EnvironmentAsia
The international journal by the Thai Society of Higher Education Institutes on Environment

EnvironmentAsia 17(3) 2024 141-150
DOI 10.14456/ea.2024.42
ISSN 1906-1714; ONLINE ISSN: 2586-8861

Emission Factor Development for Road Transportation Sector in Malaysia

Wan Nur Syuhada Wan Ata*, Alexandra Quek, Ahmad Rosly Abbas, Mohamad Fetri Zainal, Nur Zaqira Izzati Sukhairul Zaman, Md Fauzan Kamal Mohd Yapandi, and Zul Fadli Ibrahim

Built Environmental and Climate Change Unit, Generation and Environment Department, TNB Research Sdn. Bhd, Selangor, Malaysia

*Corresponding author: nursyuhada.ata@tnb.com.my
Received: October 12, 2023; Revised: December 5, 2023, Accepted: May 29, 2024

Abstract

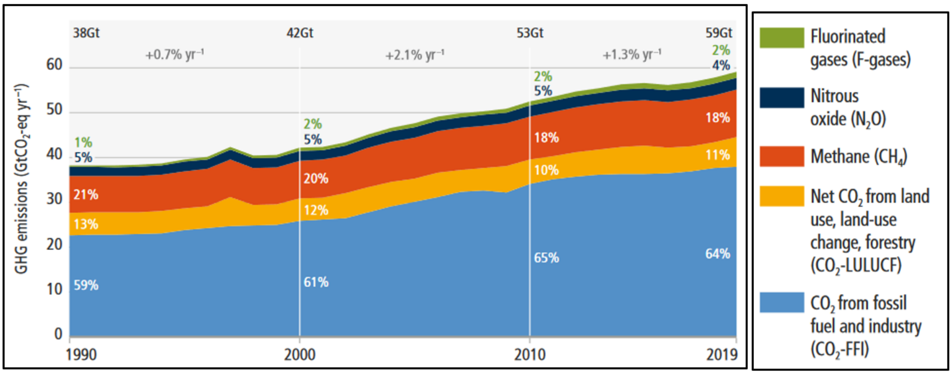
The transportation sector plays a vital role in the economy, contributing significantly to the country's socio-economic development. Indeed, conflicts often arise when attempting to balance mobility desire by society with the needs to improve the environmental quality. While the transportation sector is crucial for meeting the demand for mobility, it also has a significant impact on the environment. Malaysia in their recent submission of Fourth Biennial Update Report to the United Nations Framework Convention on Climate Change (UNFCCC) has reported that the energy sector's greenhouse gas (GHG) emissions increased by 27.95% in 2019 compared to the 2005 base year emissions with an important indicator that road transportation is the second sector of the vital source categories of GHG emissions among other sectors. From this perspective, continuous efforts should be made to improve the estimation of GHG emissions in the road transport sector by applying a country-specific emission factor. However, to date, there is limited study focusing on the emission factor development for road transportation sector in Malaysia. Therefore, this study presents the approach used to develop the emission factor with a specific focus on analyzing the carbon content and calorific factor of fuel. The novelty of this study lies in the utilization of the actual fuel composition commonly used in Malaysia. As a result of this study, emission factors have been established for petrol, conventional diesel and compressed natural gas (CNG) with the value of 70,408.84 kg CO_2/TJ, 73,715.19 kg CO_2/TJ and 55,835 kg CO_2/TJ, respectively. This study is expected to strengthen the GHG inventory reporting for Malaysia through a more accurate methodological shift for energy sector and contribute to more effective policymaking in addressing climate change and promoting sustainable development.

Keywords: Greenhouse gas; Transportation; Liquid Fuel; Compressed Natural Gas; Emission Factor; Country-specific

1. Introduction

Climate change refers to the changes in temperatures and weather patterns across a longer time. It is believed that the changes were attributed to the increasing amount of greenhouse gases (GHG) in the atmosphere due to the anthropogenic or human activities including combustion of fossil fuels, industrial activities, transportation industry and deforestation.

The global net anthropogenic emissions have continued to rise across all major groups of greenhouse gases from 1990 until 2019. The increasing trend in GHG emissions is supported by reports and assessment by The Intergovernmental Panel on Climate Change (IPCC) as illustrated in the Figure 1.



Source: Climate Change 2022: Mitigation of Climate Change, IPCC Sixth Assessment Report

Figure 1. Global net anthropogenic GHG emissions 1990 – 2019

Apart from this, a report by International Energy Association (IEA) revealed that power generation and transport sector has accounted for over two thirds of the total global emissions in 2019 and have been responsible for almost all global growth since 2010. Whereas, the remaining was mainly contributed by the industry and buildings sectors.

It is well known that the transport industry is a significant economic sector, in which the country's socioeconomic growth has greatly benefited from the sector's rapid development (Aziz *et al.,* 2012). However, there are still conflicts arising to balance the needs for society's mobility with conserving the environment (Rawshan *et al.,* 2015; Hasan *et al.,* 2019). Apart from this, the worldwide transportation industry contributes 23% of all CO_2 emissions, and its growth rate is greater than that of any other energy-related industry (IEA, 2012) and a recent study revealed that transportation sector would soon be the most significant contributor to environmental problems (Unger *et al.,* 2010). In addition to this, Masjuki *et al.* (2004) in their research work revealed that road transport is the biggest mode of transportation system which involve about 85.71% of total passengers with higher fuel consumption and emissions per kilometre travelled (Soylu, 2007). This is also supported by Giannakis *et al.* (2020) in his study, stated that the land transportation sector is also one of the leading emitters of CO_2. Thus, road transport is essential to become a top priority sector to achieve the targets for CO_2 emissions reduction as it contributed to major source of pollutants and GHG emissions such as carbon dioxide (CO_2), nitrogen oxides (NOx), carbon monoxide (CO), and particulate matter (Van Fan *et al.,* 2018). These gases may possess threats to the air quality and contributes to global warming phenomena (Saija *et al.,* 2002).

Malaysia as one of the developing countries has shown tremendous effort towards climate action through submission of National Communication and Biennial Update Report to the United Nations Framework Convention on Climate Change (UNFCCC). According to Malaysia's Forth Biennial Update Report published in 2022, the energy sector's greenhouse gas (GHG) emissions increased by 27.95% in 2019 compared to the 2005 base year emissions. This report presented road transportation as the second sector of the vital source categories of GHG emissions among other sectors, as per in key category analysis in Figure 2.

From this perspective, continuous effort should be made to improve the estimation of GHG emissions in the transport sector by applying a country-specific emission factor. In this case, the national emission factor being developed from this study will help in accurate quantification of the amount of pollutants and greenhouse gases released into the atmosphere from vehicles. It will also enable the tracking and monitoring of progress towards reduction in the emission from road transportation sector. Utilization of accurate emission factors will enable the policymakers and stakeholders to assess the current level of emissions from the road transportation sector and setting the realistic reduction targets. These targets can be used to guide the implementation of various measures and initiatives aimed at reducing emissions, such as promoting the use of electric vehicles, improving fuel efficiency, and implementing sustainable transportation policies.

Although the default values are provided by the 2006 IPCC Guidelines for National Gas Inventory, it is recommended to apply country-specific emission factors when estimating national greenhouse gas emissions (IPCC, 2006). Furthermore, the IPCC guidelines are based on the vehicle fleets in Europe and the USA and that they reflect the vehicle types, emission controls and legislation, driving patterns, fuel types and quality in Europe and the USA. Moreover, the emission models proposed in the IPCC guidelines are indeed based on the available statistical data. It is important to note that different countries may have different statistical data available, which may require adjustments to fit with the emission factor information. These adjustments are necessary to ensure accurate and reliable emission estimations for each specific country or region (IPCC, 2000)

Apart from that, an article explores the techniques employed to assess road vehicle emissions in relation to the development of emission factors utilized in emission inventories where it covers various measurement techniques commonly used for collecting road vehicle emissions data, including chassis and engine dynamometer measurements, remote sensing, road tunnel studies, and portable emission measurement systems (PEMS). This study showed that emission factor could be derived from the test data while distinguishing between data obtained under controlled conditions (such as engine and chassis dynamometer measurements using standard driving cycles) and measurements conducted during a real-world operation (Franco *et al.*, 2013). The development of emission factor using chassis dynamometer testing under controlled condition is found to be the most reliable method for measuring the vehicle emissions, primarily due to its high level of standardization. The robustness of the emission factor could be increased by evaluating numerous vehicles under different driving cycles and plotting the combined results of various driving cycles for a specific parameter, such as mean speed or aggregated kinematic parameters like mean acceleration or relative positive acceleration. A polynomial trend line is then fitted to the experimental data using mathematical regression where the resulting formula of the trend line represents the emission factor, expressing vehicle emissions as a function of the selected parameter. Other than this, emission factors are also developed under the real-world conditions by using remote sensing measurements to determine the ratios of pollutant and carbon-containing species concentrations in vehicles. These measurements are then compared to the amount of fuel consumed and utilizing specific equation to obtain the emission factor.

However, to date, there is no specific study conducted on the development of emission factor for road transportation in Malaysia to improve the accuracy and completeness of the national GHG inventory. Thus, this study is aimed to develop emission factors for road transport specifically for liquid fuel and CNG which is expected to serve as indicators of promising strategies to mitigate GHG emissions in the road transportation sector.

2. Methodology

The methodology approach for assessing the CO_2 emission factor involves analysis of fuel based on the standard test method to analyse the composition of hydrocarbons, carbon, hydrogen, nitrogen, oxygen, sulphur. Apart from that, the heat value and density of fuels are also determined based in the specific standard method. This is to ensure that the developed emission factor represents the actual fuel composition being used in Malaysia.

Sector	IPCC Category Code	IPCC Category Name	Greenhouse Gas	2019 Year Estimate (Gg CO_2 Eq)	Level Assessment (%)	Cumulative (%)
Energy	1.A.1.a	Main Activity Electricity and Heat Production – Solid Fuels	CO_2	73,653.01	22.29%	22.29%
Energy	1.A.3.b	Road Transportation – Liquid Fuels	CO_2	53,995.92	16.34%	38.64%
Energy	1.A.1.a	Main Activity Electricity and Heat Production – Gaseous Fuels	CO_2	33,811.76	10.23%	48.87%
Energy	1.A.2	Manufacturing Industries and Construction – Gaseous Fuels	CO_2	18,087.71	5.48%	54.35%
Waste	4.D.2	Industrial Wastewater Treatment and Discharge	CH_4	14,462.46	4.38%	58.73%
Energy	1.A.1.c	Manufacturing of Solid Fuels and Other Energy Industries – Gaseous Fuels	CO_2	13,724.22	4.15%	62.88%
Waste	4.A	Solid Waste Disposal	CH_4	11,681.20	3.54%	66.42%
Energy	1.B.2.a	Oil	CH_4	10,750.91	3.25%	69.67%
IPPU	2.A.1	Cement Production	CO_2	9,120.65	2.76%	72.43%
Energy	1.A.2	Manufacturing Industries and Construction – Liquid Fuels	CO_2	8,535.30	2.58%	75.02%
Energy	1.A.1.b	Petroleum Refining – Liquid Fuels	CO_2	8,200.82	2.48%	77.50%

Source: Malaysia Forth Biennial Update Report to UNFCCC, 2022

Figure 2. Key category analysis of greenhouse gas emissions for 2019, without land use, land-use change and forestry emission

Table 1. Test methods used for the fuel analyses.

No.	Parameter	Test Method
1	Hydrocarbon (C4-C20)	GC-FID
2	Carbon. Hydrogen, Nitrogen	ASTM D5291
3	Oxygen (O_2)	ASTM D5291
4	Sulphur	ASTM D2622
5	Gross Heating Value (GHV), Lower Heating Value (LHV), Higher Heating Value (HHV)	ASTM D240
6	Density	ASTM D4052

The result from fuel analysis will provide a better and accurate value for development of the emission factor. As part of the data validation, the final value will be compared against the default value published in 2006 IPCC Guidelines for GHG Inventory. It is best to emphasise that the local or national data provides more accuracy to the assessment since the default emission factors are overestimated for conservatism. The Principles of Carbon Accounting outlined in the GHG specified that overestimation or underestimation of emissions shall be avoided where realistically practicable.

According to the 2006 IPCC Guidelines, derivation of emission factor for road transport should be based on the carbon composition of the fuel with assumption of 100 percent oxidation of fuel if there is no further data available. It is also good practice to use net calorific value (NCV) and CO_2 emission factor representing the country's actual data if possible. Hence, it is important to note that the analysis involved in this project will focusing on the carbon content and NCV of the fuel.

The reliability and appropriateness of the methodology used for data collection are essential in developing the emission factor. In the context of CO_2 emissions, there are two approaches which are commonly used known as Tier 1 and Tier 2. The Tier 1 approach involves multiplying the estimated fuel sold with a default CO_2 emission factor to estimate CO_2 emissions as mentioned in Equation below. This approach provides a simplified estimation based on general assumptions. In contrast, the Tier 2 approach utilizes country-specific carbon contents of the fuel sold in the road transport sector as the primary activity data. This approach takes account the specific characteristics of the fuel used in a particular country, resulting in more accurate estimations. Both approaches are represented in equation below, serves as a framework for estimating CO_2 emissions in the road transport sector.

$$Emission = \sum_{a} (Fuel_a \ x \ EF_a)$$

Where:

Emission = Emissions of CO_2 (kg)

$Fuel_a$ = Fuel sold (TJ)

EF_a = Emission factor (kg/TJ). This is equal to the carbon content of fuel multiplied by 44/12

a = Type of fuel (e.g., petrol, diesel, natural gas, LPG, etc.)

In this study, the CO_2 emission factors are determined based on the carbon content of the fuel and complete oxidation of the carbon during combustion is assumed, unless specific information on oxidation factors is available. Hence, as being mentioned before, this study prioritizes on the analysis of carbon content and net calorific values (NCV) with specific local fuel quality and composition. This approach ensures that the CO_2 emission factors used in the study accurately reflect the characteristics of the fuels used in Malaysia while considering variations in carbon content and energy content.

2.1 *CO_2 Emission Factor for Liquid Fuel*

Specific emission factor is determined by analysing data on the carbon content and calorific value of the fuels used. This approach allows for a more precise estimation of CO_2 emissions in the context of road transportation. In this case, the CO_2 emission factor (CO_2/TJ) for liquid fuel which covers petrol and conventional diesel are derived based on the equation below:

$$EF_{i,CO2} \quad : \frac{Ci}{100} \times \frac{Di}{ECi} \times \frac{44}{12}$$

Where:

$EF_{i,CO2}$: CO_2 emission factor for fuel (i) (kg-CO_2/ GJ-fuel)

C_i : Carbon content in fuel (i) (%)

D_i : Density of fuel (i) (kg-fuel/ kℓ- fuel)

E_{ci} : Calorific factor of fuel (i) (Net calorific value of fuel, GJ/ kℓ- fuel)

2.2 *CO_2 Emission Factor for CNG*

In the case of gaseous fuels, the molecular masses, densities, and amount of carbon related to mass, or the gas volume were calculated while considering only the combustible components that contain carbon. Similarly, the same assumption of complete oxidation of fuel during combustion is used.

The equation adopted from the Korean National GHG Emission and Absorption Factor Development and Verification 1st Plan Report (2014) below was used to derive the emission factor for gaseous fuel.

$$EF_{co2} = \sum \frac{\left[\left(\frac{\frac{mol_y\%}{V}}{\sum \frac{mol_y\% \ x \ mw_y}{V}} \right) x \ (44.010 \ x \ N_y \ x \ f_i) \right]}{EC_i \ x \ D_i}$$

Where,

EFi, CO_2 : CO_2 emission factor for fuel type i, (kgCO_2/GJ-fuel);

EC_i : calorific factor of fuel type i (net fuel calorific value), (GJ/1000m^3-fuel);

D_i : density of fuel type i, (kg/1000 m^3-fuel);

moly% : composition of gas component y in 1 mol fuel type i, (%);

mw_y : molecular weight of gas component y of the fuel i, (kg/k-mol);

V : volume of 1 kmol of fuel type i under standard configuration (usually 22.4 m^3), (m^3);

N_y : number of carbon atoms in the gas component y of fuel type i;

f_i : oxidation factor in fuel type i

3. Results and Discussion

3.1 Analysis of CO_2 emission factor for petrol

In this study, analysis has been conducted on petrol type RON 95 and RON 97 used in road transportation sector in Malaysia. Table 2 and Table 3 showed the fuel properties of RON 95 and RON 97 respectively. For simplicity, the fuel samples are represented by alphabet where the same alphabet for RON95 and RON97 represents the same fuel supplier's company in Malaysia.

The emission factor for each sample of RON95 and RON97 were developed by incorporating the fuel properties data into the formula presented earlier. Figure 3 showed the emission factor for each sample representing RON 95 and RON 97 respectively.

Table 2. Fuel properties of the RON 95 sample

Sample	Carbon Content (wt%)	Oxidation Factor	Density [kg/m^3]	NHV [MJ/kg]
A	83.9	1.0	762.0	43.96
B	84.3	1.0	751.6	44.06
C	84.2	1.0	756.1	44.00
D	84.8	1.0	758.6	44.01
E	84.5	1.0	752.4	43.99

Table 3. Fuel properties of the RON 97 sample

Sample	Carbon Content (wt%)	Oxidation Factor	Density [kg/m^3]	NHV [MJ/kg]
A	84.40	1.0	769.10	44.00
B	83.70	1.0	756.60	43.99
C	84.80	1.0	767.70	43.96
D	85.70	1.0	756.94	44.06
E	84.40	1.0	754.36	43.97

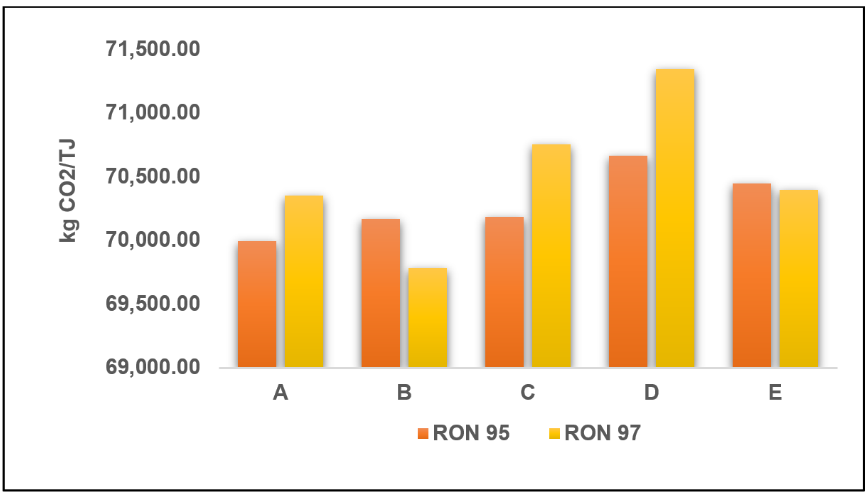


Figure 3. Calculated emission factor for RON 95 and RON 97

It is observed that the sample D for both RON 95 and RON 97 exhibited the highest emission factor due to the fact that it contains the highest carbon content among the other samples. It is worth to note that the amount of carbon content in fuel played significant role in development of emission factor in which higher carbon content will result in higher emission factor (Papailias and Mavroidis, 2018).

The emission factors for both types of petrol were averaged which resulted in 70,408.84 kg CO_2/TJ to serve for the main objective of developing the national emission factor for petrol in Malaysia. This value was 1.60% higher than the default values published by IPCC (69,300 kg CO_2/TJ). The higher value for the calculated emission factor is due to higher amount of carbon in the fuel being analysed as the carbon dioxide emission is directly related to the carbon content of fuel. Furthermore, it is worth to note that the higher emission factor will contributes to the higher emission. However, this discrepancy is acceptable as the calculated value has a quite small difference from the default value in which it represents actual data appropriate to local fuel quality and composition. Absolutely, comparing the calculated emission factor with the default value provided by IPCC is crucial. This comparison allows us to assess the accuracy and reliability of the calculated emission factor and ensure that it is adhered to established standards in the field.

3.2 Analysis of CO_2 emission factor for conventional diesel

Similarly, in the case of conventional diesel, analysis have been conducted on a few samples received from the main fuel supplier in Malaysia. As per the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 2: Energy, the quantification of emission factor for diesel fuel is differentiated between conventional diesel and biodiesel respectively in which for biodiesel, it should only account for bio parts of the fuel. Hence, this study is focusing on developing the emission factor for conventional diesel which the fuel properties are presented in Table 4.

Table 4. Fuel properties of diesel samples

Sample	Type	Carbon Content (wt%)	Oxidation Factor	Density [kg/m^3]	NHV [MJ/kg]
A	B0	86.5	1.0000	841.4	42.7740
B	B0	86.5	1.0000	840.8	42.7820
C	B0	85.5	1.0000	834.0	42.880
D	B0	86.0	1.0000	829.7	42.945
E	B0	86.0	1.0000	831.5	42.870
F	B0	86.4	1.0000	832.9	42.9200

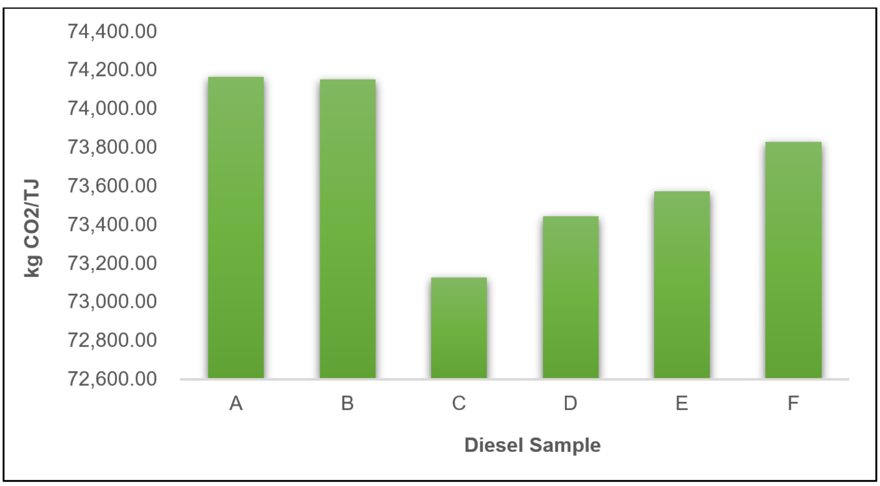


Figure 4. Emission factor for conventional diesel

The emission factor for conventional diesel was calculated for each sample and presented in Figure 4 above. The calculated emission factors were averaged which resulted in 73,715.19 kg CO_2/TJ. There is a slightly small difference by 0.52% between the calculated EF with the default value published by the IPCC (74,100 kg CO_2/TJ). Based on the analysed results of the conventional diesel samples, it showed that the carbon content of diesel falls within the standard range of 86 weight percent, as specified for diesel properties whereas it is proven that the content of carbon played significant role for the emission factor as can be seen in Figure 4, the sample with higher carbon content exhibits higher emission factor. However, similarly with the previous case, the variance is considered acceptable as it was within the lower and upper range of the default value published by IPCC. In the case of developing the national emission factor, it is crucial to understand that the calculated value is derived from actual data that reflects the local fuel quality and composition. This localized approach provides a more accurate representation of the emissions associated with the conventional diesel usage in a specific context.

3.3 Analysis of emission gactor for CNG

For the case of CNG, 3 different samples (A, B, and C) were used to develop the CO_2 emission factor of CNG for road transport in Malaysia. The samples were originated from the northern, southern, and central regions of Malaysia. Table 5 and 6 showed the carbon content and fuel properties of the 3 samples, respectively.

By incorporating the fuel analysis data into the previous equation for gaseous fuel, the emission factors for the CNG were developed. Figure 5 displays the emission factors for the 3 samples calculated in kgCO_2/TJ. As the main objective of this study is to develop the national emission factor of CNG in Malaysia, the emission factors of the 3 samples were averaged to obtain a value of 55,835.41 kgCO_2/TJ as the representative national emission factor of CNG used in road transportation sector (Figure 5). Carbon content is an important determinant of CO_2 emissions. Natural gas which primarily consists of methane has lower carbon content and emit lesser CO_2 emissions relative to its energy content when compared to conventional petrol or diesel.

Table 5. Carbon content of compressed natural gas samples

Samples	C_1 (%)	C_2 (%)	C_3 (%)	iC_4 (%)	nC_4 (%)	iC_5 (%)	nC_5 (%)	C_6+ (%)	C_7 (%)	C_8 (%)	CO_2 (%)	N_2 (%)
A	93.69	2.629	0.519	0.131	0.104	0.039	0.024	0.027	0.00	0.00	1.93	0.91
B	84.778	4.630	1.479	0.121	0.084	0.078	0.038	0.032	0.00	0.00	7.03	1.73
C	93.731	2.690	0.602	0.149	0.131	0.039	0.023	0.025	0.00	0.00	1.80	0.81

Table 6. Fuel properties of compressed natural gas samples

Samples	Oxidation Factor	Gross Heating Value (MJ/kg)	Net Heating Value (MJ/kg)
A	1.0000	51.4033	46.3093
B	1.0000	49.9554	45.0049
C	1.0000	51.6545	46.5356
Average	1.0000 ± 0.00	51.0044 ± 0.75	45.9499 ± 0.67

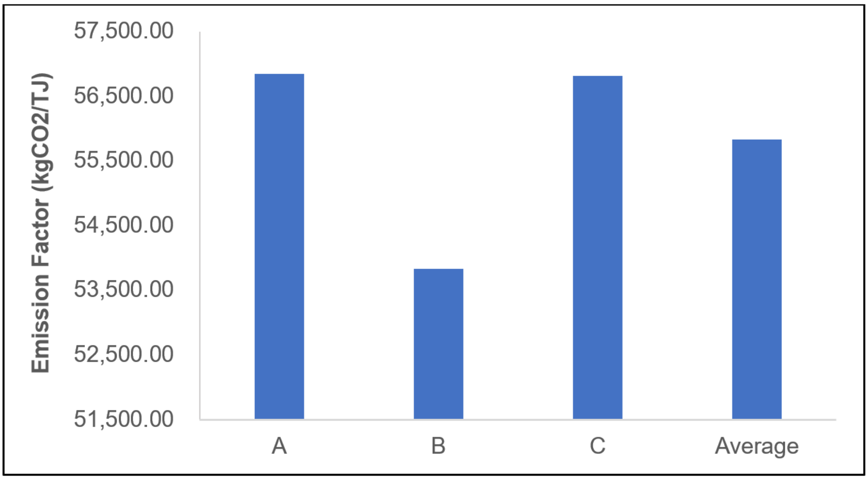


Figure 5. Emission factors for samples A, B, and C, and average emission factors

The final emission factor is compared against the default value published in the 2006 IPCC Guidelines for the GHG Inventory which showed a slight difference of 0.47%. Similarly, deviations were also found between other country-specific emission factors compared to the IPCC default emission factor for natural gas. According to the 2006 IPCC guidelines, the discrepancies between country-specific emission factors and the default emission factor are mainly attributed to the country-specific values that better align with the country's situation. Thus, the difference between the emission factor calculated in this study and the IPCC default emission factor is observed since the actual fuel quality and composition of the CNG used in Malaysia, including factors like net heating value, carbon content, and density, differs from those of IPCC. For instance, the average net heating value of the fuel samples (45.95 ± 0.67 MJ/kg) used in this study differs from the net heating value (48.00 MJ/kg) used for the development of the emission factor by IPCC (2006 IPCC Guidelines for National Greenhouse Gas Inventories). It is also worth noting that the qualities of the gas often differ according to the provenience.

4. Conclusion

A comprehensive methodology has been outlined for the development of emission factor for liquid and gaseous fuel used in road transportation specifically for petrol, conventional diesel and compressed natural gas. This study has successfully provided a novel result of emission factor for petrol and conventional diesel with value of 70,408.84 kg CO_2/TJ and 73,715.19 kg CO_2/TJ respectively, and 55,835 kgCO_2/TJ for CNG. This study utilizes the actual fuel composition used in Malaysia, making the findings relevant to the local context. Apart from that, the calculated emission factors were compared with the default value provided in the 2006 IPCC Guidelines for GHG Inventory to ensure the accuracy and reliability of the values. However, there is a need for further study on the oxidation factor to improve the accuracy of emission factor calculations and develop more effective control measures. Oxidation factors represent a fraction of carbon in a fuel that remains unoxidized and solid after combustion. The amount of unoxidized carbon depends on a few factors such as the type of fuel used, the type of combustion technology, the age of the equipment, and the operating procedures. These factors can also vary, even for an individual combustion unit. Additionally, exploring the relationship between oxidation and emission factors could provide valuable insights into the overall environmental impact of the emissions. Most importantly, this study has provided a valuable outcome in terms of emission factor for liquid and gaseous fuel used in road transportation sector in Malaysia. It will assist in strengthen the GHG inventory reporting for Malaysia through a more accurate methodological shift for road transportation sector.

Acknowledgement

This research work is funded by the Ministry of Natural Resources, Environment and Climate Change. Special thanks are extended to the stakeholders and experts who provided valuable data and insights throughout the study.

References

Abdul Aziz A, Mohd Amin NF. Transforming the Land Public Transport System in Malaysia. JOURNEYS. 2012 May.

Begum RA, Sohag K, Abdullah SMS, Jaafar M. CO2 emissions, energy consumption, economic and population growth in Malaysia. Renewable and Sustainable Energy Reviews [Internet]. 2015 Jan; 41: 594–601.

Climate change – Topics - IEA. Climate change – Topics - IEA [Internet]. IEA. 2018. Available from: https://www.iea.org/topics/climate-change

Fan YV, Perry S, Klemeš JJ, Lee CT. A review on air emissions assessment: Transportation. Journal of Cleaner Production [Internet]. 2018 Sep; 194: 673–84.

Franco V, Kousoulidou M, Muntean M, Ntziachristos L, Hausberger S, Dilara P. Road vehicle emission factors development: A review. Atmospheric Environment. 2013 May; 70: 84–97.

Giannakis E, Serghides D, Dimitriou S, Zittis G. Land transport CO2 emissions and climate change: evidence from Cyprus. International Journal of Sustainable Energy. 2020 Mar 22; 1–14.

Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories [Internet]. Intergovernmental Panel on Climate Change; 2000 May. Available from: https://www.ipcc.ch/publication/good-practice-guidance-and-uncertainty-management-in-national-greenhouse-gas-inventories/

Hasan MA, Frame DJ, Chapman R, Archie KM. Emissions from the road transport sector of New Zealand: key drivers and challenges. Environmental Science and Pollution Research. 2019 Jun 20; 26(23): 23937–57.

Hj Hassan M, Karim MR, Mahlia TMI. Energy Use in The Transportation Sector of Malaysia. Economic Planning Unit, Prime Minister’s Department; 2005 May.

Intergovernmental Panel on Climate Change. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Japan. 2006.

Korean National GHG Emission and Absorption Factor Development and Verification 1st Plan Report. Korea. 2014.

Malaysia Fourth Biennial Update Report to the UNFCCC. 2022. Available from: https://unfccc.int/sites/default/files/resource/

Papailias G, Mavroidis I. Atmospheric Emissions from Oil and Gas Extraction and Production in Greece. Atmosphere. 2018 Apr 18; 9(4): 152.

Saija S, Romano D. A methodology for the estimation of road transport air emissions in urban areas of Italy. Atmospheric Environment. 2002 Nov; 36(34): 5377–83.

Sixth Assessment Report of the Intergovernmental Panel on Climate Change. 2022. Available from: https://unfccc.int/documents/636583?gad_source=1&gclid=CjwKCAjwrcKxBhBMEiwAIVF8rGqzu7k4dAMHUUXFF91qeXp1P-bVoMWuCYVZ11csvb-D2r2MbLZDjRoCrZ0QAvD_BwE

Soylu S. Estimation of Turkish road transport emissions. Energy Policy. 2007 Aug; 35(8): 4088–94.

Unger N, Bond TC, Wang JS, Koch DM, Menon S, Shindell DT, et al. Attribution of climate forcing to economic sectors. Proceedings of the National Academy of Sciences. 2010 Feb 3; 107(8): 3382–7.