CHEMICAL ENGINEERING TRANSACTIONS

VOL. 120, 2025

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.cetjournal.it

Guest Editors: Bing Shen How, Viknesh Andiappan, Denny K.S. Ng, Hon Loong Lam, Petar S. Varbanov

ISBN 979-12-81206-21-2; **ISSN** 2283-9216

DOI: 10.3303/CET25120057

Performance-based Mapping of Electric Tricycle Considering Road Grade in the Philippines

Mardione Albert Mozo, Villanueva Banaguas, Job Immanuel Encarnacion, Carl Michael Odulio*

University of the Philippines Diliman. Quezon City, Philippines
carl.odulio@eee.upd.edu.ph

Electric tricycle (e-trike) adoption in the Philippines has gained traction in recent years. This supports the country’s goal of promoting sustainable transportation and emission reduction. Despite the growth of the local e-trike industry, there is limited data on their performance and gradeability which hinders stakeholder confidence and overall adoption. This study evaluated and mapped the suitability of existing e-trike designs on actual road conditions that include moderate to adverse road gradients. Required road load and resulting vehicle dynamics were obtained using drive cycle simulations. The simulations employed representative drive cycles incorporated with actual road grade of an urban area with flat and hilly terrains. A localized e-trike performance-based map was then generated, targeted towards providing information on routes that are underserved and unserved by current e-trike units. The map provides the required vehicle specification and applicable local e-trike models that can traverse specific routes. This may be used by manufacturers, distributors, and local government units to plan for e-trike adoption and rollout.

1. Introduction

The transportation system fosters economic transformation and regional development through a network of efficiency, accessibility and opportunity (Abad et al., 2023). A good transportation system facilitates the movement of goods and people, which is essential for trade, access to markets, job creation, and the overall connectivity of societies. The transportation sector in Southeast Asian (SEA) countries plays a crucial role in the economic development, regional connectivity and social development. The rapid increase of the population and economic growth in the Association of Southeast Asian Nations (ASEAN) members led to the urbanization of the major cities (Grütter and Kim, 2019)

Economic growth and rapid urbanization in the Philippines spurred increasing dependence on fossil fuel-powered three-wheelers and two-wheelers vehicles. It is driven by affordability and adaptability to solve the last-mile connectivity in narrow roads and short-distance travel needs (Luansing et al., 2015). There are eight million three-wheelers and two-wheelers vehicles in the year 2022 and it is projected to climb further due to their perceived convenience. However, the increasing demand of the said vehicles intensified the reliance of fossil fuels which contribute to greenhouse gas emissions, air pollution and environmental degradation (Abad et al., 2023). The mobile sources – vehicle and other moving machinery emissions in 202 is the largest source of air pollution in the country. It contributes to 56 % of air pollutants coming from different vehicles and moving machinery in the Philippines. It is estimated that the National Capital Region (NCR) contributed around 2 million tons of greenhouse gases in the year 2021 (DENR, 2021).

The high acceptance rate and positive outlook of the electric vehicle (EV) in the Philippines implies a transformative solution to the growing reliance on fossil fuels in the transportation sector (Guno et al., 2021). The EV adoption can help reduce greenhouse gas emission and air pollutants. This will directly improve the urban air quality and public health particularly in a densely populated area (Abad et al., 2023). The integration of EV into the public transportation network addresses the last-mile connectivity challenges. It can support the phased transition toward broader EV adoption while maintaining the accessibility and convenience of the commuters.

Paper Received: 19 May 2025; Revised: 21 August 2025; Accepted: 8 October 2025
Please cite this article as: Mozo M.A., Banaguas V., Encarnacion J.I., Odulio C.M., 2025, Performance-based Mapping of Electric Tricycle Considering Road Grade in the Philippines, Chemical Engineering Transactions, 120, 337-342 DOI:10.3303/CET25120057

The Philippine Energy Plan (2023-2050) strategically targets the 50 % penetration rate under Clean Energy Scenario in 2040. The Philippine government plans to switch from traditional internal combustion engines to electric vehicles. The adoption of EV is a collaborative effort of the government and private sectors. The government crafts policies targeting the key drivers of EV adoption such as environmental concerns, technological advancements, cost savings and infrastructure development (DOE, 2023b). Moreover, the Republic Act 11697 also known as Electric Vehicle Industry Development Act (EVIDA) outlines the strategic direction of the adoption and development of EVs in our country.

The Asian Development Bank (ADB) launched its flagship Energy Efficient Electric Vehicle Project in 2021 in partnership with the Local Government Units (LGU). It deploys 3,000 e-trikes in 32 different LGUs as beneficiaries. However, the project fell short of expectations based on ADB evaluation (Abad et al., 2023).

Previous e-trike deployment of ADB in the Philippines including the ADB's Boracay pilot testing of repurposed conventional design and the Cabanatuan City's sustainability assessment have focused on emission reductions and assessment of socio-economic factors without technical and quantifiable evaluation of energy consumption (Orpilla et al., 2023). Many cities with hilly terrain like Boracay, Cabanatuan and Marikina lack of e-trike adoption due to the unverified operational viability on gradients. Moreover, there is no quantitative information on the reduced range and energy consumption when driving on graded urban terrain that may affect the adoption of e-trike. Existing research on e-trikes, including the flagship projects of ADB's energy efficient electric vehicles, has prioritized flat-terrain performance and laboratory testing. There is research gap in quantifying energy consumption on moderate-to-steep gradients in Philippine urban terrain through performance mapping of e-trike. This gap may hinder stakeholders' confidence and broader adoption. The novelty of this research provides the first measurable data set of e-trike correlating energy consumption with gradient thresholds in the Philippine urban terrain.

The aim of the study is to address the performance gap of e-trike suitability in various terrains using representative drive cycles. It will assess the existing e-trike models capabilities of meeting local specific routes. The e-trike performance, particularly the gradeability and energy consumption, will be evaluated using AVL Cruise M. Then, a localized e-trike performance-based map will be generated to provide information on routes that are underserved and unserved by current e-trike units.

2. Methodology

The methodology consists of field data gathering and simulation. The researcher gathered details of the existing e-trike specifications and used the Garmin application and QGIS software in creating the actual-trip route and elevation profile. Then, it will be simulated using AVL Cruise M to assess the route viability. An assessment of the e-trike performance based on the trip-coverage of the TODA will be discussed in the results. Lastly, the study recommended e-trike models from DOE's registered EV list if there are no e-trikes available in the area.

2.1 Study Area

The study area considers the localized tricycle transport group in Marikina City, Philippines called Tricycle Operators and Driver's Associations (TODAs) that manage tricycle routes and operations. The varying Marikina's terrain helps simulate real-world energy consumption patterns. Also, some TODA routes cover both flat commercial districts and uphill residential areas. TODAs are typically stationed near public markets, transport terminals, residential areas and commercial districts (Preciados, 2018).

2.2 Data Gathering

The researchers checked the availability of the e-trikes in the selected TODAs of Marikina City. The technical specifications of the e-trike such as motor power, battery capacity and gross weight under full load capacity were documented. Moreover, the random trip trajectory was plotted using the Garmin application for the latitude and longitude in GPX format while the elevation profile was processed using the QGIS software using the GPX file from the Garmin application.

2.3 E-trike Performance Evaluation

The AVL Cruise M software is an industry-standard vehicle simulation tool that is capable of modelling and assessing vehicle performance under real-world dynamic conditions. The input variables for the simulations were e-trike specifications and road gradients. The TODA stations are strategically placed to serve the last-mile connectivity where public transportation such as jeepneys and buses do not operate. The output of the simulations are the performance metrics of the e-trike such as the motor torque output and energy consumption based on the TODA 2 km radius as a last mile connectivity from TODA stations. The study focuses on a 2 km radius around TODA stations with elevation variation analysis in assessing e-trike performance and it is randomly selected using GARMIN application from TODA stations to the diverse residential destinations.

A performance-based mapping of e-trike will be presented based on the route viability classification:
• Served: existing e-trikes model/s can serve the area
• Underserved: e-trikes model/s can serve the area with minor design adjustments
• Unserved: e-trikes model/s cannot serve the area

3. Results

This section discusses the elevation profile of the selected location, the specification of the e-trike brands, and the energy consumption of the e-trike brands as it traverses the static gradients at an average of 25 kph.

Table 1: E-trike models specification

Parameters	E-future	Piaggio	Atul
Model	EFTP1	Ape E-City FX MAX	Atul Mobili
Battery			
Nominal Voltage	72 V	51.2 V	48 V
Capacity	7.5 kWh	8 kWh	8 kWh
E-motor			
Max power	3 kW	5.44 kW	9.92 kW
Max torque	25 Nm	29 Nm	44.32
Top speed	50 kph	50 kph	55 kph
Passengers			
Full capacity	4 passengers	4 passengers	4 passengers
Vehicle Dimension			
Length (mm)	2,650	2,700	2,836
Width (mm)	1,100	1,370	1,390
Height (mm)	1,750	1,725	1,890

The three selected locations in Figure 1 were used to generate random routes in a 2 km radius around the TODA area using the Garmin Connect application. The application can export a GPS Exchange Format (GPX) that provides precise topographic data, elevation profiles and varying grades which are critical for the performance assessment of the e-trike.

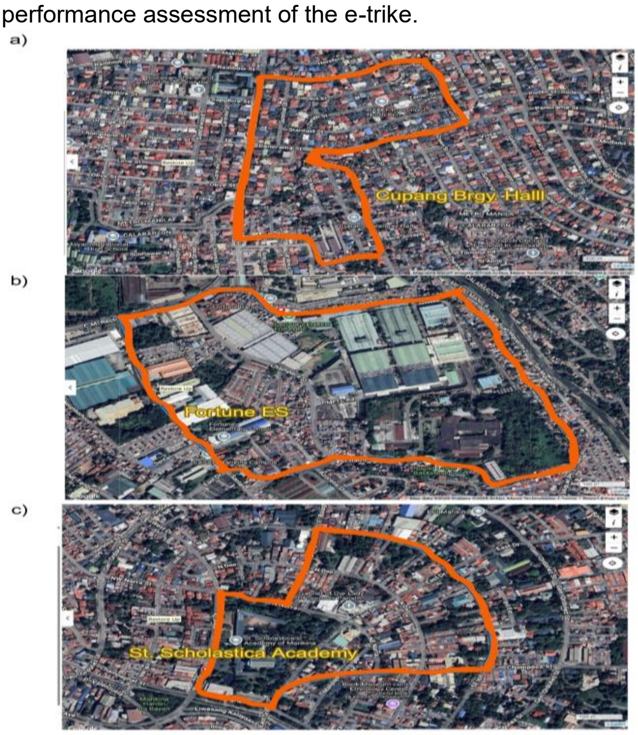

Figure 1 : Route location: (a) Cupang Brgy. Hall (b) Fortune ES (c) St. Scholastica Academy

The varying grades from the sample locations are 2 %, 3 %, 4 %, 5 %, 6 %, and 7 % as shown in Figure 2. These grades will be incorporated into the simulations for a comprehensive assessment of how different inclines impact the energy consumption of the different e-trike models. The simulation will assume an average e-trike speed of 25 kph, a representative value for urban and semi-urban environments.

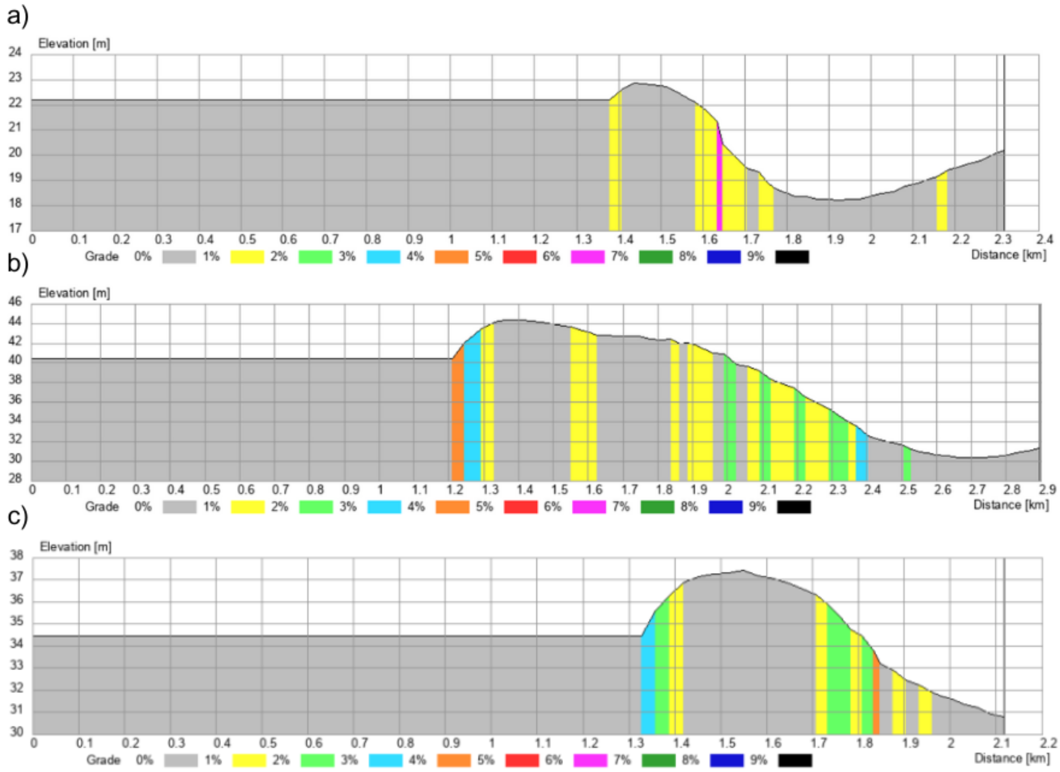

Figure 2: Elevation profile: (a) Cupang Brgy. Hall, (b) Fortune ES (c). St. Scholastica Academy

The e-trike system model, as shown in Figure 3, represents an electrically driven three-wheeler vehicle. It structurally consists of vehicle chassis, three wheels, driveline, battery, power electronics – which regulate energy flow between battery, motor, and auxiliary systems, and e-motor. The integration of these systems is critical in determining the e-trike's operational effectiveness.

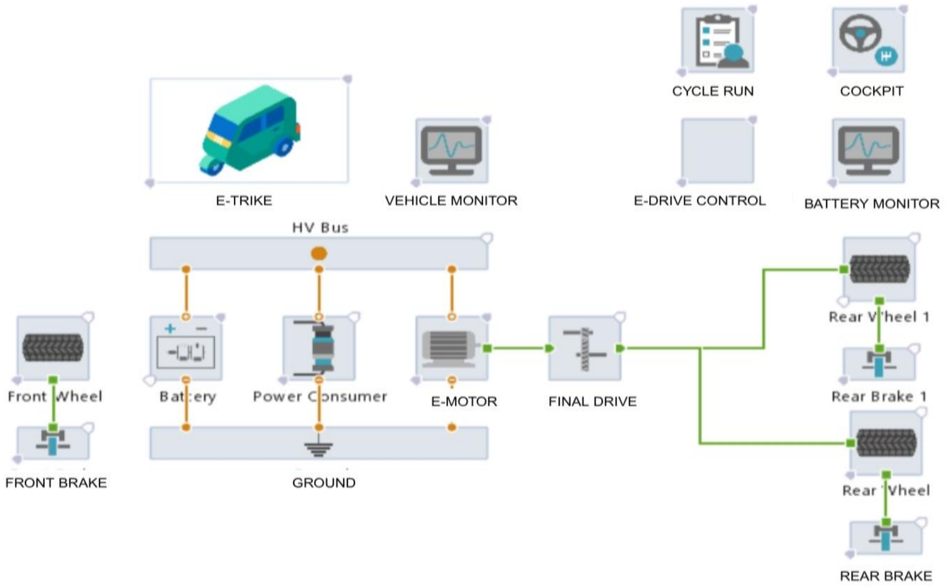

Figure 3: E-trike system model

The simulation results in Figure 4, using AVL Cruise M software at constant speed of 25 kph over 1,140 s duration, showed a significant variation in climbing capability and energy consumption among three e-trike brands under static gradients from 2 % to 7 %. The E-future e-trike, as shown in Figure 4 demonstrated a sustained operation on 2 % and 3 % gradients, consuming 1096 Wh and 1310 Wh, respectively. However, its performance declined sharply on steeper inclines of 4 % to 7 %, sustaining only 25 s to 45 s before power limitations. In contrast, the Piaggio e-trike successfully operated the tested gradients, with increasing energy consumption from 886.55 Wh (2 % grade) to 2,076.37 Wh (7 % grade), highlighting its superior powertrain and energy management. The Atul e-trike showed a better performance compared to E-future, efficiently handling up to 6 % gradients but struggling at 7 % gradients, where its climbing speed notably decreased after 36 s.

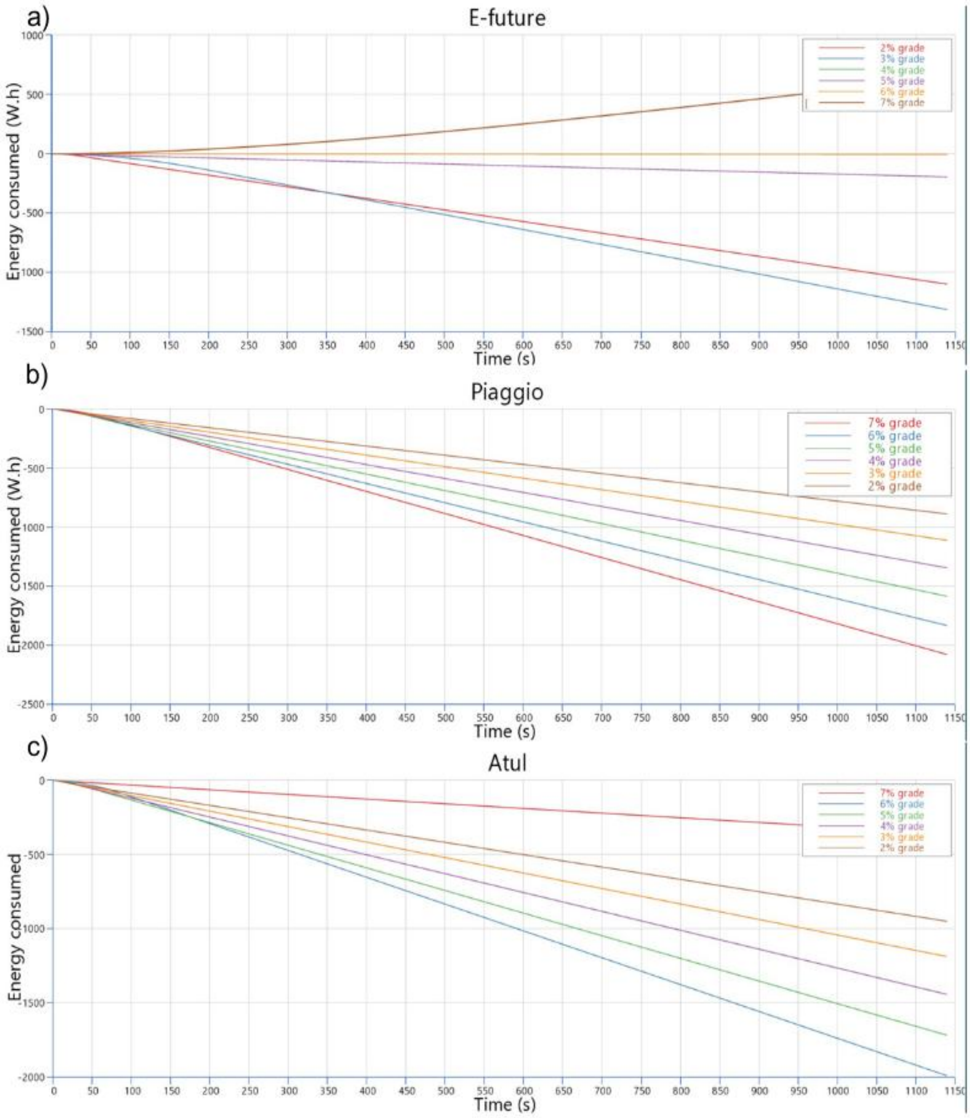

Figure 4: Energy consumption with varying grades: (a) E-Future, (b) Piaggio, (c) Atul

4. Discussions

The three e-trike brands (E-future, Piaggio and Atul) can efficiently operate the 2 % grade while the 7 % grade poses challenges. Only the Piaggio model demonstrates full capability on the steep grade, whereas Atul and E-future fail to sustain the 7 % grade. Thus, Cupang Barangy Hall TODA can be classified as underserved, as minor powertrain adjustments could enable the Atul model to serve the area while the E-future would require significant redesign. While, St. Scholastica Academy and Fortune Elementary School, with gradients 2 % to 5 % are fully served by all brands except E-future which struggles beyond 3 %. The Piaggio and Atul models can perform reliably across these grades, suggesting these locations are viable for immediate e-trike deployment.

Based on the technical specifications and climbing performance of the evaluated e-trike brands, it is evident that the motor power, battery capacity and drivetrain efficiency are the primary determinants of gradient-climbing capability. The Piaggio's performance across all gradients (2 % to 7 %) suggests a higher torque motor, as evidenced by the linear increase of the energy consumption. The Atul model's inability to sustain the 7 % grade beyond 36 s, despite handling the 2 % to 6 % gradients with progressively higher energy consumption, indicates either the sufficient continuous power output or voltage sag under peak loads. The E-future's failure beyond 3 % grade reveals a fundamental limitation in either motor's torque characteristics or battery discharge rate. Thus, the performance disparities of the e-trike models suggest that the manufacturer should specify not just the range and speed but also the hill-climbing capabilities, duration at specified gradients and associated energy penalties.

5. Conclusion

The findings of the research highlight the critical importance of the need for strategic e-trike deployment in topographically challenging cities like Marikina, where no e-trikes currently operate. The Piaggio model demonstrates comprehensive serviceability across all tested gradients (2 % to 7 %), making it possible for citywide implementation. The Atul and E-future models require targeted modifications before deployment to routes 6 % and 3 % grades respectively.

The simulation results show moderate gradients impact the operational viability of e-trikes. For both E-future and Piaggio models, energy consumption surged from 1,096 Wh at 2 % grade to 1,310 Wh at 3 % grade, a 19.5 % increase for just 1 % additional incline. This translates to severe range penalties in a standard 2.5 kWh battery with the operational range of 3 % gradients. This could mean 8 to 10 km less range per charge. The simulated performance of the e-trike models can be linked to infrastructure development where the high energy consuming routes or areas are priority candidates for deploying fast-charging stations or battery swapping zones to support e-trikes operations.

Thus, the government can do a strategic pre-deployment assessment. The government can use performance thresholds to classify routes as served, underserved or unserved, define route-specific technical specifications for e-trike franchises and implement transparency protocols for manufacturers' claim. To address the energy penalties and range limitations, future researchers should prioritize battery enhancements through next-generation chemistries, advanced thermal management systems and capacity optimization for hill climbing terrain. The energy-grade consumption data can strategically help LGU in putting charging stations or battery-swap zones.

References

Abad R., Saripada N., Alcanzare M., Tinio M., 2023, Advancing electric vehicle adoption in the Philippines through policy integration. Clean Air Asia, <cleanairasia.org/our-resources/publications/advancing-electric-vehicle-adoption-philippines-through-policy>, accessed 19.02.2025.

DENR, 2021, Emissions inventory 2021. Air Quality Management Section, <air.emb.gov.ph/emission-inventory-2018/>, accessed 14.03.2025.

DOE, 2023a, Comprehensive roadmap for the electric vehicle industry 2.

DOE, 2023b, Philippine energy plan 2023-2050, <doe.gov.ph/pep>, accessed 17.02.2025.

Grütter J., Kim K., 2019, E-mobility options for ADB developing member countries, <adb.org/sites/default/files/publication/494566/sdwp-060-e-mobility-options-adb-dmcs.pdf>, accessed 07.02.2025.

Guno C.S., Collera A.A., Agaton C.B., 2021, Barriers and drivers of transition to sustainable public transport in the Philippines. World Electric Vehicle Journal, 12(1), 46.

Luansing R., Pesigan C., Rustico Jr. E., 2015, An e-trike ICE project - innovative, concrete and ergonomic: systems design to support sustainable e-trike commercialization. Procedia Manufacturing, 3, 2333-2340.

Orpilla M.B., Ibanez A.G., Dumlao F.S., Tolentino H.B., 2023, Comparative study between conventional and converted electric tricycle. Philippine Journal of Science, 152(3), 1235–1244.

Preciados L., 2018, Comparative profitability analysis among electric tricycle, pedicab and gasoline-fueled tricycle in Isabel, Leyte, <scispace.com/papers/comparative-profitability-analysis-of-electric-pedicab-and-1qc6dh6rm2 >, accessed 19.02.2025.