

Jaworski *et al.* [14] experimented emission test using R101 with three different R/L, NEDC table, resistance calculation, and worldwide harmonized light vehicle test procedure (WLTP) alternative. There was an increase in CO_2 emission and energy generated by the vehicle using the NEDC table and WLTP alternative. There was a 35 % CO_2 emission increase from a 31 % increase in energy consumption. This condition is in line with our study that the higher energy generated by the vehicle will increase the emission of CO_2.

IV. Conclusion

Based on this study, it was found that the use of different R/L resulted in a different CO_2 emission under the R101 method. R/L represents the vehicle's condition when driven on the road, simulated by a dynamometer chassis system. The closer to the real conditions, the more vehicle will operate in actual condition. From the difference in the use of R/L, it was found that using actual R/L for R101 testing would reduce CO_2 emissions by an average of 7.3 %. In line with CO_2 emissions, fuel use will be more efficient, with an average of 7.9 %. The decrease in emissions may be due to a reduction in the energy produced by the vehicle when using actual R/L compared to using R/L from the table. The average energy decrease during the test was around 17 %, with the highest energy decrease in vehicles with an inertia of 1700 kg, which decreased to 27 %. The highest reduction in CO_2 emissions occurred in vehicles with an inertia of 1360 kg. Based on this study, it is recommended to utilize the parameters specified in the Euro standard R/L table for conducting the testing. This suggestion is grounded on the fact that employing these standard parameters represents the most unfavorable conditions that a vehicle may experience while being driven on the road.

Acknowledgements

I wish to thank the laboratory for thermodynamics engine and propulsion technology team for their help in conducting tests and collecting all test data.

Declarations

Author contribution

KFAS is a main contributor who submits ideas, writes, and performs data analysis. HP checked the final review and supervised the experiment. YAE review final article. DI, MAW, and IYI contribute to carrying out tests and processing test data.

Funding statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Additional information

Reprints and permission: information is available at https://mev.lipi.go.id/.

Publisher's Note: National Research and Innovation Agency (BRIN) remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

References

[1] A. Rehman, H. Ma, M. Ahmad, M. Irfan, O. Traore, and A. A. Chandio, "Towards environmental sustainability: Devolving the influence of carbon dioxide emission to population growth, climate change, forestry, livestock and crops production in Pakistan," *Ecol. Indic.*, vol. 125, p. 107460, 2021.

[2] K. Sohag, R. A. Begum, S. M. Syed Abdullah, and M. Jaafar, "Dynamics of energy use, technological innovation, economic growth and trade openness in Malaysia," *Energy*, vol. 90, pp. 1497–1507, 2015.

[3] E. G. Sari and M. Sofwan, "Carbon dioxide (CO_2) emissions due to motor vehicle movements in Pekanbaru city, Indonesia," *J. Geosci. Eng. Environ. Technol.*, vol. 6, no. 4, pp. 234–242, Dec. 2021.

[4] P. Siskos and Y. Moysoglou, "Assessing the impacts of setting CO_2 emission targets on truck manufacturers: A model implementation and application for the EU," *Transp. Res. Part A Policy Pract.*, vol. 125, no. February 2019, pp. 123–138, 2019.

[5] L. Yang, Y. Wang, S. Han, and Y. Liu, "Urban transport carbon dioxide (CO_2) emissions by commuters in rapidly developing cities: The comparative study of Beijing and Xi'an in China," *Transp. Res. Part D Transp. Environ.*, vol. 68, pp. 65–83, 2019,

[6] S. M. Labib, M. N. Neema, Z. Rahaman, S. H. Patwary, and S. H. Shakil, "Carbon dioxide emission and bio-capacity indexing for transportation activities: A methodological development in determining the sustainability of vehicular transportation systems," *J. Environ. Manage.*, vol. 223, no. May, pp. 57–73, 2018,

[7] Presiden Republik Indonesia, Peraturan Pemerintah Republik Indonesia nomor 73 tahun 2019 tentang Barang Kena Pajak yang Tergolong Mewah Berupa Kendaraan Bermotor yang Dikenai Pajak Penjualan Atas Barang Mewah, no. Kementrian Sekretariat Negara Republik Indonesia. Indonesia, 2019, pp. 1-35.

[8] Presiden Republik Indonesia, Peraturan Pemerintah Republik Indonesia Nomor 74 Tahun 2021 tentang Perubahan Atas Peraturan Pemerintah Nomor 73 Tahun 2019 tentang Barang Kena Pajak yang Tergolong Mewah berupa Kendaraan Bermotor yang Dikenai Pajak Penjualan atas Barang Mewah, no. Kementrian Sekretariat Negara Republik Indonesia. Indonesia, 2021, p. 12.

[9] P. C. Mishra, R. B. Ishaq, and F. Khoshnaw, "Mitigation strategy of carbon dioxide emissions through multiple muffler design exchange and gasoline-methanol blend replacement," *J. Clean. Prod.*, vol. 286, p. 125460, 2021,

[10] X. Zhang, G. Zhang, C. Song, and X. Guo, "Catalytic conversion of carbon dioxide to methanol: Current status and future perspective," *Front. Energy Res.*, vol. 8, no. February, pp. 1–16, Feb. 2021.

[11] J. Zheng, X. Sun, L. Jia, and Y. Zhou, "Electric passenger vehicles sales and carbon dioxide emission reduction potential in China's leading markets," *J. Clean. Prod.*, vol. 243, p. 118607, 2020.

[12] J. Son, J. Ko, K. Kim, C.-L. L. Myung, S. Park, and C. Kim, "Correlation analysis of road load fuel economy variations by energy difference for gasoline direct injection and diesel-

powered vehicles," *Proc. Inst. Mech. Eng. Part D J. Automob. Eng.*, vol. 234, no. 2–3, pp. 897–911, Feb. 2020.
[13] J. Kühlwein, "The impact of official versus real-world road load on CO_2 emissions and fuel consumption of european passenger cars," Berlin, 2016. [Online].
[14] A. Jaworski *et al.*, "Evaluation of the effect of chassis dynamometer load setting on CO_2 emissions and energy demand of a full hybrid vehicle," *Energies*, vol. 15, no. 1, 2022,
[15] "Regulation No. 83 of the economic commission for europe of the United Nations (UN/ECE) – uniform provisions concerning the approval of vehicles with regard to the emission of pollutants according to engine fuel requirements." pp. 223–495, 2006. [Online].
[16] Z. Yang, B. Deng, M. Deng, and S. Huang, "An overview of chassis dynamometer in the testing of vehicle emission," *MATEC Web Conf.*, vol. 175, pp. 2–5, 2018.
[17] b. giechaskiel, f. forloni, m. otura, c. engström, and p. öberg, "experimental comparison of hub and roller‑type chassis dynamometers for vehicle exhaust emissions," *Energies*, vol. 15, no. 7, pp. 1–15, 2022.
[18] M. Di Russo, K. Stutenberg, and C. M. Hall, "Analysis of uncertainty impacts on emissions and fuel economy evaluation for chassis dynamometer testing," *IEEE Trans. Veh. Technol.*, vol. 72, no. 4, pp. 4236–4251, 2022.
[19] M. A. de M. Lourenço, J. J. Eckert, F. L. Silva, M. H. R. Miranda, and L. C. de A. e. Silva, "Uncertainty analysis of vehicle fuel consumption in twin-roller chassis dynamometer experiments and simulation models," *Mech. Mach. Theory*, vol. 180, no. June 2022, p. 105126, 2023.
[20] G. Kadijk and N. Ligterink, "Road load determination of passenger cars," 2012. [Online].
[21] "Regulation No 101 of the economic commission for Europe of the United Nations (UN/ECE) — uniform provisions concerning the approval of passenger cars equipped with an internal combustion engine with regard to the measurement of the emission of carbon diox." pp. 89–139, 2004. [Online].