TRANSPORT PROBLEMS 2025 Volume 20 Issue 1
PROBLEMY TRANSPORTU DOI: 10.20858/tp.2025.20.1.05

Keywords: electric motorcycles; EMs; sustainable transportation; two-wheeled transport; GHG emissions; environmental impacts; renewable energy; Australia

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TOWARDS SUSTAINABLE TWO-WHEELED TRANSPORT IN AUSTRALIA: AN ENVIRONMENTAL ASSESSMENT OF ELECTRIC MOTORCYCLES

Summary. Due to the continuous increase in fuel consumption in the transportation sector and the related environmental issues, such as climate change and energy depletion, there is a pressing need to research, develop, and implement more sustainable modes of transportation. This study assesses the expected environmental implications of the penetration of electric motorcycles in the Australian market. For this purpose, the total greenhouse gas (GHG) emissions to be produced by motorcycles during the next 15 years were determined by developing relevant ARIMA and exponential smoothing prediction models and using different scenarios (25%, 50%, 75%, and 100% electric motorcycles penetration). Moreover, this study considered the future contribution of renewable energy to electricity sources. The results showed that the continuous dependence on the internal combustion engine motorcycle (ICEM), as a two-wheeled mode of transportation, can lead to a considerable increase in GHG emissions and fossil fuel consumption in the long term, and in this case, the expected increase in GHG emissions could be around 40% from 2020–2040. Meanwhile, the partial substitution of ICEMs with electric motorcycles at a percentage of more than 25% by 2040 could lead to substantial GHG emissions reductions. With EM penetration rates of 50% and 75%, the corresponding fall in GHG emissions would be 44.56% and 66.84%, respectively. Meanwhile, a complete replacement of ICEMs with electric motorcycles could lead to an 89.12% reduction in GHG emissions by 2040.

1. INTRODUCTION

Generally, the motorcycle is a space-efficient mode of transportation used widely in congested cities worldwide due to its low purchase and operating costs and ease of riding and parking. Motorcycles also play a vital role on road networks that are difficult to access with other modes of transportation. Another significant advantage of motorcycles is their ability to provide first- and last-mile connectivity [1]. On the other hand, adopting motorcycles for ride-hailing has increased people's dependency on motorcycles [2].

In 2023, the global sales of two-wheeled vehicles were 62.6 million, and the global motorcycle market achieved its second-highest level of sales after its highest level was reached in 2018 [3]. The global pandemic that commenced in 2020 was a major contributor to the drop in motorcycle sales in large markets from 2019 to 2022. The motorcycle industry is expected to increase steadily in the current decade to reach over 80 million units by 2030 [4].

As a result of the growing demand for transportation, the transport sector has consumed more energy, and therefore, more frequent and more intense environmental issues have arisen, such as higher

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greenhouse gas (GHG) emissions and the depletion of energy. The transportation sector produced around a quarter of global emissions of CO_2 and 17% of the total consumption of hydrocarbon fuel. Moreover, 23% of the total emissions of CO_2 are related to vehicles [5]. About 65% of the total global demand for energy is provided by liquid forms of fossil fuels, and this value is expected to increase by up to 75% by 2050 [6]. Therefore, substantial efforts and investments have been made to implement more sustainable alternatives to conventional modes of transportation, including motorcycles.

Recently, electric motorcycles (EMs) have been developed as a sustainable alternative to internal combustion engine motorcycles (ICEMs) to mitigate environmental problems related to the GHG emissions and noise pollution produced by conventional ICEMs. The global EM market size expanded to USD 20263.57 million in 2022 and is expected to increase to USD 28.552 billion by 2028. EMs are two-wheeled plug-in electric vehicles powered by electricity, which is stored in a rechargeable battery that operates one or more electric motors [7]. Several types of batteries have been used in EMs, including lithium batteries, lithium-ion batteries, lithium phosphate batteries, lead acid batteries, lithium-ion phosphate batteries, and nickel metal hydride batteries [8].

Since EMs are still an emerging technology, the impacts of implementing this technology are still unclear in various regions. During the last three years, studies have investigated the impacts of this technology based on specific aspects, such as energy and cost, but few of them have investigated the environmental impacts under controlled conditions and in specific regions. In this study, the environmental implications of EM penetration in the Australian market were assessed by estimating the total GHG emissions produced by motorcycles over the next 15 years based on different scenarios (25%, 50%, 75%, and 100% EM penetration) taking into consideration the future renewable energy contribution in electricity sources.

2. LITERATURE REVIEW

In contrast to four-wheeled electric vehicles, which have been extensively studied over the last two decades, there is a need to investigate the potential and the implications of EMs for a variety of aspects, as EMs are still an emerging technology. Few studies have addressed this issue during the last three years. One such study by Koossalapeerom et al. compared the driving patterns of ICEMs and EMs in the real world [9]. An on-board system was developed and installed in ICEMs and EMs to measure and compare outcomes such as CO_2 emissions. The results indicate that the CO_2 equivalent emissions for EMs were approximately two times lower than those of ICEMs. Onggaria et al. [10] compared the impacts of ICEMs and EMs using Viar Q1 and Honda Beat 110cc as representatives of ICEMs and EMs, respectively. Their results indicate that the EM has lower carbon emissions than the ICEM by up to 2% and has significantly lower hydrocarbon emissions. A study by Achmad et al. [11] evaluated the sustainability of EMs compared to ICEMs based on different aspects, including carbon emissions and noise level. The authors concluded that EM conversion is the best alternative based on sustainability considerations and could lead to a 22.7% reduction in noise.

Other studies focusing on aspects other than the environment have addressed performance, energy consumption, and economic aspects. For example, a study was conducted in Tanzania by Shirima et al. [1] to estimate the energy usage of EMs compared to ICEMs in precarious routes. The results indicated that an EM can save around 24.3 TZS (Tanzanian shillings) per kilometer, compared to 754.8 TZS/km for its ICEM counterpart, and achieve 97% savings in fuel cost. Another study by Kusalaphirom et al. [12] examined the factors that could influence the electricity consumption of EMs using an on-board device to collect data, such as speed and consumption. The results show that rider weight and speed positively influence energy consumption. A study by Shaikh et al. [13] investigated the factors that influence EM adoption. These factors included perceived values, usefulness, ease of use, and environmental concerns. The results indicate that effective marketing, friendly design, and appropriate policies and education can substantially enhance EM adoption. Similarly, a study by Waluyo et al. [2] investigated the willingness to adopt EMs among 416 ride-hailing drivers. The results indicate that EM ownership is less likely than EM adoption. A study by Suwingnjo et al. [14] was performed in Indonesia to quantify the economic benefits of implementing EMs in ride-sharing activities compared to ICEMs. The results indicate that riders could save up to 68% of their income by using EMs instead of ICEMs.

During the last three years, some studies have addressed the implications of this technology based on specific aspects, such as energy, cost, and performance, but only a few studies have investigated the environmental implications. More specifically, some of these studies assessed the environmental impacts based on one model of EMs with specific features and performance, while other studies were conducted based on theoretical data for the energy consumption of motorcycles, which differ from real-world energy consumption. In the present study, the environmental implications of EM penetration in the Australian market were investigated by quantifying the total GHG emissions to be produced by motorcycles during the next 15 years based on different scenarios. The results were obtained by using developed prediction models and considering the future renewable energy contribution in electricity sources. Moreover, the average real-world values of energy consumption for popular motorcycles models and brands were considered.

3. DATA AND METHODOLOGY

3.1. Data Collection

Different types of data from a variety of sources were collected, including the total annual GHG emissions produced by motorcycles from 1989–2022 in 1000 tons of CO_2-eq for all Australian provinces, the annual distance traveled by motorcycles from 1970–2022 in millions of km based on average daily traveled distance, average fuel consumption of motorcycles based on the average values of different models and brands, current generated electricity emissions factors, and the future renewable energy contribution in the sources of electricity.

3.2. Methodology

An exponential smoothing model was developed using the total annual of GHG emissions produced by ICEMs from 1989–2022, which was selected based on the availability of data. This was done to estimate the expected GHG emissions to be produced by ICEMs during the next 15 years, considering that the majority of the current motorcycles are ICEMs. It is worth mentioning that using a sample size (number of years) of 15 to 45 years could be acceptable; however, it is better to increase the sample size.

The exponential smoothing technique, which is widely used to predict future data, is a time series method by which data in a time series are smoothed exponentially. In this method, recent time series data have a greater weight, and earlier data have a lower weight on the forecast process. Different types of models are used for exponential smoothing: triple or Winters smoothing, single, and double or Holt's smoothing [15]. In this study, Holt's exponential smoothing method was used since it is the most suitable for the used data, as presented in Equation (1) [15, 16].

$$F_{t+m} = s_t + m b_t, \qquad (1)$$
$$s_t = \alpha x_t + (1-\alpha)(s_{t-1} + b_{t-1}),$$
$$b_t = \beta(s_t - s_{t-1}) + (1-\beta) b_{t-1},$$

where F refers to an estimated value for the m + t year, st refers to the value that is smoothed for t year, m refers to a number greater than 0, bt refers to the best trend that is estimated for year t, α refers to a smoothing factor between values of 0 and 1, xt is the sequence of data, and β is the trend factor between 0 and 1.

After that, an ARIMA model was developed using Box and Jenkins methodology [17] to estimate the expected annual total traveled distance by motorcycles during the next 15 years, considering the penetration of EMs and using the annual distance traveled by motorcycles during the period 1970–2022, which was selected based on the availability of data. Generally, ARIMA prediction models have three components: the autoregressive, the integrated part, and the moving average part. The process demonstrated in Fig. 1 has been applied to find the best-fit ARIMA model. It is worth mentioning that the IBM SPSS program was used to select the best model based on the type of data since different models can be used in this field.

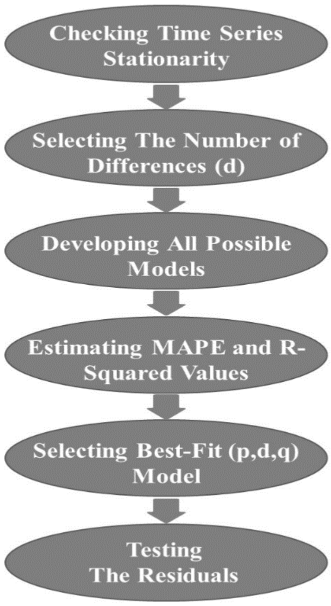

Fig. 1. ARIMA model development methodology

The expected GHG emissions by EMS in Australia in 2040 were determined based on the estimated annual traveled distance by motorcycles, the average electricity consumption of EMs, and the future generated electricity emission factor. It is worth mentioning that the emission factor for future generated electricity was determined by considering the emission factor for the current generated electricity and the future renewable energy contribution in the sources of electricity.

4. DATA ANALYSIS AND DISCUSSION

Considering that currently, most motorcycles are ICEMs, the expected GHG emissions to be produced by ICEMs during the next 15 years were predicted using the annual GHG emissions produced by motorcycles from 1989–2022 [18]. Note that using a data sample size of 15 to 45 years could be acceptable; however, a larger sample size is better. In order to predict the GHG emissions by motorcycles, the best-fit exponential smoothing prediction model was created, as shown in Fig. 2.

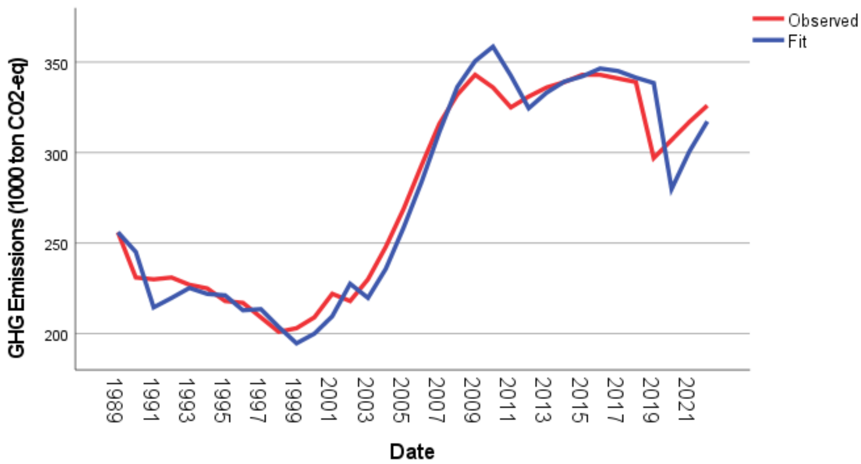

Fig. 2. Fit and observed values of prediction model

R-squared and mean absolute percentage error (MAPE) values were calculated to test the accuracy of the created model, as illustrated in Table 1. Based on the MAPE value, which was 3.390 (a MAPE value less than 5 represents an acceptable forecast accuracy), and the R-squared value, which was 0.945, the model can be applied without any reservations.

Table 1
Statistics and Parameters of Holt's Exponential Smoothing Model

Model	Model Statistics		
	MAPE		R Squared
Holt's Model	3.390		0.945
Estimated Parameters			
	Estimate	SE	t
Alpha (Level)	1.000	0.172	5.810
Beta (Trend)	0.400	0.204	1.964

Considering the penetration of EMs and using the annual traveled distances by motorcycles from 1970–2022 [18], an ARIMA model was created in order to estimate the annual traveled distance by motorcycles over the next 15 years. Initially, an augmented Dicky-Fuller test was performed in order to test the time series stationarity. The results showed that the probability (P-value) was 0.489; thus, the times series was nonstationary. The first difference was applied to the time series, and the stationarity test was conducted again, but the test result showed that the time series was still nonstationary. Finally, the test results confirmed the stationarity of the time series after the second difference was applied. When the second difference was applied, all possible ARIMA models and their parameters were determined, as presented in Table 2.

Table 2
Statistics and Parameters of the ARIMA Models

Model	Model Statistics			Q(18)
	R squared (Stationary)	R squared	MAPE	Sig
ARIMA (0,2,0)	0	0.914	3.630	0.061
ARIMA (0,2,1)	0.237	0.935	3.777	0.380
ARIMA (1,2,0)	0.138	0.926	3.765	0.039
ARIMA (1,2,1)	0.251	0.936	3.628	0.372
ARIMA (0,2,2)	0.250	0.936	3.652	0.403
ARIMA (2,2,0)	0.183	0.930	3.765	0.149
ARIMA (2,2,2)	0.263	0.937	3.644	0.257
ARIMA (3,2,0)	0.252	0.936	3.618	0.786
ARIMA (0,2,3)	0.253	0.936	3.607	0.294
ARIMA (3,2,3)	0.266	0.937	3.735	0.230
ARIMA (1,2,3)	0.257	0.936	3.577	0.321
ARIMA (3,2,1)	0.259	0.936	3.559	0.503

The results in Table 2 show that ARIMA (2,2,2) and ARIMA (3,2,3) had the highest R-squared value (0.937). Based on its lower MAPE value, ARIMA (2,2,2) was selected as the best-fit model. A Ljung-Box test was conducted in order to test the independence of the residuals, and the results showed that the P-value was 0.257; thus, the null hypothesis was not rejected, indicating that the residuals are independent. The ARIMA (2,2,2) prediction model can be presented as in Equation 2, while Fig. 3 illustrates the prediction curve fit and observed values.

$$\Delta (Yt, 2) = -1.680 - 0.762Yt\text{-}1 + 0.143Yt\text{-}2 - 0.248\varepsilon t\text{-}1 + 0.750\varepsilon t\text{-}2, \quad (2)$$

where Yt is the total traveled distance forecast at time (year) t and Yt-1 and Yt-1 are the total distances traveled at time lags t-n.

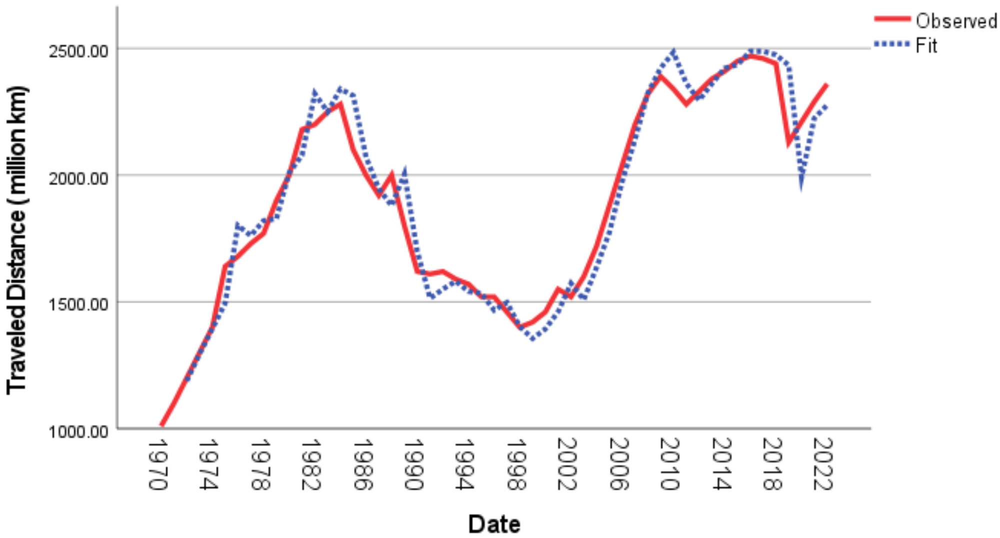

Fig. 3. Fit and observed values for ARIMA model

When the developed exponential smoothing and the ARIMA (2,2,2) models were run, the expected annual GHG emissions by ICEMs (393,000-ton CO_2-eq) and the expected annual traveled distance by motorcycles (2408.60 million km) in 2040 were determined, as illustrated in Table 3.

Table 3
Predicted total GHG Emissions and Traveled Distance by Motorcycles (2025-2040)

Year	2025	2030	2035	2040
Total Motorcycles Traveled Kilometers (Million km)	2433.48	2457.76	2461.04	2408.60
Total Motorcycles GHG Emissions (1000-ton CO_2-eq)	337	356	375	393

The expected GHG emissions by EMs in Australia in 2040 (in the case of EM penetration) were determined based on the estimated total annual traveled distance by motorcycles, the average electricity consumption of EMs (57.83 Wh/km [12]. Moreover, the future generated electricity emission factor (307 gm CO_2-eq/ kWh), which was estimated using the electricity generation emissions factor in 2022 (770 gm CO_2-eq/ kWh [19]), and the expected increase of renewable energy contribution in the sources of electricity between 2022 and 2040 (60.1% [20]) were considered, as illustrated in Table 4. It is worth mentioning that in order to check the reliability of the data related to the average EMS electricity consumption (57.83 Wh/km), which was used based on the results of a previous study, the average electricity consumption for four popular EMs (BMW C Evolution, Vespa Elettrica, and Energica Eva 107 [21]) was estimated, and the result (59.47 Wh/km) was very close to the used value. Therefore, the value (57.83 Wh/km) can be used without reservation.

The total annual GHG emissions by motorcycles in 2040 were estimated considering different EM penetration scenarios (0%, 25%, 50%, 75%, and 100%) and compared in order to quantify the environmental implications of EMs, as presented in Table 5.

Overall, the results show that reductions in GHG emissions by 87,559.54, 175,119.08, 262,678.63, and 350,328.17 ton CO_2-eq could be achieved in cases of 25%, 50%, 75%, and 100% EM penetration, respectively. Therefore, moving from ICEMs to EMs at a percentage of more than 25% by 2040 could lead to a substantial reduction in GHG emissions. In other words, the quantity of GHG emissions reduction in the case of 100% EM penetration is even more than the total GHG emissions produced by motorcycles in 2022, which was 326,000 ton CO_2-eq [18].

Table 4

Expected Total Annual GHG to be Produced by EMs in 2040

E-Motorcycles Estimated Energy Consumption (Wh/km)	Electricity Generation Emissions Factor (gm CO_2-eq/ kWh) in 2022	Estimated Electricity Generation Emissions Factor (gm CO_2-eq/ kWh) in 2040	Expected Traveled Distance by E-Motorcycles in 2040 (million km)	Total GHG Emissions in 2040 (ton CO_2-eq)
57.83	770	307	2408.60	42,761.83

Table 5

Expected Total Annual GHG Emissions by Motorcycles I 2040, based on Different EM Penetration Scenarios

Motorcycle Type	Case 0 (0% EMs)	Case 1 (25% EMs)	Case 2 (50% EMs)	Case 3 (75% EMs)	Case 4 (100% EMs)
ICE Motorcycles (ton CO_2-eq)	393,000	10,690.46	21,380.92	32,071.37	0
Electric Motorcycles (ton CO_2-eq)	0	294,750	196,500	98,250	42,761.83
Total GHG Emissions (ton CO_2-eq)	393,000	305,440.46	217,880.92	130,321.37	42,761.83

5. CONCLUSIONS

In the last three years, only a few studies have assessed the impacts of implementing EM technology. The present study determined the environmental impacts of EM penetration in the Australian market by quantifying the total GHG emissions to be produced by motorcycles over the next 15 years by developing relevant ARIMA and exponential smoothing prediction models, evaluating different scenarios (25%, 50%, 75%, and 100% EM penetration), and considering the future renewable energy contribution in the sources of electricity. Based on the results, the following conclusions are presented:

- The continuous dependence on the ICEM as a two-wheeled mode of transportation can lead to a considerable increase in GHG emissions and fossil fuel consumption in the long term. In this case, the expected increase in GHG emissions from 2020–2040 could be around 40%.
- Replacing ICEMs with EMs could reduce GHG emissions in the short term, and the magnitude of the reduction is expected to increase substantially in the long term due to the continuous increase in renewable energy contribution in the sources of electricity, which is expected to increase by around 60% from 2022–2040.
- A partial shift to EMs at a percentage greater than 25% in 2040 could lead to a substantial reduction in GHG emissions. The expected decreases in GHG emissions in the cases of 50% and 75% EM penetration are 44.56% and 66.84%, respectively. A complete shift to EMs could lead to an 89.12% reduction in GHG emissions in 2040.
- The expected total GHG emissions to be produced by motorcycles in 2040 in the cases of 25%, 50%, 75%, and 100% EMs penetration are 305,440.46, 217,880.92, 130,321.37, and 42,761.83 ton CO_2-eq, respectively.
- The reliability and economic aspects of EMs in Australia should be addressed in future studies, as only the environmental aspect has been investigated in this article due to the lack of relevant data.

References

1. Shirima J, & Kiiza, R. & Kusekwa, M. Energy assessment of e-motorcycles as a clean transport mode for passenger mobility: A case of Ilala District, Dar es Salaam. *Tanzania Journal of Engineering and Technology*. 2022. Vol. 41(4). P. 219-228.
2. Waluyo, T.A. & Irawan, M.Z. Dewanti. Adopting electric motorcycles for ride-hailing services: influential factors from driver's perspective. *Sustainability*. 2022. Vol. 14(19). No. 11891.
3. MCD Team. World motorcy,cles market hit 62.6 million sales in 2023. Motorcycles Data. 2024. Available at: https://www.motorcyclesdata.com/.
4. MCD Team. Motorcycles industry must be considered by nations to counteract the climate changes emergency. Motorcycles Data. 2024. Available at: https://www.motorcyclesdata.com/.
5. Tan, X. & Chen, W. & Pan, F. Fuel cell heavy-duty trucks: application and prospect. *Engineering*. 2021. Vol. 7(6). P. 728-730.
6. Baptista, P. & Ribau, J. & Bravo, J. & Silva, C. & Adcock, P. & Kells, A. Fuel cell hybrid taxi life cycle analysis. *Energy Policy*. 2011. Vol. 39(9). P. 4683-4691.
7. Research reports world. *Global electric motorcycle industry research report 2023, competitive landscape, market size, regional status and prospect*. Maharashtra. 2023.
8. Direct Asia. *The Electric Motorcycle*. 2022. Available at: https://www.directasia.com/.
9. Koossalapeerom, T. & Satiennam, T. & Satiennam, W. & Leelapatra, W. & Seedam. A. & Rakpukdee, T. Comparative study of real-world driving cycles, energy consumption, and CO_2 emissions of electric and gasoline motorcycles driving in a congested urban corridor. *Sustain Cities Soc*. 2019. Vol. 45. P. 619-627.
10. Onggaria, E. & Marhaendra, F. & Pratama, I.N. & Manurung, O.E. & Nurdini, A. & Nurcahyo, R. Comparative analysis of combustion and electric motorcycle as an alternative online-based transportation in Indonesia. In: *Proceedings of the International Conference on Industrial Engineering and Operations Management*. Michigan, USA: IEOM Society International; 2023.
11. Habibie, A. & Hisjam, M. & Sutopo, W. & Nizam, M. Sustainability evaluation of internal combustion engine motorcycle to electric motorcycle conversion. *Evergreen*. 2021. Vol. 8(2). P. 469-76.
12. Kusalaphirom, T. & Satiennam, T. & Satiennam, W. Factors influencing the real-world electricity consumption of electric motorcycles. *Energies*. 2023. Vol. 16(17). No. 6369.
13. Shaikh, S. & Talpur, M.A.H. & Baig, F. & Tariq, F. & Khahro, S.H. Adoption of electric motorcycles in Pakistan: A technology acceptance model perspective. *World Electric Vehicle Journal*. 2023. Vol. 14(10). No. 278.
14. Suwignjo, P. & Yuniarto, M.N. & Nugraha, Y. & Desanti, A.F. & Sidharta, I. & Wiratno, S.E. & Yuwono, T. Benefits of electric motorcycle in improving personal sustainable economy: a view from indonesia online ride-hailing rider. *International Journal of Technology*. 2023. Vol. 14(1). P. 38-51.
15. Makridakis, S. & Wheelwright, S.C. & Hyndman, R.J. *Forecasting methods and applications.* 3rd ed. Wiley. 2008.
16. Hassouna, F.M.A. & Shin, K. Hydrogen fuel cell vehicles as a sustainable transportation alternative: environmental impacts assessment. *International Review of Civil Engineering*. 2024. Vol. 15(6).
17. Box, G. & Jenkins, G. *Time series analysis: forecasting and control*. San Francisco: Wiley sons. 1976.
18. Transport Regional Development C, of Infrastructure AD. *Australian Infrastructure and Transport Statistics.* Yearbook 2023.
19. Footprint, C. *Country Specific Electricity Grid GHG Emissions Factors*. 2023.
20. Hassouna, F.M.A. & Pringle, I. Long-term electric vehicles outlook in Australia: environmental benefits. *International Journal on Energy Conversion*. 2024. Vol. 12(3).
21. Electric Motorcycles. Electric motorcycle database. *Electric Motorcycles*. 2024. Available at: https://www.electricmotorcycles.net/all-motorcycles/

Received 16.02.2024; accepted in revised form 07.03.2025