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Simulink-based powertrain validation of an archetype-driven electric motorcycle retrofit recommendation framework

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ABSTRACT

Retrofitting internal combustion engine (ICE) motorcycles into electric motorcycles offers a scalable pathway for transport electrification in motorcycle-dependent regions. A data-driven retrofit-as-a-service (RaaS) decision framework was previously developed that clusters motorcycles into five retrofit archetypes and maps each to electric vehicle component tiers, with feasibility assessed through a conservative steady-state lower-bound range estimate. That estimate, however, had not been validated against dynamic driving conditions, leaving its conservatism unverified. This paper presents a drive-cycle validation of the framework using a longitudinal powertrain model implemented in MATLAB and Simulink over a representative world motorcycle test cycle (WMTC). The simulation reproduces the transient acceleration and braking energy that the steady-state model omits. Results show that the original steady-state estimate was not conservative for lightweight archetypes, where simulated energy demand exceeded the analytical prediction. To address this, a speed-dependent transient correction factor is derived and frozen, restoring the lower-bound range to a true conservative floor across all five archetypes. The MATLAB and Simulink implementations agree to within 0.2 percent. The corrected lower bound remains below the simulated range in every case, with feasibility margins from 3.6 to 34 percent. The validated framework provides a defensible early-stage planning tool, with conversational decision support identified as future work.

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1. INTRODUCTION

Motorcycles are a major mode of transportation across Southeast Asia, accounting for nearly half of registered vehicles in motorcycle-dependent markets such as Malaysia [1], [2]. They support commuting, logistics, and last-mile mobility, making the existing fleet important to transport decarbonization. Retrofitting ICE motorcycles with electric powertrains offers a practical pathway to electrification while retaining the existing chassis and embodied value [3], [4]. Previous studies have demonstrated the feasibility of replacing

the ICE powertrain with an electric drivetrain, including a 250 cc-class motorcycle converted to a brushless DC motor system [5]. The retrofit process generally covers chassis assessment, component selection, installation, integration, and testing [6]-[8], but scaling these individual conversions into a consistent retrofit service remains challenging.

Despite its potential, motorcycle retrofitting remains largely manual and experience-driven. Installers vary in motor power, battery capacity, voltage, and controller ratings, leading to inconsistent outcomes [3]. Adoption is further influenced by conversion cost, perceived reliability, and limited standardized support networks [9], [10]. The absence of standardized testing, accreditation, and homologation also creates safety and regulatory uncertainty [3], [9]. These issues highlight the need for a structured decision-support methodology that produces transparent and reproducible component recommendations based on vehicle characteristics and expected performance.

Recent studies have applied data-driven methods to electric vehicle conversion and system optimization. Clustering and rule-based approaches support vehicle grouping and transparent component selection [11], while a conceptual RaaS architecture integrates data management, AI-assisted decision support, technician interaction, and evaluation [12]. Machine-learning methods have also been applied to battery estimation, component selection, and energy management [13]-[15]. Building on these developments, a framework for motorcycles up to 900 cc grouped vehicles into five retrofit archetypes and assigned motor, voltage, controller, and battery tiers using a lower-bound range estimate [16], but dynamic validation remained unaddressed.

The principal gap is the lack of dynamic validation of the existing feasibility estimates, which were derived from a steady-state cruise model at a single reference speed for each motorcycle archetype [16]. This approach does not capture transient effects such as acceleration and deceleration, which may increase energy demand, particularly for lightweight motorcycles, and could therefore compromise the conservatism of the predicted range. In addition, the framework provides component tiers rather than specific ratings, limiting its practical use for procurement and workshop implementation. Dynamic validation is therefore required to verify the range estimates and translate the archetypes into actionable component specifications.

This study dynamically validates the archetype-based RaaS framework using a WMTC drive cycle and a longitudinal powertrain model. It assesses the conservatism of the steady-state range estimate, derives a speed-dependent transient correction factor, and extends the framework to specific component selections with indicative costs. It also independently verifies the analytical, MATLAB, and Simulink implementations, which agree within 0.2%.

2. METHOD

2.1. Validation design

Each archetype representative is simulated over the WMTC using a longitudinal powertrain model implemented independently in MATLAB and Simulink. The analytical estimate, MATLAB result, and Simulink result are compared, and when the steady-state estimate is non-conservative, a correction factor is derived, frozen, and re-evaluated. This approach validates the conservatism of the original framework by capturing transient acceleration and braking dynamics that steady-state models omit.

2.2. Representative drive cycle

A representative WMTC profile defined under UNECE Global Technical Regulation No. 2 is used for class 1 and 2 motorcycles up to about 900 cc [17]. The 1 Hz cycle contains acceleration, cruise, deceleration, and idle segments, with a maximum speed of 80 km/h, mean speed of about 49 km/h, duration of 475 s, and distance of 6.51 km. The cycle is deterministic and reproducible, with no random elements, and is shown in Figure 1.

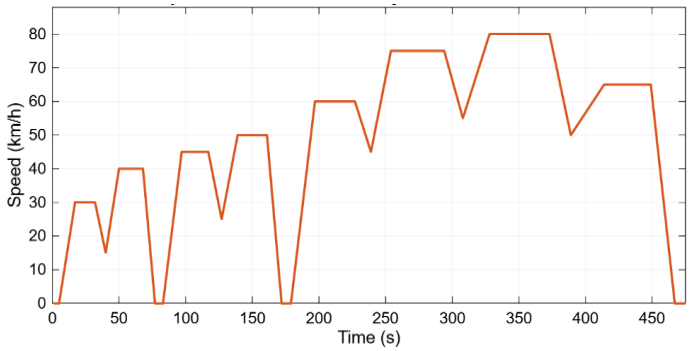

Figure 1. Representative WMTC drive cycle used for simulation

2.2.1. Software implementation and reproducibility

The model was implemented independently in MATLAB R2023b and Simulink. Similar MATLAB/Simulink powertrain modelling and drive-cycle validation approaches have been demonstrated for electric vehicles [18], [19]. MATLAB used 1 Hz discrete time stepping over the 475 s WMTC, while Simulink used variable-step ode45 with relative and absolute tolerances of 1e-3 and 1e-6. The predicted ranges differed by 0.2%, confirming numerical consistency; the MATLAB code is archived in Zenodo for reproducibility.

2.3. Longitudinal powertrain model

The longitudinal model resolves the tractive force into rolling, aerodynamic, and inertial components at each time step. The formulation follows established vehicle powertrain simulation practice [20]:

$$F_{roll} = mgC_{rr} \tag{1}$$

$$F_{aero} = \frac{1}{2}\rho C_d A v^2 \tag{2}$$

$$\mathrm{F_{inert}} = \mathrm{ma} \tag{3}$$

$$F_{grade} = mg\sin(\theta) \tag{4}$$

$$F_{trac} = F_{roll} + F_{aero} + F_{inert} + F_{grade} \tag{5}$$

where m is the combined vehicle and rider mass, g is gravitational acceleration, C_{rr} is the rolling resistance coefficient, rho is air density, C_{dA} is the effective drag area, v is speed, a is acceleration, and theta is the road grade angle. The rolling-resistance coefficient is taken within a band consistent with pneumatic tires on paved surfaces [21], and the aerodynamic term follows the standard drag relationship [22]. Wheel power is:

$$P_{wheel} = F_{trac} v \tag{6}$$

Battery-side power applies the drivetrain efficiency to traction and recovers braking energy at a regenerative efficiency η_{regen}:

$$P_{batt} = \frac{P_{wheel}}{\eta_{drv}}, \quad P_{wheel} \geq 0 \tag{7}$$

$$P_{batt} = P_{wheel}\eta_{regen}, \quad P_{wheel} < 0 \tag{8}$$

Battery energy over the cycle is the time integral of P_{batt}, and distance is the time integral of v. The simulated energy intensity is:

$$e_{sim} = \frac{E_{cycle}}{d_{cycle}} \tag{9}$$

and the simulated range is:

$$Range_{sim} = \frac{E_{use}}{e_{sim}} \tag{10}$$

where E_{use} is usable pack energy. To support component sizing, the model also records the peak wheel power over the cycle, the peak wheel torque.

$$T_{wheel} = F_{trac} R_{wheel} \tag{11}$$

Using a drive-wheel radius R_{wheel} of 0.28 m, the required motor rating is estimated as the peak wheel power divided by the drivetrain efficiency. A road-grade force term:

$$F_{grade} = mg\sin(\theta) \tag{12}$$

is included in the tractive-force summation for completeness; it is evaluated at theta = 0 for the present flat-cycle results.

The framework feasibility model that this simulation evaluates uses a resistive-loss cruise formulation in which the required traction power is (13).

$$P_{req} = \frac{(mgC_{rr}+0.5\rho C_d A v^2)v}{\eta_{drv}} \quad (13)$$

The conservative upper-bound energy intensity is (14):

$$e_{UB} = \frac{P_{req}}{v} \quad (14)$$

and the conservative lower-bound range is (15):

$$Range_{LB} = \frac{E_{use}}{e_{UB}} \quad (15)$$

with bounded upper-bound parameters for rolling resistance and drag area [16]. The simulation uses the same bounded parameters (C_{rr} = 0.015, C_{dA}= 0.45, η_{drv} = 0.85, rho = 1.225 kg/m^3, usable-energy fraction 0.85), with η_{regen} = 0.35 and a rider mass of 75 kg, so that any difference between framework and simulation arises from transient dynamics rather than from parameter changes.

2.4. Simulink implementation

The longitudinal model was implemented as equivalent MATLAB code. A Simulink block diagram was also developed, as shown in Figure 2, following established MATLAB/Simulink powertrain modelling practice [23]. The same drive-cycle inputs were applied to both models, and their outputs were cross-checked for all archetypes.

2.4.1. Model assumptions and limitations

The model assumes a constant drivetrain efficiency (η_{drv} = 0.85) and a fixed regenerative efficiency (η_{regen} = 0.35). It also assumes zero road grade, a rider mass of 75 kg, and sea-level air density [24], [25]. These assumptions are suitable for early-stage planning and can be refined using efficiency maps and state-dependent models.

2.5. Transient recalibration

When the steady-state estimate is not conservative against the dynamic cycle, a speed-dependent transient correction factor kappa is introduced to scale the steady-state energy intensity:

$$e_{UB} = \kappa(v_{ref})\, e_{steady_state} \quad (16)$$

$$\kappa(v_{ref}) = \max(1,\ c_0 - c_1 v_{ref}) \quad (17)$$

The coefficients are fitted across the archetype representatives, then frozen and used to recompute the lower-bound range. κ exceeds unity at low reference speeds to account for transient energy and returns to unity above the threshold where the steady-state estimate is already conservative.

$$Range_{LB} = \frac{E_{use}}{e_{UB}} \quad (18)$$

2.6. Validation acceptance criteria

The acceptance criteria are ΔR% < 1% for MATLAB–Simulink agreement and positive feasibility margins for all archetypes, with no margin below 2%. The 1% threshold ensures numerical consistency between the two independent implementations. The 2% minimum margin requirement maintains conservatism to account for modeling uncertainties and field implementation variations.

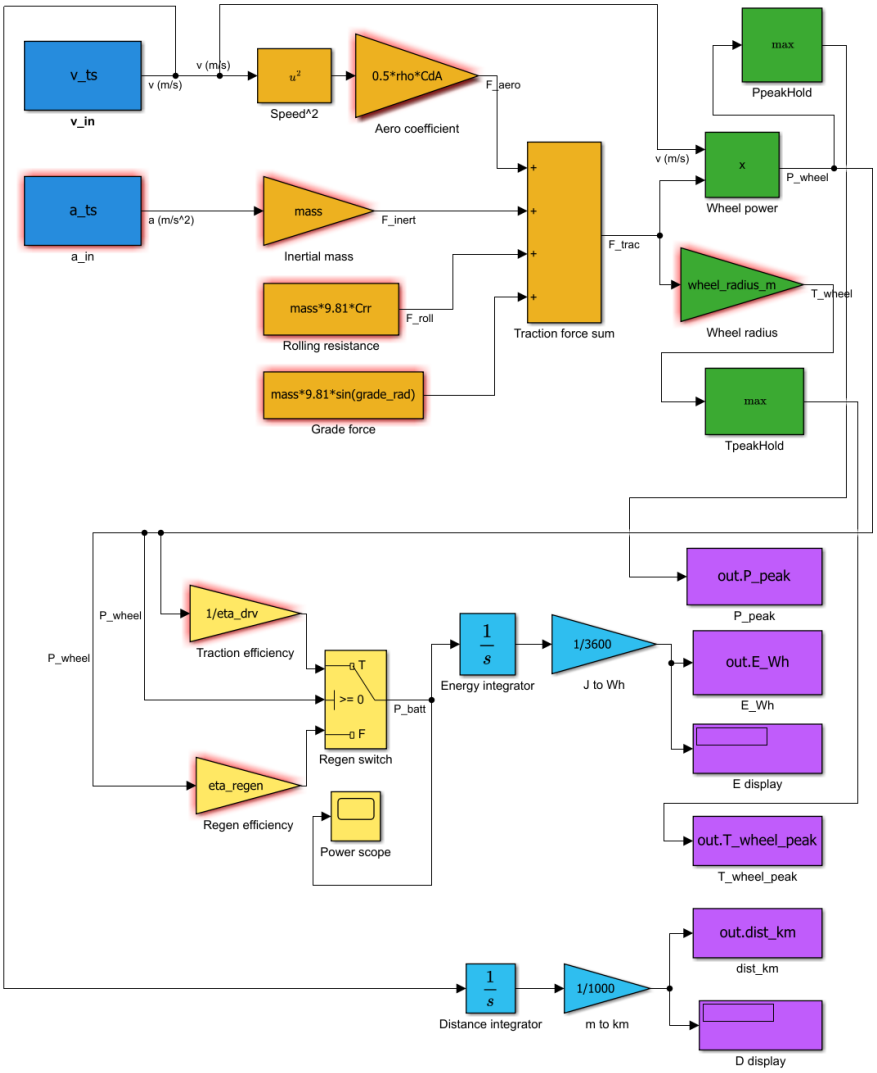

Figure 2. Simulink block diagram of the longitudinal powertrain model; displayed values correspond to the F1 representative case

3. RESULTS AND DISCUSSION

3.1. Model consistency

MATLAB and Simulink agree within 0.2% in predicted range across all five archetypes. This agreement confirms the numerical equivalence of the two models. The small difference arises from continuous-time solver integration in Simulink compared with 1 Hz discrete integration in MATLAB.

3.2. Conservatism of the steady-state estimate

The lightweight archetypes show steady-state energy intensity below the dynamic result, so the original lower-bound range was not conservative. Repeated acceleration in the WMTC introduces inertial energy demand not captured by the single-speed cruise model. For heavier archetypes, higher reference speeds and aerodynamic drag make the steady-state estimate conservative.

3.3. Recalibrated feasibility

After calibration, κ decreases from about 1.47 at 50 km/h to unity at roughly 65–70 km/h. The corrected lower-bound range falls below the simulated range for all five archetypes, with feasibility margins of 3.6–34%. Table 1 presents the recalibrated framework range estimates and feasibility margins for each archetype. The stricter energy model also increases the battery tier for F1 and F2 from 2.5 to 3.5 kWh and from 3.5 to 5.0 kWh, respectively.

Table 1. Framework lower-bound range (recalibrated) versus WMTC simulated range

Archetype	v_{ref} (km/h)	$Range_{LB}$ (km)	$Range_{sim}$ (km)	Margin (%)
F1	50	76.5	79.2	+3.6
F2	55	101.1	106.1	+5.0
F3	60	108.3	112.7	+4.0
F4	70	123.1	134.9	+9.6
F5	80	160.5	215.2	+34.1

Figure 3 compares the recalibrated lower bound with the simulated range per archetype, and Figure 4 compares the corresponding energy intensities. A side effect of the stricter energy model is that the range-stretch refinement rule escalates the battery tier for the two lightest archetypes, from 2.5 to 3.5 kWh for F1 and from 3.5 to 5.0 kWh for F2, to preserve feasibility. This demonstrates the recommendation logic responding correctly to the corrected demand.

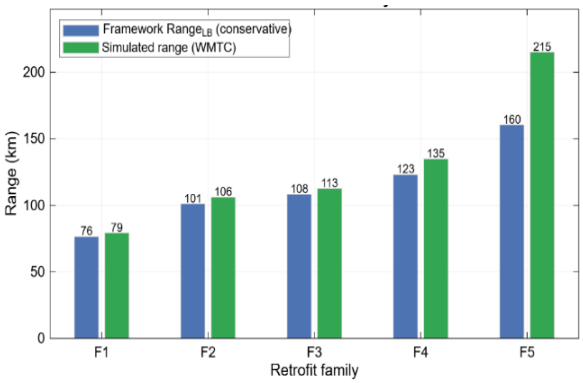

Figure 3. Conservative framework: estimates vs dynamic simulation

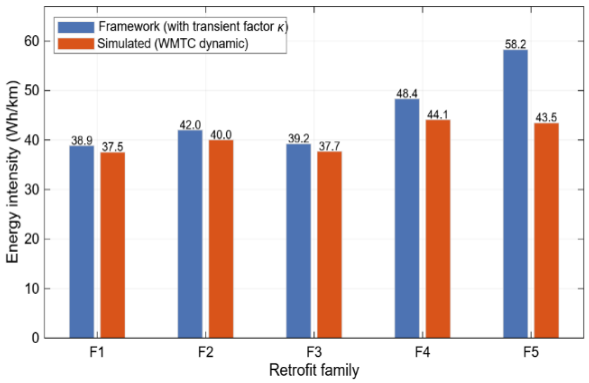

Figure 4. Energy intensity: framework vs dynamic cycle

3.4. Motor and torque sizing

The longitudinal model also reports three sizing indicators evaluated over the drive cycle: the peak wheel power, the peak wheel torque, and the corresponding required motor rating, taken as the peak wheel power divided by the drivetrain efficiency. These quantities support motor and inverter selection, which the tier labels alone do not specify. Table 2 reports the values for the five representatives. The required motor rating is 5.8–7.7 kW across the five archetypes, indicating that a 6–8 kW class motor covers the evaluated range. A reported 5 kW BLDC retrofit for a 250 cc-class motorcycle [5] supports the plausibility of the sizing results.

Table 2. Sizing indicators over the WMTC cycle (flat road)

Archetype	Peak wheel power (kW)	Peak wheel torque (Nm)	Required motor rating (kW)
F1	4.97	75	5.84
F2	5.57	88	6.55
F3	5.01	76	5.90
F4	6.53	108	7.69
F5	6.38	105	7.50

3.5. Component and cost outcomes

The framework also resolves the tier labels into specific components covering the motor, controller, battery, BMS, DC-DC converter, throttle, charger, contactor, and instrumentation. Indicative totals are provided in Table 3 for early-stage budgeting. Indicative component totals increase from about USD 1,160 for F1 to USD 3,900 for F5, driven mainly by battery and motor tiers. The estimates exclude labor and import duties and are intended for planning rather than procurement quotations.

3.6. Comparison with previous studies

The 5.8–7.7 kW motor requirements are consistent with practical retrofit implementations, including a reported 5 kW BLDC conversion [5], while the feasibility margins of 3.6–34% support the use of the

framework as a planning-level tool [11]. The higher transient energy demand observed for lightweight archetypes is also consistent with the importance of dynamic effects reported in EV energy-management studies [14]. The corrected range, specific component selections, and simple $\kappa(v_{ref})$ formulation therefore provide practical support for workshop planning and future decision-support tools.

Table 3. Indicative component cost per archetype

Archetype	Battery (kWh)	Indicative component total (USD)
F1	2.5	1,158
F2	3.5	1,518
F3	5.0	2,163
F4	7.0	2,493
F5	11.0	3,903

3.7. Discussion and limitations

The recalibrated framework provides a conservative range estimate under the evaluated WMTC conditions, but several limitations remain. Recent validated electric-motorcycle studies likewise emphasize the importance of measured drive cycles, terrain, payload, and component behavior when assessing energy consumption [26], [27]. The cycle is representative rather than locally measured; road grade is zero; mass excludes equivalent rotational effects; drivetrain and regenerative efficiencies are fixed; and the battery is represented by usable energy rather than a full SOC/SOH model. Because κ is calibrated and evaluated within the same simulation framework, its conservatism is internal rather than experimentally validated. Instrumented road testing is therefore required to establish broader applicability.

4. CONCLUSION

This study developed a longitudinal powertrain model for electric motorcycle retrofit energy estimation and independently implemented it in MATLAB and Simulink. The model was evaluated using the WMTC to dynamically validate an archetype-based RaaS framework, after which the range estimation was recalibrated to provide conservative feasibility bounds under transient operation. The original steady-state estimate was not conservative for lightweight archetypes because repeated WMTC acceleration introduced inertial energy demand. A speed-dependent correction factor κ restored the conservative lower-bound range across all archetypes, with margins of 3.6–34%. Motor sizing indicated 6–8 kW classes for the evaluated archetypes, while MATLAB and Simulink agreed within 0.2%.

Validation was limited to one WMTC cycle and simplified assumptions for road grade, mass, drivetrain efficiency, regenerative braking, and battery behavior. The correction factor was internally calibrated and requires independent field validation. The framework also covers motorcycles up to 900 cc and has not yet been validated with measured vehicle data. Future work should prioritize instrumented road testing, additional driving cycles, variable road grade and payload, efficiency maps, state-dependent regenerative braking, and a more comprehensive battery model. Extension to larger motorcycles and integration with conversational decision-support interfaces are also promising directions.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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Siti Fauziah Toha	✓	✓					✓	✓	✓	✓	✓	✓	✓	✓
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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

The MATLAB and Simulink models, the drive-cycle definition, the parameter files, and the result files that support the findings of this study are openly available in Zenodo at https://doi.org/10.5281/zenodo.20761879.

REFERENCES

[1] International Energy Agency, "Global EV outlook 2025," 2025. [Online]. Available: www.iea.org

[2] Government of Malaysia, "Vehicle registrations," data.gov.my, 2024. [Online]. Available: https://data.gov.my/dashboard/vehicle-registrations/motorcycle

[3] R. Watts, A. Ghosh, and J. Hinshelwood, "Exploring the potential for electric retrofit regulations and an accreditation scheme for the UK," *Electronics*, vol. 10, no. 24, Dec. 2021, doi: 10.3390/electronics10243110.

[4] A. D. Santoso *et al.*, "Conversion of motorcycles to electric vehicles towards sustainable mobility," *Global Journal of Environmental Science and Management*, vol. 10, no. SI, pp. 181–200, 2024, doi: 10.22034/gjesm.2024.10.SI.12.

[5] M. Ramadhan, D. S. Putra, W. Purwanto, M. Y. Setiawan, and M. Muslikhin, "Implementation of Conventional Motorcycle Conversion into Electric Motorcycle Using BLDC Motor and LiFePO4 Battery," *MOTIVECTION : Journal of Mechanical, Electrical and Industrial Engineering*, vol. 6, no. 3, pp. 281–292, Oct. 2024, doi: 10.46574/motivection.v6i3.339.

[6] A. Habibie and W. Sutopo, "A literature review: commercialization study of electric motorcycle conversion in Indonesia," *IOP Conference Series: Materials Science and Engineering*, vol. 943, no. 1, 2020, doi: 10.1088/1757-899X/943/1/012048.

[7] F. Hoeft, "Internal combustion engine to electric vehicle retrofitting: Potential customer's needs, public perception and business model implications," *Transportation Research Interdisciplinary Perspectives*, vol. 9, 2021, doi: 10.1016/j.trip.2021.100330.

[8] A. Habibie and W. Sutopo, "A literature review: commercialization study of electric motorcycle conversion in Indonesia," *IOP Conference Series: Materials Science and Engineering*, vol. 943, no. 1, Oct. 2020, doi: 10.1088/1757-899X/943/1/012048.

[9] M. Rizki, O. Rossolov, and Y. O. Susilo, "The barriers, determinants, and willingness-to-pay in electric motorcycle conversion (EMC) adoption," *Energy Policy*, vol. 195, Dec. 2024, doi: 10.1016/j.enpol.2024.114361.

[10] R. Zaino, V. Ahmed, A. M. Alhammadi, and M. Alghoush, "Electric vehicle adoption: a comprehensive systematic review of technological, environmental, organizational and policy impacts," *World Electric Vehicle Journal*, vol. 15, no. 8, Aug. 2024, doi: 10.3390/wevj15080375.

[11] N. Bocaneala, M. Mayouf, E. Vakaj, and M. Shelbourn, "Artificial intelligence based methods for retrofit projects: a review of applications and impacts," *Archives of Computational Methods in Engineering*, vol. 32, no. 2, pp. 899–926, Mar. 2025, doi: 10.1007/s11831-024-10159-7.

[12] B. Nolte *et al.*, "Retrofit as a module driver: enabling circular and service-oriented vehicle architectures," *Procedia CIRP*, vol. 140, pp. 533–538, 2026, doi: 10.1016/j.procir.2026.05.090.

[13] M. Cavus, D. Dissanayake, and M. Bell, "Next generation of electric vehicles: ai-driven approaches for predictive maintenance and battery management," *Energies*, vol. 18, no. 5, Feb. 2025, doi: 10.3390/en18051041.

[14] L. Kopp, N. Ockert, L. Cadau, and M. Kley, "Development of a digital twin of a powertrain for efficiency estimations with machine learning and physical modeling," *Advanced Modeling and Simulation in Engineering Sciences*, vol. 13, no. 1, Jun. 2026, doi: 10.1186/s40323-026-00333-w.

[15] J. B. Kondru and Y. P. Obulesu, "Machine learning techniques for the multi-state estimation of electric vehicle batteries: A comprehensive review," *Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering*, May 2026, doi: 10.1177/09544070261446990.

[16] A. Alqedra, S. F. Toha, M. Abdullah, A. S. Idris, R. Ibrahim, and S. Ahmad, "Data-driven decision framework: electric motorcycle archetype clustering for retrofit-as-a-service," in *2026 12th International Conference on Communication and Signal Processing (ICCSP)*, IEEE, Apr. 2026, pp. 1–6, doi: 10.1109/ICCSP68173.2026.11539451.

[17] United Nations Economic Commission for Europe, "Global Registry: Addendum 2: united nations global technical regulation No. 2: united nations global technical regulation on measurement procedure for two-wheeled motorcycles equipped with a positive or compression ignition engine with regard to the emiss," 2022. [Online]. Available: https://unece.org/transport/standards/transport/vehicle-regulations-wp29/global-technical-regulations-gtrs
[18] F. Adegbohun, A. von Jouanne, B. Phillips, E. Agamloh, and A. Yokochi, "High performance electric vehicle powertrain modeling, simulation and validation," *Energies*, vol. 14, no. 5, Mar. 2021, doi: 10.3390/en14051493.
[19] M. N. Yuniarto, S. E. Wiratno, Y. U. Nugraha, I. Sidharta, and A. Nasruddin, "Modeling, simulation, and validation of an electric scooter energy consumption model: a case study of Indonesian electric scooter," *IEEE Access*, vol. 10, pp. 48510–48522, 2022, doi: 10.1109/ACCESS.2022.3171860.
[20] K. B. Wipke, M. R. Cuddy, and S. D. Burch, "ADVISOR 2.1: a user-friendly advanced powertrain simulation using a combined backward/forward approach," *IEEE Transactions on Vehicular Technology*, vol. 48, no. 6, pp. 1751–1761, 1999, doi: 10.1109/25.806767.
[21] Jerzy A. Ejsmont, Beata Świeczko-Żurek, Grzegorz Ronowski, and J. Wilde, "Rolling resistance measurements at the MnROAD facility, round 2," 2014. [Online]. Available: http://www.lrrb.org/pdf/201429.pdf
[22] Z. Wei, "Electro-mechanical braking system development and hybrid electric vehicle power management for urban driving," University of Nottingham, 2017.
[23] MathWorks, "Define virtual vehicle components: motorcycle," *MATLAB & Simulink Help Center*, 2026. https://www.mathworks.com/help/autoblks/ug/define-virtual-vehicle-components-motorcycle.html
[24] K. B. Wipke, M. R. Cuddy, and S. D. Burch, "ADVISOR 2.1: a user-friendly advanced powertrain simulation using a combined backward/forward approach," *IEEE Transactions on Vehicular Technology*, vol. 48, no. 6, pp. 1751–1761, 1999, doi: 10.1109/25.806767.
[25] E. M. Szumska, "Regenerative braking systems in electric vehicles: a comprehensive review of design, control strategies, and efficiency challenges," *Energies*, vol. 18, no. 10, May 2025, doi: 10.3390/en18102422.
[26] L. Kopp, N. Ockert, L. Cadau, and M. Kley, "Development of a digital twin of a powertrain for efficiency estimations with machine learning and physical modeling," *Advanced Modeling and Simulation in Engineering Sciences*, vol. 13, no. 1, Jun. 2026, doi: 10.1186/s40323-026-00333-w.
[27] H. Adams, S. Botha, and M. J. Booysen, "A validated physics-based powertrain model for an electric motorcycle in sub-saharan africa," *World Electric Vehicle Journal*, vol. 17, no. 2, Feb. 2026, doi: 10.3390/wevj17020090.

BIOGRAPHIES OF AUTHORS



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