Preliminary Study on Road Test for Performance Evaluation of Electric Motorcycles in Vietnam

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Abstract

Electric Motorcycles (EMs) are proving themselves to be efficient, low-polluting vehicles and a worthy replacement for gasoline-powered vehicles in Vietnam. This paper aims to study and introduce the road test procedure for EMs riding in Ho Chi Minh City, Vietnam. The performance characteristics and energy consumption efficiency of EMs are evaluated using various input values. To reach this aim, two electric motorcycles prototypes were investigated through mathematical modeling and road test. Mathematical formulas clearly define key variables of interest such as vehicle mass, rider mass, speed, and frontal area. These are recorded by monitoring and measuring equipment listed with a technical description. The procedure starts with preparation, inspection and ends with data analysis. Finally, case study applications in Ho Chi Minh City, Vietnam applied and evaluated the obtained results. Energy consumption is 157 - 265 Wh/10km with a 21 – 27 km/h speed profile and powertrain efficiency with the 27 km/h profile is 87%. The experimental results like manufacturer's specifications and research reports on EMs. The next development direction is to research and evaluates rider behavior which is an important factor affecting the performance of EMs.

Keywords: Electric motorcycles, procedure, energy consumption, efficiency, battery.

1 Introduction

Motorcycles are popular means of transport in Vietnam's urban areas. Private motorcycle contributes 74% of the total vehicle need in HCMC-the primary economic center of Vietnam (Duc Nguyen Huu, 2021). But gasoline-powered motorcycles are also one of the main factors of air pollution, as Hanoi and HCMC were among the top 15 polluted cities in Southeast Asia (Duc Nguyen Huu, 2021). In order to reduce pollutants from motorcycles, EMs have been brought to the front as an alternative solution to replacing gasoline-powered motorcycles. EMs have all advantages of gasoline-powered motorcycles while having other advantages like reducing carbon footprint; being more lightweight, which is easier to drive; less noise, and being more cost-effective. The transition to EMs is obvious and inevitable, and the transition has a promising future as the demand for EMs increases day by day.

Electric motorcycles use traction battery or rechargeable battery to power electric motors. A traction battery is commonly a lithium-ion battery, which has many desirable characteristics such as high efficiencies, a long cycle life, high energy density, and high-power density (Da Deng, Li-ion batteries, 2015).

This paper study about EM’s performance using Electric motorcycle modeling combined with a road test. The main factors considered in this study are the energy consumption of different velocities, as well as driving and charging efficiencies. The routes were monitored in the city, covering a wide range of driving and operating conditions. As a result, the EM’s performance characteristics are evaluated, and the efficiencies of EMs are obtained. Based on the result, an optimal plan for prolonging battery life while remaining at a high efficiency has been designed for future improvement.

2 The Electric Motorcycle Modeling

The energy consumed by the EM was modeled using the block diagram shown in Fig. 1 (Muhammad, 2022). This was determined by the amount of energy necessary to operate the electric scooter or to power its load attachments. Meanwhile, the needed energy was calculated by its dynamic properties. As a result, the longitudinal modeling of the scooter was necessary.

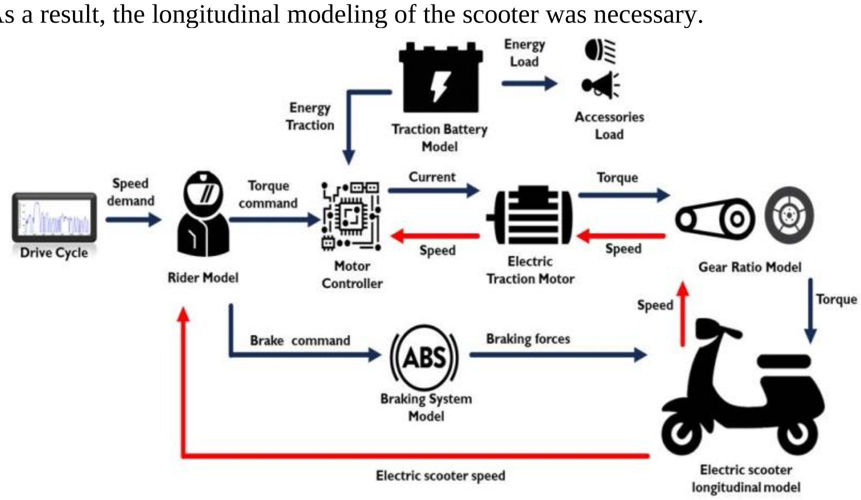

Figure 1: Electric motorcycle energy flows model architecture.

The source of electric energy was drawn from the traction battery. According to the conservation energy laws, the total energy input is equal to the total energy output and energy loss, hence:

$$E_{Batt} = E_{Tractrion} + E_{Load} + E_{Loss} - E_{Regen} \quad (1)$$

where, $E_{Traction}$ is the total energy required for moving the vehicle; E_{Load} is the total energy to power up any accessories found in the vehicle; E_{Loss} is the total energy loss due to inefficiency in the vehicle energy conversion and E_{Regen} is defined as the total energy generated during vehicle regenerative braking events, respectively.

According to (Abousleiman, Rami, 2015), it is defined that $E_{Traction}$ + E_{Load} + E_{Loss} is equivalent to the total energy drawn from the battery and it is denoted as E_{Batt_out}. Therefore, (1) can be rewritten as:

$$E_{Batt} = E_{Batt\_out} - E_{Regen} \quad (2)$$

it can be expressed as:

$$E_{Batt} = \int_{Traction} P_{Batt\_out}(t)\,dt - \int_{Regen} P_{Batt\_in}(t)\,dt \quad (3)$$

$$P_{Batt\_out} = \frac{R_{Total} \cdot V_{EM}}{\eta_{PowerTrain}} \quad (4)$$

$$P_{Batt\_in} = \beta \cdot P_{Regen} \quad (5)$$

where, P_{Batt_out} is the total power (including loss) to propel the EM. The traction battery should be able to supply all the power required to drive the motor (overcome all of the resistive force (R_{Total}) and losses in its power transmission ($\eta_{PowerTrain}$) system) at a specified velocity (V_{EM}). P_{Batt_in} is the total energy recovered by the traction battery during regenerative braking.

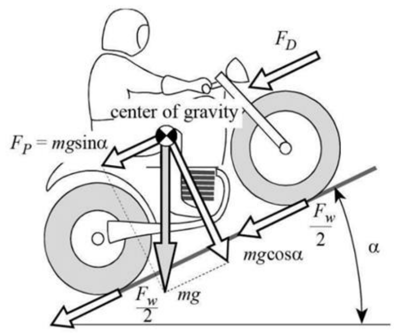

Figure 2: Electric motorcycle dynamics longitudinal with rider diagram

The total resistive force of the motorcycle when moving can be derived from its dynamic equation of motion. This was determined using the longitudinal model shown in Fig. 2 (Vittore, 2006).

In Fig. 2, the total resistive forces for a moving electric scooter in an inclination road angle of α (using the longitudinal model) can be derived as follows.

$$R_{Total} = F_{Traction} \quad (6)$$

$$P_{Wheel} = F_{Traction} \cdot V_{EM} \quad (7)$$

$$F_{Traction} = F_{Drag} + F_{RollingResistance} + F_{Grade} + F_{Inertia} \quad (8)$$

where,

$$F_{Drag} = \frac{1}{2}\rho \cdot C_d \cdot A_f \cdot V_{EM}^2 \quad (9)$$

$$F_{RollingResistance} = C_{RR} \cdot M_{EM} \cdot g \cdot cos\alpha \quad (10)$$

$$F_{Grade} = M_{EM} \cdot g \cdot sin\alpha \quad (11)$$

$$F_{Inertia} = M_{Intertia} \cdot a \quad (12)$$

$$M_{Intertia} = \varepsilon_i \cdot M_{EM} \quad (13)$$

The efficiency of the powertrain is described by (4). It is also calculated using the resulting energy (14). This energy (E_{Wheel}) is defined as the output energy, and it is computed based on a time, force and speed measurement. The energy flows from the battery (E_{Batt_out}) of the vehicle to the electric motor.

$$\eta_{PowerTrain} = \frac{E_{Wheel}}{E_{Batt\_out}} \cdot 100\% \quad (14)$$

Based on (1) to (14), it is easy to investigate and evaluate the motorcycle's performance characteristics via experimental process.

3 Road test process

Testing procedures and measurements on EMs are very important to obtain a reliable evaluation of their behavior and efficiency in day-by-day use as well as in non-usual road conditions. Therefore, our team has developed a complete testing method, which is described in this section.

3.1 Installation of monitoring equipment

To ensure high reliability and economic benefits, monitoring equipment could be selected from commercial products or developed by the testing requirements. Furthermore, these devices must comply with the manufacturer's or the technical safety test center's quality certificate. Based on the measuring standards, the following are the required measuring devices and functions:

Table 1: Technical description of the equipment

Monitoring equipment	Data acquired	Accuracy	Resolution
GPS Equipment Tracking	Speed (km/h); Time (s) Altitude (m); Location	Altitude 3 m Speed 0.1 km/h	0.1 km/h
Electric-Energy Meter	Consumption Charge Energy	1%	0.01 Wh
Battery Parameter Measuring	Voltage (V); Current (A)	Voltage 1% Current 2%	0.1 V 0.1 A
Human Machine Interface Display in EMs	SoC (%); Speed (km/h)	SoC 1% Speed 1 km/h	1% 1 km/h
Connected Vehicle Applications *(extra)*	Battery's temperature (ºC); Charge cycles; Configure	1ºC	1ºC

- **GPS Equipment Tracking**

The GPS tracking allows for collecting speed, location, and altitude information via an integrated barometric altimeter, which allows calculating road grades based on distance and altitude. The GPS tracking is carefully covered, to avoid pressure fluctuations due to the movement which could affect the altitude readings and an external antenna can be used to avoid GPS signal losses.

- **Battery Parameter Measuring**

Voltage probes are installed directly in the electric motorcycle battery terminals, while current measurements are done on the circuit that connects the battery to the electric motor. Current measurements are calibrated before each measurement, by performing a zero adjustment. The signals provided by the probes were collected by the main driver, capturing all the equipment readings on a 1 Hz basis. To avoid data loss while in motion a solid-state disk can be used.

3.2 Road test implementation

The experimental procedure was modeled according to the flowchart depicted in Fig. 3. The steps of installing components such as installing the battery, and monitoring equipment onto the vehicle are not depicted in Figure 3. This procedure is now complete and ready for testing.

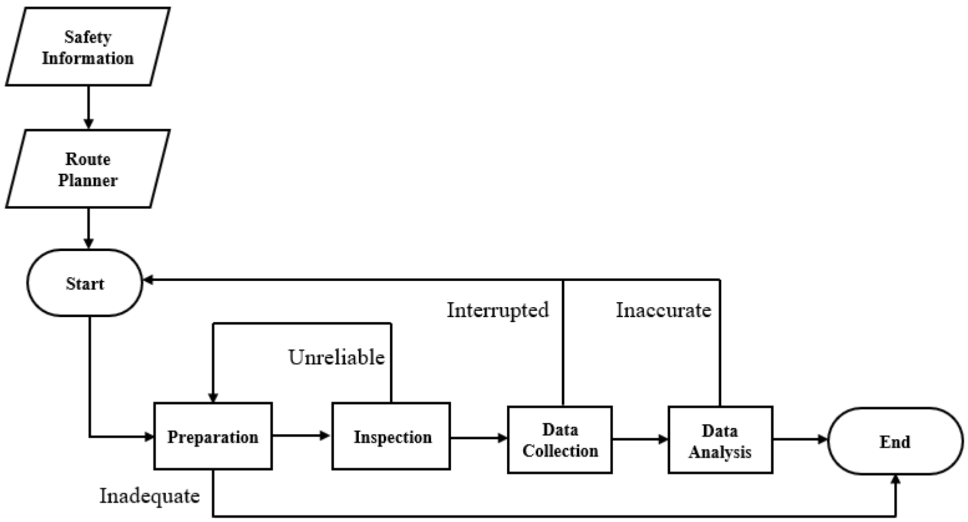

Figure 3: The experimental procedure flowchart

- **Safety Information**

To start the road test, the experimenters must have a clear understanding of the vehicle manual and how it works. In addition, driver's license is also required. The following safety information will be provided.

+ Before proceeding, make sure that you understand the operating procedures and are proficient in safe vehicle operations and skills.
+ Always comply with the safety regulations of the Road Traffic Safety Law, limit the speed, and do not drive faster than the prescribed speed. Pay attention to operating the vehicle depending on the condition of the road surface and traffic conditions.
+ Wear a helmet that has been tested for quality when riding.
+ Serious driving posture: Always keep your hands on the handlebar, both feet on the floor, and absolutely not use mobile phones or headphones while driving.
+ Remember to park or stop the vehicle on a flat and stable surface.
+ The civil voltage when charging the vehicle battery is 220V, the electrical system voltage on the vehicle higher than 48V can be dangerous for the experimenters.

- **Route Planner**

A route can be an urban, rural, or motorway with different operating conditions. Based on the Worldwide Harmonized Light Duty Test Cycle (WLTC), driving characteristics such as distance, duration, stop duration, and speed are evaluated in detail for each type of route. In addition, the traffic situation on this route is also assessed. As part of the evaluation of electric motorcycles operating in adverse conditions, a route with many intersections, high traffic density, and frequent traffic jams was selected. According to all the above, a route is appropriately selected to the vehicle's performance parameters and satisfies the operating conditions to achieve the experimenter's aim.

- **Preparation**

The preparation of monitoring equipment is carried out after understanding the safety information and selecting the proper route. Experimenters must have an EM's battery fully charged on hand. These requirements apply to all monitoring equipment, including GPS tracking battery and battery of parameter measurement. This battery is fully charged in order to limit the device's measurement error and interrupt the data collection process. In case, the mobile device connects to the EMs via an application, it must be fully charged and have the connection app downloaded.

- **Inspection**

During this time, all monitoring equipment is checked to ensure maximum accuracy. First, investigate GPS Tracking (time, time zone, unit; satellite connection status). Normally, the satellite signal will connect automatically between 30 and 120 seconds. However, keeps the standby state for 60 seconds after the GPS Tracking receives the satellite signal before moving. This is to stabilize the connection signal.

Second, check the application's vehicle connection status. The manufacturer has integrated an application that connects to the vehicle via mobile devices on the Android and iOS platforms in modern EMs. The application allows users to manage the vehicle by monitoring the battery, searching for a location, and managing the journey. Each manufacturer has its own vehicle management software; to perform the connection check, you must first read the user manual.

Check the battery parameter measuring as well. Next, inspect the vehicle's condition (tires, braking system, electric throttle,) before unlocking the electrical system for road test. Check the vehicle for foreign objects, obstacles, and problems in general; Squeeze the brakes one at a time, then push the vehicle forward and backward to check the brakes; Return to the top of the throttle position table by turning the lock to the OFF position, attempting to use and release the throttle to check possible operation; Check the pressure and wear of both tires. In case, the monitoring equipment is unreliable, it should be replaced with another device and re-checked.

- **Data collection**

Perform typical riding actions such as increasing and decreasing the throttle, stopping/parking traffic lights, and so on. During road test, data logging programs record information such as the date, time, speed, battery temperature, battery capacity, voltage, current, etc.

Suppose the data logging program or the driving process is interrupted caused by technical problems or a traffic incident. In that case, the obtained data must be discarded, and the preparation process must be restarted.

- **Data Analysis**

After the EM has completed its trip, stop it by returning the throttle to its original position and placing it on standby. Finally, the data logging program on monitoring equipment should be terminated. The data collected by the logging programs will be saved in a solid-state disk or the mobile device's internal memory. Continue by encrypting data, filtering, and sorting data.

During data collection, singular values will appear and falsify the analysis results. Therefore, to consider the accuracy of the results, it is necessary to compare the results with each other and compare them with the theoretical results calculated from section 2. As well as compare with the published results.

4 Case study applications in Ho Chi Minh, Vietnam

The procedure was applied in Ho Chi Minh city, Vietnam. The tested motorcycle technologies were two electric motorcycle model Impes manufactured by Vinfast LLC. This is presented in Fig. 4. The prototype specifications are shown in Table 2.

Figure 5 presented a route that was monitored on the HCMUT campus. Two volunteers 21 years-old and 65 kg weight performed the motorcycle route. The vehicle was monitored several times in each trip (up to 10 times) and the total distance traveled was of 400 km.

Figure 4: Tested vehicle, Impes

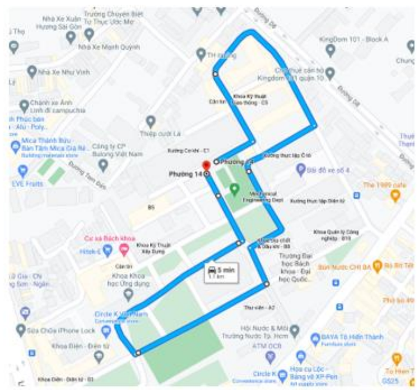

Figure 5: Case study route, Source: GG Maps

The monitoring device is equipped with a GPS to record the dynamic profile of the trip (including location and vehicle speed). Electric energy meter to assess the energy consumption by batteries charger. The description of the equipment used is presented in Table 3.

Table 2: Impes prototype specifications

Specifications	
Type	Electric scooter
Range per charge	70 km/charge
Top speed	49 km/h
Electric motor /power / Torque / max rpm	BLDC / 1.2 kW 80 N.m / 550 rpm
Battery / capacity	Li Ion (NMC) / 22 Ah
Charger type	400 W
L × W× H (mm)	1800 × 710 ×1070
Weight	75 kg

Table 3: Technical description of the equipment

Monitoring equipment	Accuracy
GPS (iGS130) (IGSPORT)	Altitude 3 m 95% of time
Pansong PS 178 (LSE)	Power meter ±1% of measured value

Based on the data obtained from the experimental procedure and the input parameters showed in Table 4, it can evaluate the motorcycle's performance characteristics via (1) to (14). Assume the route is flat ($\alpha = 0$). It is worth noticing that wind speed was not accounted. Since it is difficult to quantify intensity and direction in a second-by-second basis, even considering an average value of wind speed would not be representative, since it could have positive or negative impacts according with relative direction with the rider. However, it should be noticed that when the on-road monitoring was performed there were no windy days. (Magno Mendes, 2014)

Table 4: The electric motorcycles parameters for modeling

Parameter	Notes	Values	Units
M_{EM}	Total EM mass including its rider	140	kg
g	The gravitational constant	9.81	m/s^2
ρ	Air density	1.164	kg/m^3
A_f	Frontal area	0.65	m^2
C_d	The aerodynamic coefficient	0.75	-
C_{RR}	The rolling coefficient	0.014	-
ε_i	The effect of translational mass of powertrain rotating components	1.01	-

5 Results

The aim of the measurements is to determine the range of distance, compare the consumption of different velocities, as well as to see driving behavior. The results and conclusions below are expressed from current experimental data on the HCMUT campus.

5.1 Energy Consumption

The speed-dependent energy consumption data can be applied to clustered speed data from real-driving profiles. Figure 6 presents clustered data from a route.

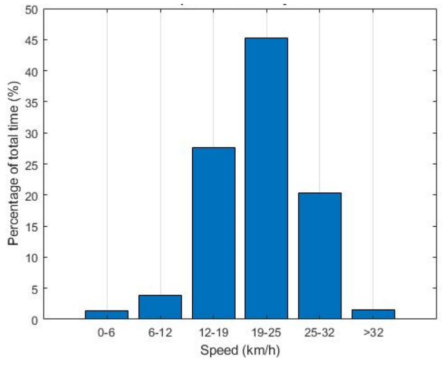

Figure 6: Percentage share of different velocities for a 24 km/h profile.

Table 5: Energy consumption

Average Speed (km/h)	Energy Consumption (Wh/10 km)
21	157.46
22	182.56
23	186.14
24	223.82
25	229.75
26	255.32
27	265.10

For each 10-kilometer distance, the maximum speed reached is 40 km/h meanwhile the average speed recorded is 21 - 27 km/h (higher speeds are not included as this is a HCMUT campus). It consumed between 14 and 23% SoC in battery. Furthermore, to avoid breaking the warranty of the vehicle, at the end of the test, 25% SoC in battery remainder is required, resulting in a total distance of approximately 40 km for each charging stroke.

Table 5 shows the energy consumed per 10 km at each different speed level. At 21 km/h the Impes consumed 157.46 Wh, which is less than half that at 27 km/h (265.10 Wh). It is comparable to the average energy consumption of electric motorcycles while driving in urban areas is 0.028 kWh/km (Koossalapeerom, 2018).

5.2 Powertrain Efficiency

Table 6 shows the resulting efficiencies for each velocity profile. The powertrain shows the worst efficiency with 72.20% in the profile with 21 km/h average speed. At low vehicle speeds, the efficiencies in the electric machine are low due to ohmic losses. In the mechanical drive train the efficiency is low due to a relatively high proportion of frictional losses. The best efficiency is achieved with the 27 km/h profile and is 87.36%. It is comparable to the electric vehicle powertrain efficiency ranges 73 ~ 90% (Jeong-Min Kim, 2019).

Table 6: Powertrain efficiency data.

Average Profile V_{EM} in km/h	21	22	23	24	25	26	27
$\eta_{PowerTrain}$ in %	72.20	77.00	78.34	78.59	78.93	85.93	87.36

6 Conclusion

In the present work, we have proposed a preliminary road test procedure used to measure and collect the performance characteristics data of electric motorcycles. A detailed description of the phase working, and the monitoring equipment is provided to highlight the requirements of each one. A most desirable feature of the present approach is its ability to provide energy consumption and travel distance as a function of velocity. These values are important if we intend to compare on-road tests to computational results since these are usually obtained for a predefined velocity.

The present approach was implemented to investigate an Impes electric motorcycle prototype in Ho Chi Minh, Vietnam. The approach successfully demonstrated the ability of the method to define the most adequate drive velocity for the vehicle. Since one of the primary goals of investigation is to achieve the best in energy efficiency.

On the other hand, the high-speed level is not reached when testing on the HCMCT campus. It means that the powertrain efficiency degradation at high speed is not investigated. As well as the peak efficiency is not defined, thus it must be conducted in future studies. The battery temperature is not monitored and recorded during experimental testing. In general, the battery temperature plays a major role in terms of a vehicle’s energy consumption. This temperature can deviate from the ambient temperature and thus the internal resistance of the battery also changes independent of ambient conditions and should also be considered in future studies.

Acknowledgement

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References

Anja Konzept , Benedikt Reick, André Kaufmann, Ralf Hermanutz, Ralf Stetter. (2022). *Battery Electric Vehicle Efficiency Test for Various Velocities.* Basel: MDPI .

Bogdan Ovidiu Varga , Arsen Sagoian and Florin Mariasiu. (2019). *Prediction of Electric Vehicle Range: A Comprehensive Prediction of Electric Vehicle Range: A Comprehensive.* Basel: MDPI.

Deng, D. (2015). Li-ion batteries: basics, progress, and challenges. *Energy Science and Engineering*, 385–418.

DJ Alexander, Amman Asfaw. (2020). *Electric Motorcycle Lithium-Ion Battery System.* San Luis Obispo: California Polytechnic State University.

Duc Nguyen Huu, Van Nguyen Ngoc. (2021). *Analysis Study of Current Transportation Status in Vietnam's Urban Traffic and the Transition to Electric Two-Wheelers Mobility.* Basel: MDPI.

Ir. W. Deloof, Ir. J. Van Mierlo, Ir. P. Van den Bossche, Ir. H. Jiang, Dr. K.B. Beya, Prof. Dr. Ir. G.Maggetto. (n.d.). *On-Road Measuring and Testing Procedures for Electric Vehicles.* Brussels: Vrije Universiteit Brussel.

Joris C Verster, Thomas Roth. (2011). Standard operation procedures for conducting the on-the-road driving test, and measurement of the standard deviation of lateral position (SDLP). *International Journal of General Medicine*, 359–371.

Kim, J.-M. (2019). Comparative Study of Powertrain Loss and Efficiency for the Electric Vehicle and Internal Combustion Engine Vehicle. *Journal of the Korean Society of Manufacturing Process Engineers*, 29-35.

Le Trong Hieu, Nguyen Xuan Khoa, Ocktaeck Lim. (2021). *An Investigation on the Effects of Input Parameters on the Dynamic and Electric Consumption of Electric Motorcycles.* MDPI: Basel.

Magno Mendes, Gonçalo Duarte, Patricia Baptista. (2014). *Introducing specific power to bicycles and motorcycles:.* Amstedam: Elsevier.

Martin Weiss, Kira Christina Cloos, Eckard Helmers. (2020). *Energy efficiency trade-offs in small to large electric vehicles.* New York: Springer Open.

Matthias Kerler, Peter Burday, Michael Baumannz, Markus Lienkampx. (n.d.). *A Concept of a High-Energy, Low-Voltage EV Battery Pack.* Munich: Institute of Automotive Technology.

Monica Tutuianu, Pierre Bonnel, Biagio Ciuffo, Takahiro Haniu, Noriyuki Ichikawa, Alessandro Marotta, Jelica Pavlovic, Heinz Steven. (2015). *Development of the World-wide harmonized Light duty Test Cycle (WLTC) and a possible pathway for its introduction in the European legislation.* Amstedam: Elsevier.

Muhammad Nur Yuniarto, Stefanus Eko Wiratno, Yoga Uta Nugraha, Indra Sidharta, Achimad Nasurddin. (2022). *Modeling, Simulation, and Validation of An Electric Scooter Energy Consumption Model: A Case Study of Indonesian Electric Scooter.* New York: IEEE.

Triluck Koossalapeerom, Thaned Satiennam, Wichuda Satiennam, Watis Leelapatra, Atthapol Seedam, Thana Rakpukdee. (2019). Comparative Study of Real-World Driving Cycles, Energy Consumption, and CO2 Emissions of Electric and Gasoline Motorcycles Driving in a Congested Urban Corridor. *Sustainable Cities and Society*, 619-627.