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Research Paper

A Comprehensive Study of Electric Vehicle Performance under Diverse Powertrain Architecture using 1D Simulation Approach

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Abstract

Electric vehicles (EVs) are becoming popular because of their potential for reducing carbon emissions and promoting sustainable transportation. However, the driving range and energy consumption performance could be a limitation on EVs' performance, which are influenced by various technical and environmental factors. This study investigates the effects of key powertrain parameters of EVs, such as battery capacity, motor efficiency, motor power, and transmission setup, on the driving range and energy consumption of EVs through simulation analysis. The Nissan Leaf and Hyundai Kona, two different EV model categories from the hatchback and Sport Utility Vehicle (SUV), were selected for analysis using 1D simulation method. The models were tested under two standardized driving cycles, which are the New European Driving Cycle (NEDC) and Worldwide Harmonised Light Vehicles Test Cycle (WLTC). The validation results showed that the absolute percentage error is less than 10 % against the key technical specifications provided by the EV manufacturers. This study considered variations in battery capacity (±30%), motor power (±30%), motor efficiency (-15% to 5%), and transmission configurations. The outcomes from this study showed that battery capacity performance, motor efficiency, and transmission gear ratio configuration significantly impacted the driving range performance. In contrast, only motor efficiency and transmission gear ratio configuration significantly contributed to energy consumption performance. This research can be considered a benchmark in optimizing EV powertrain design, which can contribute to EV development in terms of cost and productivity.

Keywords: Driving range; Energy consumption; Electric vehicles; Powertrain configuration; 1D simulation

1. Introduction

The automotive industry has seen a drastic transition in recent. Electric vehicles (EVs) are emerging as leaders in the race for cleaner and greener modes of transportation. Besides that, EV applications are directly aligned with the United Nations' global Sustainable Development Goals (SDGs), especially SDG 7, which is Clean Energy, and also pave the way for action on SDG 13, which is on Climate Action for a low-carbon future. With the increase in environmental pollution and climate change, many countries, especially China and Europe, are promoting the use of EVs [1]. The adoption of EVs can be seen from the increase in global EV sales, while Global EV sales have increased from 3.2 million in 2020 to 17.1 million in 2024 [2], [3].

In Southeast Asia, particularly in Malaysia, the demand for EVs has shown a marked upward trend. Although petrol vehicles continue to dominate consumer preference, the adoption of EVs is steadily rising. According to the Malaysian

Automotive Association (MAA) [4], the number of registered EVs rose significantly to 63,906 units as of February 2025, representing a 31% increase compared to 48,732 units recorded in January 2024. This surge aligns with the broader recovery in the automotive market, where Total Industry Volume (TIV) demonstrated strong growth following a temporary decline in January.

The TIV for 2024 reached 816,747 units, exceeding the historical threshold target of 800,000 units for the first time in Malaysia's automotive history [5]. This robust performance reflects not only increased consumer confidence but also a stabilized macroeconomic environment. It was shown that Malaysia's economy exhibited resilience, as evidenced by a GDP growth rate of 5.2% during the first three quarters of 2024 [6].

Compared to internal combustion engine (ICE) vehicles, EVs have many advantages. The ultimate and undeniable reason is the reduction in the emission of harmful compounds at the place of use such as carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NO_x), hydrocarbons (HC) / volatile organic compounds (VOCs), sulphur dioxide (SO_2) and Ammonia (NH_3) other than emitted less noise and vibration during driving [7], [8], [9], [10]. Besides that, the efficiency of the EVs is significantly tremendous compared to an ICE vehicle. It is estimated that the efficiency of electric power by the electric motor is 90% - 98% [11], [12], [13]. Moreover, the torque generated by the electric motor is available almost from zero rotational speed. This allows the parameters of the electric motor driving the vehicle to be selected in such a way as to ensure that the driving speed can be changed within the required range without the use of an additional transmission [14].

Despite the significant development in electric vehicle technologies, the limitation of driving range and energy consumption remains one of the most critical concerns for both manufacturers and users [15]. This is influenced by the level of readiness of charging facilities. Like other developing countries, the level of readiness of charging facilities in Malaysia is still low and can be improved. This has also given rise to a new fear among EV owners called Range Anxiety [16], [17]. Range anxiety is the fear that EV users worry about an insufficient charge to complete their travel, and is still perceived to be one of the greatest barriers preventing fleets from going electric.

Range miscalculation is another significant issue where drivers either overestimate or underestimate the remaining battery life. This miscalculation can lead to situations where the vehicle unexpectedly runs out of charge, causing inconvenience and safety concerns. Advanced trip planning and more accurate real-time battery-monitoring systems are essential to minimize range miscalculations. Additionally, factors such as driving habits, weather conditions, and the use of in-car electronics can impact the actual range of an EV, making it more challenging for drivers to accurately predict their available range.

Previous studies have shown that powertrain configuration can affect EV fuel consumption and driving range. Tran *et. al.* [18] evaluated five different hybrid powertrain designs through MATLAB/Simulink simulations against performance targets that included acceleration, braking, driving range, fuel economy, and emissions. Although several configurations met most metrics, only one design fully satisfied all competition criteria which is the hybrid powertrain consisting of a 2.5 L internal combustion engine, a 150 kW electric motor with an integrated electronic drive unit, and a 133 kW battery pack. This design demonstrated the best overall balance of dynamic performance and efficiency among the alternatives considered, validating the effectiveness of model-based design and simulation tools in hybrid powertrain optimization. Du *et. al.* [19] proposed and compared several electric vehicle powertrain architectures, including traditional single-motor designs and three novel dual-motor coupling configurations, dual-motor multi-mode, torque-coupling, and speed-coupling systems through an optimization method using dynamic programming and an NSGA-II algorithm. The results demonstrate that dual-motor coupling powertrains significantly outperform conventional single-motor systems in terms of economic performance and energy consumption under different driving conditions.

Besides that, Ani *et al.* [20] investigated the energy and economic performance of the Hyundai Kona (EV) and Toyota Corolla (ICE) models. Over a similar driving distance, the Hyundai Kona consumed approximately 1.056 kWh, while the

Toyota Corolla consumed approximately 7.78 kWh. The results show that the EV standard using the default powertrain configuration can be more cost-effective, and through this study, questions may arise as to whether modifying this powertrain will affect or improve fuel consumption performance. Instead of focusing on powertrain configuration changes, Ristian *et al.* [21] proposed a novel control strategy to reduce battery energy consumption in electric vehicles. The EV model was integrated with a standard Linear Quadratic Integral (LQI) controller for both speed and torque regulation, based on linear or linearized system models. Their results demonstrated that the EV model equipped with a flexible shaft in the gear train exhibited improved dynamic response and consumed approximately 10% less energy compared to a model with a rigid shaft.

Furthermore, some researchers also investigate the motor configuration and cabin ambient temperature, such as Lekshmi and Lal Priya [22], where the torque distribution strategy in the motor is the objective of their study. The torque can be optimized to minimize energy consumption during driving and maximize regenerative energy recuperation during braking. Moreover, Iora and Tribioli [23] investigated the influence of ambient temperature on EV performance using a quasi-steady, backward-facing vehicle model calibrated with experimental data from the Nissan Leaf. Their results showed that lower ambient temperatures substantially increase auxiliary power demand, mainly due to cabin heating, thereby reducing driving range under standardized driving cycles. However, their analysis primarily focused on environmental effects rather than on the influence of powertrain configuration parameters on range and energy consumption.

Unlike prior studies that primarily focus on a specific area or subsection of EV configuration, such as battery chemistry advancements, charging infrastructure expansion, or high-level energy management strategies, this work presents a validated, systematic 1D simulation-based investigation of the electric vehicle (EV) powertrain architecture using two production EV platforms: the Nissan Leaf and the Hyundai Kona Electric. The novelty of this study lies in its structured parametric evaluation of key powertrain variables, including battery capacity scaling, motor characteristics, and transmission configuration, and their simultaneous impact on driving range, energy consumption, and acceleration performance under standardized driving cycles. By isolating vehicle-level design parameters from external dependencies such as charging infrastructure readiness and next-generation battery technologies, this research establishes a controllable optimization framework that quantifies the trade-offs between performance and efficiency across different vehicle categories.

In this context, optimizing the vehicle powertrain architecture emerges as a practical, immediately implementable solution to enhance EV performance. Critical factors such as battery capacity, motor efficiency, transmission effectiveness, and overall drivetrain configuration directly influence real-world energy consumption and achievable driving range. By systematically optimizing these technical elements, manufacturers can improve range prediction accuracy, extend the operational range, and reduce range anxiety without relying on external infrastructure expansion or disruptive battery innovations. This vehicle-centric approach therefore provides a scalable engineering pathway to strengthen EV competitiveness, particularly in emerging markets where charging networks remain underdeveloped.

The purpose of this research work is to investigate the factors that influence the EVs' performance in terms of driving range, energy consumption, and acceleration time under various powertrain configurations. This paper is organized into five (5) sections, beginning with an introduction and a brief review of relevant preliminary work on the EV performance in Section 1. Section 2 describes the development of the EV model using 1D simulation software, focusing on two vehicle categories: the Nissan Leaf (hatchback) and the Hyundai Kona (SUV). This section also outlines the performance influencing criteria and the driving protocols adopted for the simulation work. Then, a detailed explanation of the validation process is provided in Section 3, followed by the presentation of results and a discussion of the findings in Section 4. Finally, this work provides a summary of key insights and recommendations in Section 5.

2. Method

The method for this research was divided into several stages, focusing on building, simulating, and analysing the EV models in the 1D simulation software. The primary steps include defining the system layout, configuring powertrain components, conducting simulations, and interpreting results, which are explained in the next subsection. This approach enables the study of critical EV parameters under varying operational conditions and provides insights for performance improvement. Two (2) EV models were selected for the simulation work, which are the Nissan Leaf and the Hyundai Kona. These models were chosen due to their classification as compact and affordable EVs, which are widely available in the Malaysian market [24].

2.1. *Vehicle Modeling Description*

In this study, the general information of the standard-range variant of the Hyundai Kona was used, which states that this EV model was equipped with an electric motor delivering a maximum power of 100 kW at approximately 134 hp and a 39.2 kWh lithium-ion battery, with a single speed reduction gear transmission featuring a gear ratio of 7.981. Similarly, the standard-range variant of the Nissan Leaf (ZE1) is powered by an electric motor rated at 110 kW (at 147hp), supported by a 40 kWh lithium-ion battery, and features a single-speed reduction gear transmission featuring a gear ratio of 8.193. **Table 1** summarizes the key technical specifications of the Nissan Leaf and Hyundai Kona, as provided by the manufacturers, which were used in the simulation work.

To simulate both EV models, the GT-SUITE software was selected. GT- Suite is a product of Gamma Technologies (GTI), a specialist software company that is solely focused on the engine and vehicle industry [25]. Practically all leading engine makers and suppliers have chosen GT-SUITE because it is supplied as an all-inclusive package with many valuable productivity tools. These tools increase user efficiency, offering a versatile set of tools for simulation of vehicles with conventional, HEV, or EV drivelines, as well as the control systems and strategies that are keys to the operation of these vehicles [26]. It is also known as a unique tool that provides the ability to execute integrated simulations of the entire vehicle and engine system. The GT-SUITE software can also be used as an environment where all models undergo different driving cycles. The models predict vehicle performance criteria, including fuel economy, maximum and average acceleration, maximum & average speed, and vehicle and driveline energy losses. The results of the model show the significant benefits of EVs in terms of reducing fuel consumption, lowering running costs, and improving driving performance and ease of use.

The EV model based on the two (2) types of EV models was developed in the GT-SUITE software. The process begins with the comprehensive data collection and vehicle parameter definition phase, where all relevant technical data about the Nissan Leaf and Hyundai Kona were gathered, including the physical dimensions, battery specifications, motor characteristics, and drivetrain configuration. This data is essential for creating an accurate digital representation of the vehicle in the simulation environment.

By providing a realistic representation of the vehicle, detailed parameters enable reliable predictions of performance metrics such as acceleration, driving range, and energy consumption. Additionally, aerodynamic effects and drag forces are considered in this simulation. Several simplifying assumptions were adopted in the simulation, including constant ambient temperature, fixed battery state of charge (SOC), negligible battery degradation, a constant transmission efficiency, and thermal effects. Moreover, regenerative braking is considered negligible in this simulation. During constant-speed highway driving (such as the high-speed WLTC phase), regenerative braking has minimal impact because the vehicle seldom decelerates. This observation is supported by [27], which demonstrated that regenerative braking is rarely activated at high speeds due to the limited frequency and magnitude of deceleration events. Additionally, this study adheres to the standard laboratory conditions defined by WLTP and NEDC driving protocols. These standards require the vehicle to be tested in a controlled thermal environment. Therefore, ignoring extreme thermal transients ensures the simulation results are comparable with official manufacturer-reported fuel economy and range data [28].

Table 1. Nissan Leaf and Hyundai Kona technical specifications [29], [30], [31], [32]

Specification	Nissan Leaf	Hyundai Kona
Model Type	Hatchback	SUV
Torque	320 Nm	395 Nm
Weight	1940 kg	2020 kg
Aerodynamic Constant	0.28	0.29
Motor Power (kW)	110kW	100kW
Battery Size (kWh)	40kWh	39.2kWh
Battery Type	Laminated Lithium-Ion	Lithium-ion-Polymer
Tyre (size)	215/50 R17	215/55 R17
Range (km)*NEDC	305 km	311 km
Range (km)*WLTC	274 km	270 km
Top Speed	155 km/h	155 km/h
Acceleration	7.90 sec	9.9 sec

The detailed specifications of the EV vehicle body, electric motor, battery system, as well as the wheel and transmission configuration used in the GT-SUITE model are summarized in Tables A1–A5 in the Appendix section. **Figure 1** presents the subsystem of the EV that was developed in the 1D simulation model.

2.2. *Powertrain Variables*

Research on EVs has grown significantly in recent years as the transportation industry shifts toward electric mobility, especially in terms of driving range and energy consumption. The efficiency of battery technology is a cornerstone for determining the driving range and energy consumption performance of EVs. Studies have consistently emphasized that battery capacity, energy density, fuel consumption, and thermal management systems directly impact the driving range performance [33], [34]. For instance, lithium-ion batteries dominate the market due to their high energy-to-weight ratio, but their performance can be degraded by extreme temperatures and aging. Emerging technologies such as solid-state batteries promise to revolutionize the driving range by offering higher energy densities and enhanced safety.

The powertrain configuration, including the efficiency of electric motors and the transmission system, plays a significant role in determining the real-world range of EVs. Previous studies demonstrate that high-efficiency motors, such as PMSM, provide excellent torque delivery while minimizing energy losses [35], [36]. Powertrain simulations reveal that single-speed transmissions are ideal for urban and low-speed driving, while multi-speed configurations enhance efficiency in long-distance and high-speed scenarios. Researchers developed various simulation models to predict EV driving range under different conditions. Analytical and machine learning-based models are used to simulate battery performance, powertrain efficiency, and environmental impacts [37], [38]. These models were validated with real-world data to ensure accuracy and reliability. For example, studies using driving simulations across urban, suburban, and highway routes highlight the variations in range caused by stop-and-go driving, constant speeds, and changes in road gradients [39].

Previous studies on EV driving range emphasize the importance of battery technology, powertrain optimization, and environmental conditions in determining real-world performance [40], [41], [42], [43]. Advances in battery energy density, regenerative braking, and simulation models have significantly improved driving range. However, there remains a need for integrated studies that address the combined effects of vehicle components and driving conditions to develop more efficient and reliable EVs. Therefore, this research aims to investigate how these factors interact with one another and to identify optimal configurations of each criterias that maximize driving range while minimizing energy consumption.

Table 2 presents the summary of the criteria that were varied to evaluate their impact on the driving range, energy consumption, and acceleration time performance under both driving cycles (NEDC and WLTC driving cycles). Based on **Table 2**, a range 30% to -30% has been chosen to investigate the effect of changing battery capacity

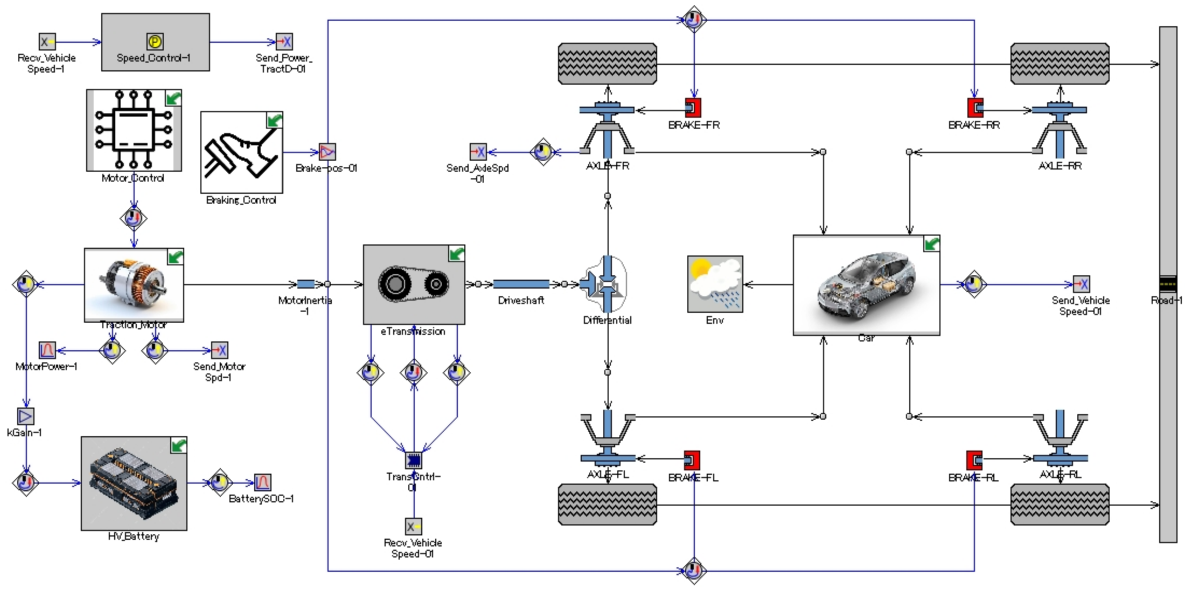

Figure 1. EV model in GT-SUITE

Table 2. Criteria of EV powertrain setup

Criteria	Nissan Leaf		Hyundai Kona	
	NEDC	WLTC	NEDC	WLTC
Battery capacity	-30% to 30%		-30% to 30%	
Motor power performance	-30% to 30%		-30% to 30%	
Motor efficiency	-15% to 5%		-15% to 5%	
Final gear ratio (transmission)	6.193, 7.193, 8.183, 9.193, 10.193		6.981, 7.981, 8.981, 9.981, 10.981	

and motor power performance on driving range and energy consumption of the EV. While the motor efficiency was selected from -15% to 5% relative to the baseline. The ±30% range has been selected for battery capacity and motor power because these variables represent core design choices with significant effects on vehicle energy consumption and performance, a range consistent with design-optimization studies in the literature [44], [45]. Besides that, motor efficiency was varied within a narrower band (−15 % to +5 %) because these parameters are typically optimized within a constrained operational range in production EVs. Larger deviations in efficiency or gear ratio are not representative of feasible motor designs or drivetrain architectures [46], [47]. Additionally, selecting 2000 rpm as the motor efficiency evaluation point in the GT-SUITE EV performance investigation is based on its representativeness of typical real-world operating conditions for passenger battery electric vehicles. At approximately 2000 RPM, the motor typically operates within the constant-torque region beneath the base speed, wherein torque regulation remains stable, and flux weakening has not yet transpired. This prevents the nonlinear dynamics observed at elevated speeds within the constant-power region and guarantees consistent comparative performance evaluation [44], [47].

2.3. *Driving cycles protocol*

This study involves two (2) types of driving cycle standards, which were developed primarily to measure the fuel consumption and emissions performance of vehicles [48]. These cycles provide a common baseline, allowing for objective evaluation of performance metrics such as acceleration, top speed, and regenerative braking efficiency [49].

As illustrated in **Figure 2**, the New European Driving Cycle (NEDC) standard was used in this study, where the entire driving cycle is about 1180 seconds, including urban driving cycles (UDCs) from 0 – 780 seconds and extra-urban driving cycles (EUDCs) from 780 – 1180 seconds. The first 195 seconds was the cold start phase, the next 585 seconds were UDC, which is the maximum speed of about 50 km/h, and the next 400 seconds were the EUDC, which is the maximum speed of approximately 120 km/h [50]. This standard was used to provide the instantaneous driving forces required to overcome the aerodynamic, rolling, grade, and inertia resistances [51].

Besides the NEDC cycle protocol, the Worldwide Harmonized Light Vehicles Test Cycle (WLTC) was also used in this study, as illustrated in Figure 3. The complete driving cycle is approximately 1800 seconds and consists of four (4) distinct phases representing different driving conditions. The first phase is the low-speed urban segment (0 - 589 seconds) with an approximate maximum speed of 56 km/h. This is followed by a medium-speed phase (589 - 1022 seconds) with speeds up to almost 76 km/h, then a high-speed phase (1022 – 1477 seconds) with speeds reaching 97 km/h, and finally, an extra-high-speed phase (1477 – 1800 seconds) with maximum speeds around 131 km/h. The WLTC is designed to more realistically represent modern driving behavior by including varying speeds and acceleration patterns [52]. Both driving cycles were used in validation phases that will be described in Section 3 and will continue to be applied in simulation work to investigate the varied criteria, which include both driving cycles as a standard test cycle, and will be explained in Section 4.

3. Validation Phase

The validation stage was conducted to assess the EV model's accuracy and reliability, which was successfully developed in the 1D simulation software. The validation was performed by comparing the simulation outputs with official manufacturer specifications for two EV models:

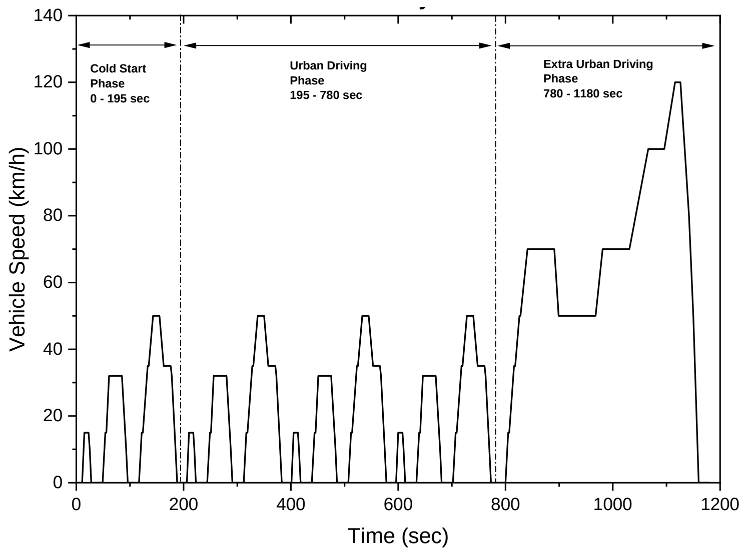

Figure 2. NEDC driving cycle protocol

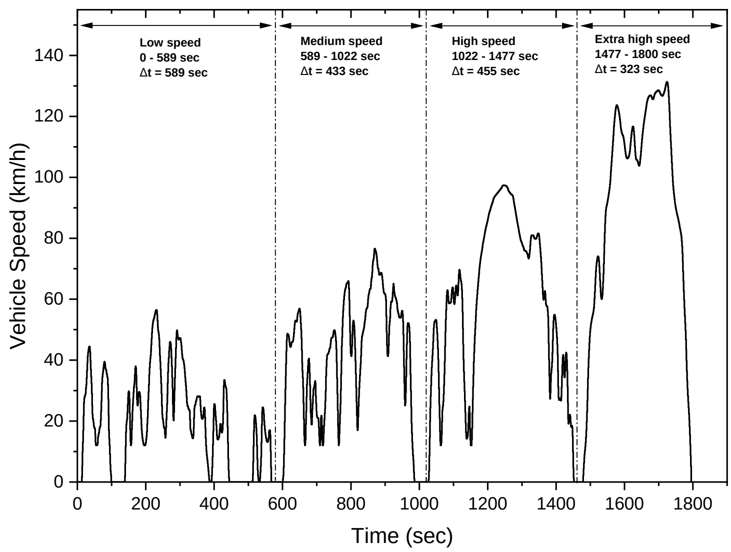

Figure 3. WLTC driving cycle protocol

the Nissan Leaf and the Hyundai Kona. Specifically, simulated results were benchmarked against data provided in the manufacturers' official brochures, focusing on vehicle range, energy consumption, and acceleration time under both the WLTC and NEDC driving cycles.

Several assumptions were made in this simulation study, particularly the use of the driving protocols, which are often based on standardized driving cycles, such as the Worldwide Harmonized Light Vehicles Test Procedure (WLTP) or the Urban Dynamometer Driving Schedule (UDDS). These cycles represent typical urban or highway driving conditions but may not fully capture the diversity of real-world driving behaviors.

Additionally, it is assumed that the powertrain components, such as the battery, motor, and transmission, operate under ideal conditions. However, in real-world scenarios, various factors can degrade component performance over time. This degradation in terms of wear and tears, and the friction losses and material fatigue, is not accounted for in most simulations, which assume a consistent battery capacity throughout the vehicle's lifespan. Additionally, this study only focuses on short-term performance and efficiency in specified conditions. It doesn't consider how component aging will affect the long-term nature of the powertrain setup.

Three (3) critical performance metrics were observed for model validation: energy consumption (EC), driving range, and acceleration time (0 – 100 km). These metrics were chosen because these parameters represent high-level system outputs that encapsulate the interactions of various subsystems in the vehicle, including: (a) battery and powertrain performance (energy consumption and acceleration), (b) vehicle dynamics and control strategies (acceleration), and (c) drivetrain efficiency and regenerative braking (energy consumption and range). Therefore, if the simulation accurately predicts these parameters, it implies that the underlying subsystems are modeled with sufficient accuracy for most vehicle-level studies. The differences between the simulation model and actual data from vehicle specifications were calculated based on absolute percentage error (APE), and the formulation is defined in the Eq. (1).

Moreover, based on Global test cycles like WLTC and NEDC, these driving cycles provide standardized protocols for measuring energy consumption and driving range. Using these as validation targets ensures that the simulation aligns with regulatory expectations and real-world comparability. **Table 3** presents a summary of the comparison results between the simulation of the EV model and the manufacturer's technical specification.

Reported findings by [53] indicate that the model's predictions between simulation and experiment/actual model are generally within ±5% for fuel economy and energy consumption, and within ±10% for emissions estimates. Similarly, as reported in [54] and [55], a percentage error less than 10% is accepted as the threshold for simulation model accuracy. Although the comparison between simulated and actual values may originate from different domains of applications, such as thermal management and CFD analysis, reports by [56] and [57] affirm that this range of error is sufficient to demonstrate that the simulation model accurately represents the real system.

The validation results, summarized in **Table 3**, compare simulation outputs against manufacturer technical data using the APE metric, as defined in Eq. (1). For the driving range parameter under the NEDC driving cycle, the APE was approximately 0% for the Hyundai Kona and 0.32% for the Nissan Leaf, indicating an excellent match with the manufacturer's data. While under the WLTC driving cycle, the APE driving range parameter was 5.84% for the Hyundai Kona and 3.33% for the Nissan Leaf, both of which fall well within the acceptable threshold.

For the energy consumption parameter under the WLTC driving cycle, the APE was 6.01% for the Hyundai Kona, and for the Nissan Leaf, there is no available data provided by the manufacturer. Although technical specifications for energy consumption under the NEDC driving cycle for both EV models were not available, the APE under

$$Absolute\ percentage\ Error\ (APE) = \left(\frac{|Actual - Simulation|}{Actual}\right) x\ 100 \tag{1}$$

Table 3. Performance comparison of the simulation model.

Test Cycle	Performance parameters	Hyundai Kona			Nissan Leaf		
		Actual data	Simulation model	APE	Actual data	Simulation model	APE
NEDC	EC	N/A	12.84	-	N/A	12.80	-
	DR	305	305	0.00	311	312	0.32
WLTC	EC	14.30	15.16	6.01	N/A	15.30	-
	DR	274	258	5.84	270	261	3.33
Acceleration time (sec) [0-100 km]		9.90	9.30	6.06	7.90	8.60	8.86

where, EC and DR are the abbreviations of energy consumption (kWh/100km) and driving range (km), respectively

the WLTC driving cycle for Hyundai Kona remains within the acceptable validated range. For the vehicle acceleration time parameter, the APE was 8.86% for the Nissan Leaf and 6.06% for the Hyundai Kona, where both results align with the acceptable error criteria.

From these validation outcomes, it was confirmed that the simulation results demonstrate a high level of fidelity in replicating the real-world performance of EVs and can be used to represent an actual EV for this study.

4. Results and Discussion

In the simulation studies, EV models were analyzed under various driving protocols. During the simulation, the EV models were tested:

a. under two standardized driving protocols (NEDC and WLTC).
b. at different battery capacity (-30%, -20%, -10%, 10%, 20%, 30%).
c. at different motor power performance (-30%, -20%, -10%, 10%, 20%, 30%).
d. At different motor efficiency (-15%, -10%, -5%, 5%).
e. At different transmission gear ratios
    - (6.193, 7.193, 8.193, 9.193, 10.193) for Nissan Leaf.
    - (6.981, 7.981, 8.981, 9.981, 10.981) for Hyundai Kona.

During the model analysis, the impact of the factors listed above on energy consumption, acceleration time, and the estimated driving range of the EVs was investigated and discussed in the next subsection.

4.1. Battery Capacity

Simulations were made for a range of battery capacities between -30% and +30% around the nominal values of the two (2) EV models. **Figure 4** summarizes the results obtained from the simulation of the Nissan Leaf and Hyundai Kona, which highlight the relationship between battery capacity and key performance metrics such as energy consumption and estimated driving range under the NEDC and WLTC driving cycle protocols.

As referred to this table, the result for energy consumption for both EV models remains nearly constant at 12.8 kWh/100 km (under NEDC driving cycle) and 15.30 kWh/100 km (under WLTC driving cycle) for Nissan Leaf, while for Hyundai Kona maintained at values of 12.84 kWh/100 km (under NEDC driving cycle) and 15.16 kWh/100 km (under WLTC driving cycle). This stability in energy consumption reflects the fact that battery capacity does not alter the intrinsic efficiency of both EV models but only the available energy storage. In practical terms, increasing battery capacity provides a larger energy reserve (kWh), but it does not inherently improve or degrade the efficiency with which the electric motor converts electrical energy into mechanical propulsion. Since energy consumption per kilometre (kWh/km) is primarily governed by power demand and drivetrain efficiency, it remains nearly constant. Therefore, the specific energy consumption (kWh/km) remains nearly constant, and the driving range increases proportionally with battery capacity.

When comparing cycles, NEDC consistently yielded lower energy consumption values than WLTC for both EVs. This outcome is expected since NEDC is characterized by lower average speeds and less dynamic acceleration, resulting in more favorable energy efficiency and inflated range values [58]. In contrast, WLTC involves higher accelerations and varied speeds, producing more realistic energy consumption values representative of actual on-road conditions [51].

Table 4. Average energy consumption (EC) and estimated driving range (DR) with different battery capacities under the NEDC and WLTC driving cycles

% difference	Nissan Leaf					Hyundai Kona				
	Battery Capacity (kWh)	NEDC		WLTC		Battery Capacity (kWh)	NEDC		WLTC	
		EC	DR	EC	DR		EC	DR	EC	DR
-30	28.00	12.80	219	15.30	183	27.44	12.84	214	15.16	181
-20	32.00	12.80	250	15.30	209	31.36	12.84	244	15.16	207
-10	36.00	12.80	281	15.30	235	35.25	12.84	275	15.16	233
Baseline	40.00	12.80	313	15.30	261	39.20	12.84	305	15.16	259
10	44.00	12.80	344	15.30	288	43.10	12.84	336	15.16	284
20	48.00	12.80	375	15.30	314	47.00	12.84	366	15.16	310
30	52.00	12.80	406	15.30	340	50.96	12.84	397	15.16	336

As a simulation test conducted under various battery capacities, the impact of varying battery capacity on the estimated driving range of the Nissan Leaf and Hyundai Kona EVs was presented in **Figure 4a** and **Figure 4b**. Based on the simulation result, a strong positive correlation was demonstrated between battery capacity used in EVs and estimated driving range under both NEDC and WLTC driving cycles.

As illustrated in **Figure 4a**, for the Nissan Leaf, increasing the battery capacity by 30% extended the driving range by 29.71%, which is a range improvement from 313 km (baseline) to 406 km under the NEDC driving cycle, whereas a 30% reduction of battery capacity decreased the driving range to 219 km. As ±10% variation in battery capacity resulted in a range change of approximately ±10.22% changes in driving range, which is about 30 - 31 km. A similar trend was observed under the WLTC driving cycle. A 10% reduction in battery capacity decreased the driving range from 261 km (baseline) to 235 km, representing a difference of about 32 km. Similarly under NEDC driving cycle, 30% reduction of battery capacity decreased the driving range to 183 km. More broadly, for every ±10% variation in battery capacity, the driving range will change by approximately less than 10.34% deviation.

While the Hyundai Kona exhibits a similar response, as shown in **Figure 4b**. Under the NEDC driving cycle, a 30% increase in battery capacity extended the driving range from 305 km (baseline) to 397 km, while a 30% reduction in battery capacity reduced the driving range to 214 km. A ±10% variation in battery capacity corresponded to a range change of about ±10.16% from nominal, which is about 30–31 km. In the case of the WLTC driving cycle, reducing the battery capacity by 10% decreased the range from 259 km (baseline) to 233 km, a reduction of about 26 km. Similarly under NEDC driving cycle, 30% reduction of battery capacity decreased the driving range to 181 km. In other words, the changes in driving range were about less than 10.04% deviation per ±10% variation in battery capacity.

Across both EV models, the results exhibited a nearly linear relationship between battery capacity and estimated driving range under NEDC and WLTC driving cycles. Importantly, the observed sensitivity of driving range to battery capacity variations highlights the critical role of battery sizing in EVs' design and consumer expectations, as even small capacity changes (±10%) can produce notable differences in driving range. A modest capacity increase (e.g., through battery module upgrades or higher energy density cells) can yield significant improvements in driving range, directly impacting EV usability and consumer acceptance. This outcome aligns with the fundamental principle that the available driving energy is proportional to the battery's usable capacity, assuming that vehicle mass and drivetrain efficiency remain constant.

4.2. *Motor Power Performance*

Table 5 shows the results obtained from the simulation of EV models with different motor power performance under NEDC and WLTC driving cycles. Generally, the motor in an EV converts electrical energy from the battery into mechanical energy, powering the wheels and typically measured in kilowatts (kW) or horsepower (hp), with higher motor power generally resulting in improved vehicle performance but potentially reduced efficiency at high loads.

Based on the simulation results presented in **Table 5**, the energy consumption for both EV models

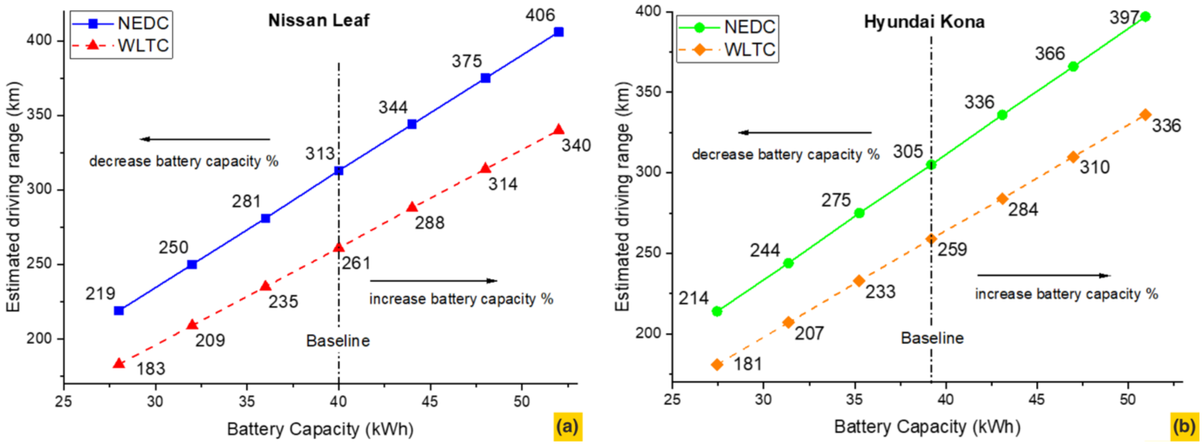

Figure 4. Battery capacity (kWh) versus estimated driving range (km) for Nissan Leaf (a) and Hyundai Kona (b) under the NEDC and WLTC driving cycles.

Table 5. Average energy consumption (EC), estimated driving range (DR), and acceleration time (0 – 100 km) with different motor power performance under the NEDC and WLTC driving cycles.

% difference	Nissan Leaf						Hyundai Kona					
	Motor Power (kW)	NEDC		WLTC		Acc. Time (sec)	Motor Power (kW)	NEDC		WLTC		Acc. Time (sec)
		EC	DR	EC	DR			EC	DR	EC	DR	
-30	77	12.80	312	15.30	261	11.90	70	12.84	305	15.16	259	12.61
-20	88	12.80	312	15.30	261	10.60	80	12.84	305	15.16	259	11.19
-10	99	12.80	312	15.30	261	9.60	90	12.84	305	15.16	259	10.11
Baseline	110	12.80	312	15.30	261	8.60	100	12.84	305	15.16	259	9.29
10	121	12.80	312	15.30	261	8.30	110	12.84	305	15.16	259	8.65
20	132	12.80	312	15.30	261	7.80	120	12.84	305	15.16	259	8.15
30	143	12.80	312	15.30	261	7.50	130	12.84	305	15.16	259	7.75

remains nearly constant across the range of motor power performance tested. For the Nissan Leaf, energy consumption was maintained at 12.80 kWh/100 km (under the NEDC driving cycle) and 15.30 kWh/100 km (under the WLTC driving cycle). Similarly, the Hyundai Kona showed consistent values of 12.84 kWh/100 km (under the NEDC driving cycle) and 15.16 kWh/100 km (under the WLTC driving cycle). This trend is consistent across simulations that varied both battery capacity and motor power output, indicating that changes in these parameters do not significantly influence energy consumption under the tested conditions. The detailed explanation as to why this occurs is that motor power primarily determines the peak torque and acceleration capability. However, the average power required to sustain normal speeds is frequently significantly lower than the rated motor power. Consequently, whether motor power is increased or decreased, the motor functions within a comparable efficiency range throughout most of the driving cycle. As a result, the total energy consumption per kilometer remains essentially constant. Therefore, modifications in motor power influence acceleration performance consistently, as indicated by the data in Table 5, but have minimal impact on steady-state energy consumption and overall driving range under typical cycle conditions.

Moreover, the estimated driving range for both the EV model under the NEDC and WLTC driving cycles remains constant, even after the 30% changes in motor power output, as shown in Figure 5a and Figure 5b. Based on these figures, the estimated driving range value for Nissan Leaf is about 312 km and 261 km under both driving cycles. While for the Hyundai Kona, the estimated driving range value is about 305 km and 259 km under both driving cycles. As mentioned earlier in subsection 4.1, the difference in value between NEDC and WLTC driving cycle protocols for both EV models is due to the intensity of the driving cycle, which involves high acceleration and a variety of speeds in the WLTC cycle compared to the NEDC cycle.

However, the acceleration time (0 – 100 km) for both EV models provided a significant impact with variations in motor power performance. As illustrated in **Figure 6a**, at -30% motor power output, which is 77 kW, the result shows the slowest acceleration time of 11.9 seconds for the Nissan Leaf. Decreasing motor power to 20% from baseline, which is 88 kW, reduced the acceleration time to 10.60 seconds. At a 10% reduction of motor power output from baseline, which is 99 kW, resulting in an acceleration time of 9.60 seconds.

As motor power performance improves above the baseline, it demonstrates an improvement in acceleration times. For instance, at 10% improvement in motor power output, which is 121 kW, the acceleration time drops to 8.30 seconds, and at 20% improvement, which is at 132 kW motor output, it decreases the acceleration time to 7.80 seconds. The best performance was observed at 143 kW (+30%), where the acceleration time was recorded at 7.5 seconds. As the motor power performance increases, there is a significant increase in the acceleration of this EV. The improvement of motor power performance to 30% resulted in a 12.79% improvement in acceleration time, whereas reducing the motor power performance to 30%, the reduction percentage of acceleration time is approximately 38.37% from the nominal value. These improvements demonstrate that even small rises in motor power performance significantly enhance the acceleration performance of the Nissan Leaf. Vice versa, as the performance of motor power decreases, resulting of a significant decrease in acceleration performance.

As shown in **Figure 6b**, it can be observed that the motor power performance from the Hyundai Kona is also proportional to the acceleration time performance, which means that increasing the motor power performance will shorten the accele-

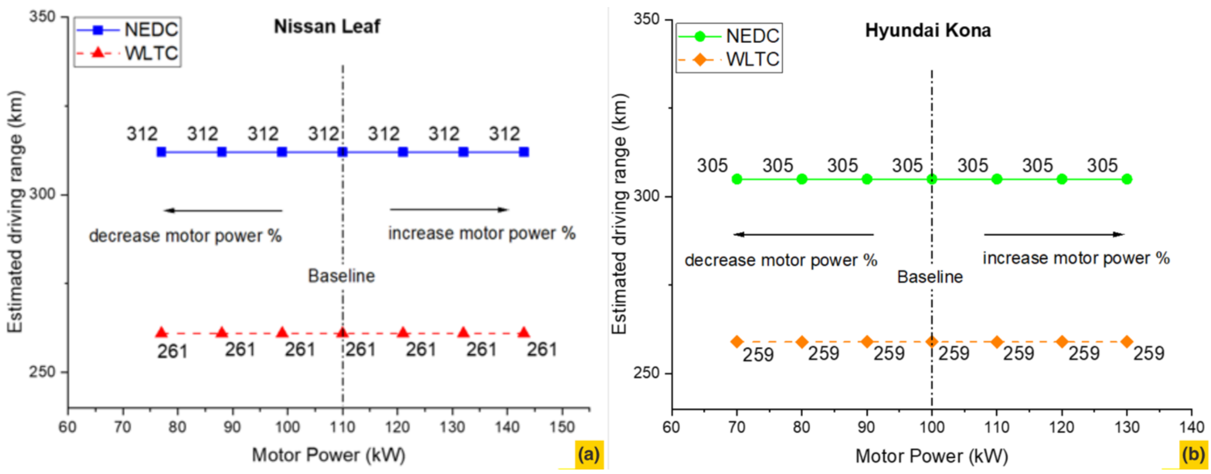

Figure 5. Motor power performance (kW) versus estimated driving range (km) for Nissan Leaf (a) and Hyundai Kona (b) under NEDC and WLTC driving cycles

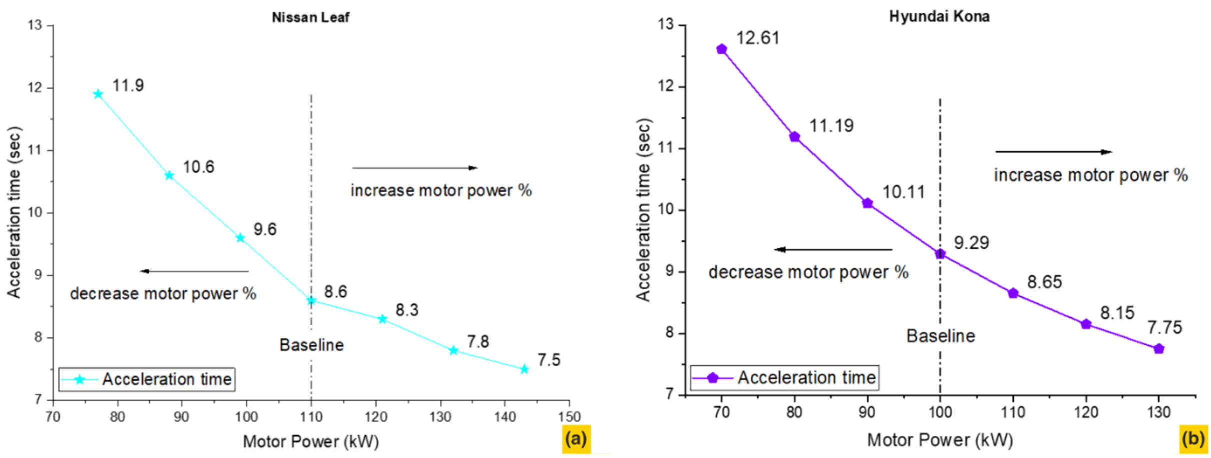

Figure 6. Motor power (kW) versus acceleration time for Nissan Leaf (a) and Hyundai Kona (b) under NEDC and WLTC driving cycles

ration times. At the baseline motor power (100 kW), the acceleration time is recorded at 9.29 seconds. By reducing motor power performance to 10% - 30% from baseline, which is to 90 - 70 kW, a substantial deterioration in acceleration time was observed. Specifically, the acceleration performance decreased to 10.11 - 12.61 seconds, highlighting a worsening performance, as well as a decrease in motor power performance.

As motor power performance improves to 10% - 30%, which is at 110 - 130 kW, a significant improvement was observed, where the acceleration time is improved to 8.65 - 7.75 seconds, yielding around a 16.58% performance gain relative to the baseline. Although these improvements remain meaningful, it demonstrates a progressive decline in acceleration time with each incremental increase in motor power output. These results are in line with the fundamental principle that the available motor output power is directly proportional to the vehicle's acceleration. In both EVs, even a modest increase in motor power can result in a disproportionately large impact on vehicle speed, particularly during acceleration phases.

Besides that, it can be explained by the fundamental power-to-weight ratio principle in vehicle dynamics, which means a higher available motor power enhances tractive effort, thereby allowing the vehicle to overcome inertia and aerodynamic resistance more quickly. However, it is also observed that performance gains tend to show diminishing returns as motor power increases. Based on the results, the percentage decline of acceleration time performance at 77-99 kW motor power output for Nissan Leaf and 70-90 kW motor power output is about 1.00 - 3.30 seconds (11.63% - 38.37% reduction in acceleration performance for Nissan Leaf) and 0.82 – 3.32 seconds (8.83% - 35.74% reduction in acceleration performance for Hyundai Kona), while between 121–143 kW motor power output for Nissan Leaf and 110–130 kW motor power output for Hyundai Kona, the improvement gain is only 0.30 – 1.10 seconds (3.49% - 12.79% improvement in acceleration performance) and 0.64 – 1.54 seconds (6.89% - 16.58% improvement in acceleration performance). This suggests that beyond a certain threshold, additional increases in motor power contribute less significantly to acceleration improvements, possibly due to limiting factors such as vehicle mass, drivetrain efficiency, and traction constraints. Therefore, this finding highlights the trade-off between motor sizing and performance optimization.

4.3. *Motor Efficiency*

Motor efficiency can be influenced by various factors, including the design of the motor, the quality of materials used, and the operating conditions. Motor efficiency directly influences energy consumption and driving range, as it determines how effectively electrical energy is converted into mechanical power to propel the vehicle. Higher motor efficiency reduces energy losses, lowering the power required from the battery for a given driving cycle and thereby extending the driving range. Conversely, lower motor efficiency increases energy losses, which raises battery demand and reduces range. This makes motor efficiency a critical factor in EV performance, particularly when optimizing powertrain design for energy efficiency and real-world driving conditions. **Table 6** presents the results of the estimated driving range and average energy consumption for different motor efficiencies at 2000 rpm for the Nissan Leaf and Hyundai Kona under the NEDC and WLTC driving cycles.

Figure 7a and **Figure 7b** illustrate the relationship between different motor efficiencies at 2000 rpm, estimated driving range and energy consumption for the Nissan Leaf. The baseline motor efficiency at 2000 rpm is 0.860, with an energy consumption of 12.80 kWh/100km and an estimated range of 312 km under the NEDC driving cycle. At +5% motor efficiency, which is at 0.903, energy consumption improved to 11.84 kWh/100km, while the estimated driving range was extended to 337 km. Conversely, the motor efficiency decreased to 15%, which is about 0.731, energy consumption degraded to 16.23 kWh/100km, while the driving range reduced to 247 km.

Moreover, under the WLTC driving cycle, the energy consumption was enhanced to 14.02 kWh/100 km, and the estimated driving range was extended to 285 km at 5% improvement of motor efficiency. On the contrary, at a 15 % reduction of motor efficiency, energy consumption deteriorated to 19.60 kWh/100 km while reducing the driving range to 204 km.

Table 6. Average energy consumption (EC) and estimated driving range (DR) with different motor efficiencies under the NEDC and WLTC driving cycles

% difference	Nissan Leaf					Hyundai Kona				
	Motor Efficiency	NEDC		WLTC		Motor Efficiency	NEDC		WLTC	
		EC	DR	EC	DR		EC	DR	EC	DR
-15	0.731	16.23	247	19.60	204	0.731	16.30	240	19.30	203
-10	0.774	15.00	266	18.00	222	0.774	15.00	261	17.76	220
-5	0.817	13.80	290	16.60	241	0.817	13.90	282	16.40	239
Baseline	0.860	12.80	312	15.30	261	0.860	12.80	306	15.30	256
5	0.903	11.84	337	14.02	285	0.903	11.90	329	14.04	279

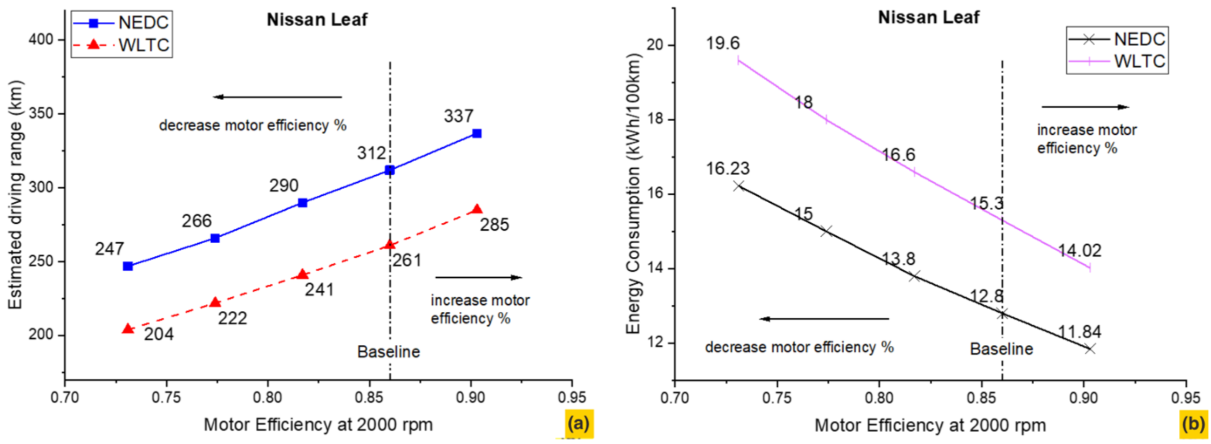

Figure 7. Motor efficiency at 2000 rpm versus (a) estimated range (km) and (b) energy consumption (kWh/100 km) for the Nissan Leaf under the NEDC and WLTC driving cycles

Based on the results, when motor efficiency improves to 5%, the driving range performance decreases to 8.01% (under the NEDC driving cycle) and 9.20% (under the WLTC driving cycle), respectively, compared to the nominal value. Conversely, at a lower motor efficiency of 0.731 (-15%), the driving range significantly improves to 20.83% (under the NEDC driving cycle) and 21.84% (under the WLTC driving cycle), respectively. Besides that, the energy consumption performance declined by 26.80% (under the NEDC driving cycle) and 28.10% (under the WLTC driving cycle), respectively, when the motor efficiency dropped to 15%. Energy consumption was improved, by improving the motor efficiency to 5%, corresponding to 7.50% (under the NEDC driving cycle) and 8.37% (under the WLTC driving cycle), respectively.

Figure 8a and Figure 8b depict performance metrics for the Hyundai Kona under two (2) driving cycles. The baseline of motor efficiency at 2000 rpm is about 0.860, with energy consumption approximately at 12.80 kWh/100km, and the estimated driving range of 306 km under the NEDC driving cycle. Energy consumption improved to 11.90 kWh/100 km, while the estimated driving range increased to 329 km, with 5% improvement in motor efficiency. At -15% motor efficiency, which is at 0.731, energy consumption performance declined to 16.30 kWh/100 km, and the driving range performance improved to 240 km. Moreover, under the WLTC driving cycle, with an improvement of 5% motor efficiency, energy consumption performance improved to 14.04 kWh/100 km, while extending the driving range to 279 km. The energy consumption performance for the Hyundai Kona reduced whenever the motor efficiency dropped to 15%, resulting in 19.30 kWh/100 km. Otherwise, the estimated driving range performance improved to 203 km.

Under both NEDC and WLTC test cycles, when motor efficiency drops to 15%, the driving range reduces significantly, representing an improvement of about 21.57% (under the NEDC driving cycle) and 20.70% (under the WLTC driving cycle), respectively, compared to the baseline. Conversely, at a higher efficiency of 0.903, the estimated driving range performance slightly decreases, corresponding to a loss of around 7.52% (under the NEDC driving cycle) and 8.98% (under the WLTC driving cycle) relative to baseline. This clearly demonstrated that higher motor efficiency will extend the vehicle range.

Moreover, improving motor efficiency to 5% enhanced energy consumption performance by 7.03% (under the NETC driving cycle) and 8.24% (under the WLTC driving cycle). Otherwise, when motor efficiency was reduced to 15%, the energy consumption performance significantly reduced, representing a loss of about 27.34% (under NEDC driving cycle) and 26.14% (under WLTC driving cycle). These results clearly demonstrated a consistent downward trend of motor efficiency, resulting in a reduction in energy consumption per 100 km performance. Overall, it confirms that motor efficiency plays a critical role in determining EV driving range and energy economy.

4.4. *Transmission Gear Ratios*

Table 7 shows the result of different gear ratios towards the estimated driving range and energy consumption for the Hyundai Kona under the NEDC and WLTC driving cycles. **Figure 9** illustrates the impact of different gear ratios on the energy consumption, driving range, and motor speed at 120 km/h of the Nissan Leaf under the NEDC and WLTC driving cycles. In **Figure 9a**, it is observed that as the final gear ratio increases, the estimated driving range performance slightly decreases for both cycles. At the baseline gear ratio of 8.193, the estimated range is 312 km (under NEDC driving cycle) and 261 km (under WLTC driving cycle). When the final gear ratio increases to 10.193, the estimated driving range performance slightly reduces to 308 km (under the NEDC driving cycle) and 255 km (under the WLTC driving cycle), representing a loss of about 1.28% and 2.30% respectively, compared to the baseline. Conversely, at a lower final gear ratio value of 6.193, the estimated driving range increases to 314 km (under the NEDC driving cycle) and 262 km (under the WLTC driving cycle), corresponding to an improvement of around 0.64% and 0.38% under both cycles relative to the baseline. The result demonstrates that decreasing the final gear ratio will extend the vehicle's driving range.

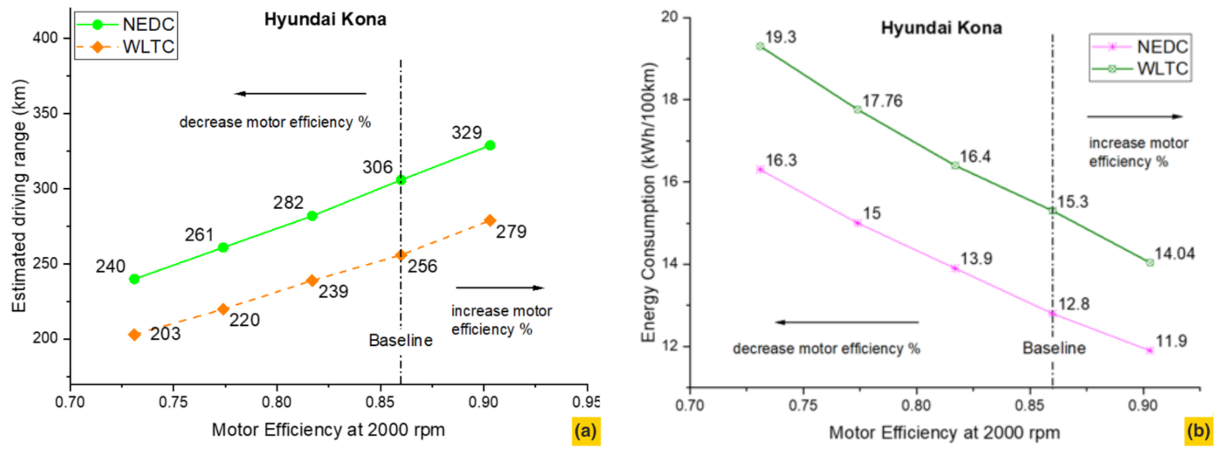

Figure 8. Motor efficiency at 2000 rpm versus (a) estimated range (km) and (b) energy consumption (kWh/100 km) for the Hyundai Kona Electric under the NEDC and WLTC driving cycles

Table 7. Average energy consumption (EC) and estimated driving range (DR) with different final gear ratios under the NEDC and WLTC driving cycles

Final Gear Ratio	Motor Speed at (120 km/h)	Nissan Leaf NEDC EC	Nissan Leaf NEDC DR	Nissan Leaf WLTC EC	Nissan Leaf WLTC DR	Final Gear Ratio	Motor Speed at (120 km/h)	Hyundai Kona NEDC EC	Hyundai Kona NEDC DR	Hyundai Kona WLTC EC	Hyundai Kona WLTC DR
6.193	6084	12.75	314	15.23	262	6.981	6858	12.82	305.77	15.13	259.10
7.193	7066	12.77	313	15.26	262	7.981 (baseline)	7840	12.84	305.30	15.16	258.57
8.193 (baseline)	8049	12.80	312	15.30	261	8.981	8823	12.90	303.88	15.27	256.71
9.193	9031	12.85	311	15.47	258	9.981	9805	13.01	301.30	15.43	254.05
10.193	10013	12.97	308	15.63	255	10.981	10780	13.15	298.10	15.58	251.60

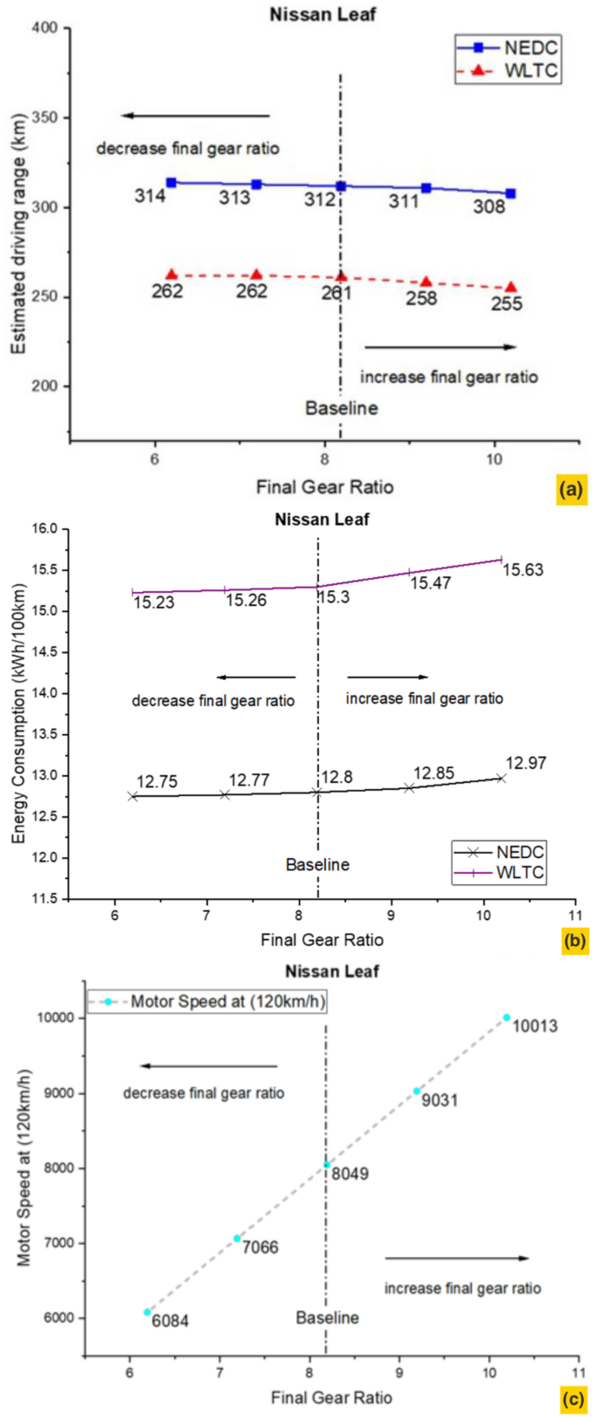

Figure 9. Relationship between final gear ratio and (a) estimated range (km), (b) energy consumption (kWh/100 km), and (c) motor speed at 120 km/h for the Nissan Leaf under NEDC and WLTC driving cycles

Figure 9b presents the correlation between the final gear ratio and energy consumption for Nissan Leaf. At 10.193 value of final gear ratio, the energy consumption reaches 12.97 kWh/100 km (under the NEDC driving cycle) and 15.63 kWh/100 km (under the WLTC driving cycle), corresponding to 1.33% (under the NEDC driving cycle) and 2.16% (under the WLTC driving cycle) degradation of energy consumption performance. Further reduction of the final gear ratio value to 6.193, improves energy consumption to 12.75 kWh/100 km (under the NEDC driving cycle) and 15.23 kWh/100 km (under the WLTC driving cycle), corresponding to an improvement of about 0.39% and 0.46% under both cycles, respectively. The results clearly demonstrate that modifications to the final gear ratio induce an approximately inversely proportional relationship with energy consumption.

Figure 9c illustrates the effect of varying the final gear ratio on the motor speed required to maintain a constant vehicle speed of 120 km/h in the Nissan Leaf. As shown, there is a near-linear relationship between the final gear ratio and motor speed at this fixed vehicle velocity. As the final gear ratio increases, from 8.193 to 10.193, the corresponding motor speed also increases, ranging from approximately 8049 rpm to 10013 rpm. Conversely, decreasing the final gear ratio reduces the motor speed at 120 km/h, which is from 8.193 to 6.193, resulting in the motor speed being about 8049 to 6084 rpm.

This trend is consistent with fundamental drivetrain mechanics, which is a higher final gear ratio resulting in a greater multiplication of motor revolutions per wheel rotation, thus increasing motor speed for a given vehicle speed. While this configuration can enhance torque at the wheels, it may have a positive impact on energy consumption, as illustrated in Figure 9b. On the other hand, lowering the final gear ratio reduces motor speed at the same vehicle velocity, potentially improving energy consumption. However, this comes at the cost of reduced torque multiplication, which may negatively affect vehicle acceleration and hill-climbing performance. These findings highlight the importance of final gear ratio selection in EV drivetrain design, balancing trade-offs between efficiency, motor speed limits, and overall performance.

Figure 10a presents the effect of variation of final gear ratio to estimated driving range for the Hyundai Kona, whereas a final gear ratio decreases to 6.981 from 7.981 (baseline), the driving range slightly improved from 305.30 km to 305.77 km (under the NEDC driving cycle) and from 258.57 km to 259.10 km (under the WLTC driving cycle), corresponding to 0.15% and 0.21% range improvement for both cycles, respectively. Furthermore, when the final gear ratio increased to 10.981 from baseline, the driving range performance significantly decreased, which a driving range became 298.10 km (under the NEDC driving cycle) and 251.60 km (under the WLTC driving cycle), representing a reduction of almost 2.36% and 2.70% under both driving cycles. The results demonstrated that changes in the final gear ratio will have a significant effect on the driving range of the EVs.

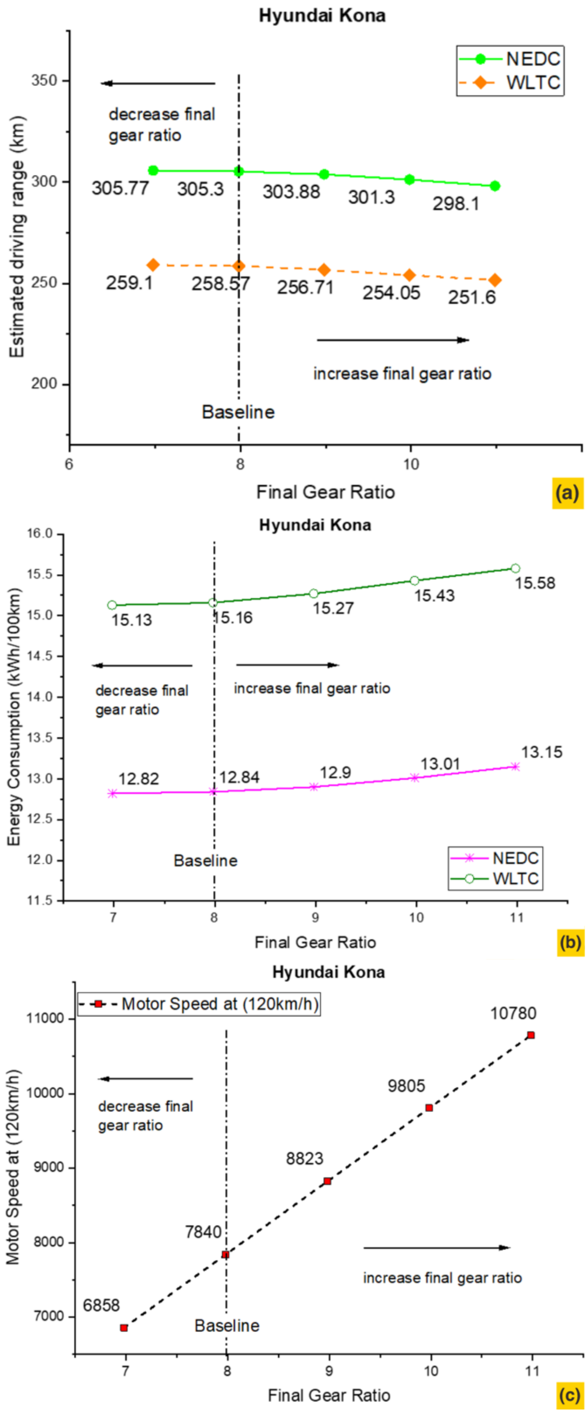

Figure 10. Relationship between final gear ratio and (a) estimated range (km), (b) energy consumption (kWh/100 km), and (c) motor speed at 120 km/h for the Hyundai Kona Electric under NEDC and WLTC driving cycles.

The energy consumption effect when applying the variations of the final gear ratio setup is shown in Figure 10b. The baseline of the final gear ratio for Hyundai Kona is 7.981, corresponding to the result of energy consumption is 12.84 kWh/100 km (under the NEDC driving cycle) and 15.16 kWh/100 km (under the WLTC driving cycle). As the final gear ratio increases to 10.981, the energy consumption becomes 13.15 kWh/100 km (under the NEDC driving cycle) and 15.58 kWh/100 km (under the WLTC driving cycle), resulting in a loss performance of almost 2.41% and 2.77% under both driving cycles of energy consumption. Furthermore, when the final gear ratio decreased to 6.981 from the nominal value, the energy consumption performance slightly improved, which is 12.82 kWh/100 km (under the NEDC driving cycle) and 15.13 kWh/100 km (under the WLTC driving cycle), corresponding to a 0.16% and 0.20% range improvement of energy consumption under both cycles. This finding shows that the decrease in the transmission gear ratio will have a slight impact on the energy consumption of EVs.

Figure 10c illustrates the effect of varying the final gear ratio on the motor speed at 120 km/h in the Hyundai Kona. By way of the final gear ratio increases, from 7.981 to 10.981, the corresponding motor speed also increases, extending from 7840 rpm to 10780 rpm. On the contrary, decreasing the final gear ratio reduces the motor speed, changing the gear ratio from 7.981 to 6.981, consequential in the reduction of motor speed from 7840 to 6858 rpm. This finding shows that there is a linear relationship between the final gear ratio and motor speed at this fixed vehicle velocity. This inclination is aligned with the fundamentals of powertrain mechanics principles, wherein a higher final gear ratio results in increased motor rotational speed.

Based on the evaluated performance test criteria, it can be concluded that variations in both battery capacity and motor power performance have no observable impact on the energy consumption of EVs. Furthermore, motor power performance does not influence the driving range under either NEDC or WLTC test cycles. In contrast, changes in battery capacity directly affect the EV's driving range, consistent with findings reported in [59], [60], [61] which highlight a positive correlation between battery capacity and driving range. Additionally, variations in motor power performance influence only the vehicle's acceleration time, aligning with previous studies such as [62], [63], [64], [65]. From an engineering standpoint, these findings suggest that enhancing battery capacity is the best way to increase range. Motor sizing should mainly focus on achieving acceleration goals, not energy efficiency. Designers can focus on upgrading batteries to boost range without changing energy consumption metrics and choose motor power levels that meet performance needs without excessive oversizing.

A detailed summary of the percentage changes for each criterion and their respective effects on energy consumption, driving range, and acceleration time is presented in **Table 8** to **Table 11**. Additionally, Table A6-A11 in the Appendix section provides the predicted trendlines derived from the simulation data, quantitatively capturing the influence of battery capacity, motor power, motor efficiency, and final gear ratio on key EV performance metrics, including driving range, energy consumption, and acceleration time.

5. Conclusion

The study successfully demonstrated the critical impact of powertrain configuration on the driving range and energy consumption of electric vehicles (EVs) through detailed 1D model simulations. The level of fidelity of both EV models was assessed through validation against the key technical data provided by the EV manufacturer. Validation results indicated that even though it has a slight deviation in absolute percentage error (APE), which is less than 10%, the simulation model effectively encapsulated the actual EV model in a real-world application. Continuing the trajectory of advancement, the study utilized two standard driving cycle protocols (NEDC and WLTC) to investigate EV performance and simultaneously applied a variety of key powertrain parameters to each EV

Table 8. Performance percentages from the nominal value of energy consumption (EC) and estimated driving range (DR) with various battery capacities and motor power performance under the NEDC and WLTC driving cycles for Nissan Leaf

Nissan Leaf										
Battery Capacity (%)	NEDC EC (%)	NEDC DR (%)	WLTC EC (%)	WLTC DR (%)	Motor Power (%)	NEDC EC (%)	NEDC DR (%)	WLTC EC (%)	WLTC DR (%)	Acc. Time (%)
-30	Constant in all conditions	-30.03	Constant in all conditions	-29.89	-30	Constant in all conditions	Constant in all conditions	Constant in all conditions	Constant in all conditions	-38.37
-20		-20.13		-19.92	-20					-23.26
-10		-10.22		-9.96	-10					-11.63
0		0		0	0					0
10		9.90		10.34	10					3.49
20		19.80		20.31	20					9.30
30		29.71		30.27	30					12.79

Table 9. Performance percentages from the nominal value of energy consumption (EC) and estimated driving range (DR) with various motor efficiency and final gear ratios under the NEDC and WLTC driving cycles for Nissan Leaf

Nissan Leaf									
Motor Efficiency (%)	NEDC EC (%)	NEDC DR (%)	WLTC EC (%)	WLTC DR (%)	Transmission gear ratio	NEDC EC (%)	NEDC DR (%)	WLTC EC (%)	WLTC DR (%)
-15	-26.80	20.83	-28.10	21.84	6.193	0.39	0.64	0.46	0.38
-10	-17.19	14.74	-17.65	14.94	7.193	0.23	0.32	0.26	0.38
-5	-7.81	7.05	-8.50	7.66	8.193	0	0	0	0
0	0	0	0	0	9.193	-0.39	-0.32	-1.15	-1.15
5	7.50	-8.01	8.37	-9.20	10.193	-1.33	-1.28	-2.16	-2.30

Table 10. Performance percentages from the nominal value of energy consumption (EC) and estimated driving range (DR) with various battery capacities and motor power performance under the NEDC and WLTC driving cycles for Hyundai Kona

Hyundai Kona										
Battery Capacity (%)	NEDC		WLTC		Motor Power (%)	NEDC		WLTC		Acc. Time (%)
	EC (%)	DR (%)	EC (%)	DR (%)		EC (%)	DR (%)	EC (%)	DR (%)	
-30	Constant in all conditions	-29.84	Constant in all conditions	-30.12	-30	Constant in all conditions	Constant in all conditions	Constant in all conditions	Constant in all conditions	-35.74
-20		-20.00		-20.08	-20					-20.45
-10		-9.84		-10.04	-10					-8.83
0		0		0	0					0
10		10.16		9.65	10					6.89
20		20.00		19.69	20					12.27
30		30.16		29.73	30					16.58

Table 11. Performance percentages from the nominal value of energy consumption (EC) and estimated driving range (DR) with various motor efficiency and final gear ratios under the NEDC and WLTC driving cycles for Hyundai Kona

Hyundai Kona									
Motor Efficiency (%)	NEDC		WLTC		Transmission gear ratio	NEDC		WLTC	
	EC (%)	DR (%)	EC (%)	DR (%)		EC (%)	DR (%)	EC (%)	DR (%)
-15	-27.34	21.57	-26.14	20.70	6.981	0.16	0.15	0.20	0.21
-10	-17.19	14.71	-16.08	14.06	7.981	0	0	0	0
-5	-8.59	7.84	-7.18	6.64	8.981	-0.47	-0.47	-0.73	-0.72
0	0	0	0	0	9.981	-1.32	-1.30	-1.78	-1.75
5	7.03	-7.52	8.24	-8.98	10.981	-2.41	-2.36	-2.77	-2.70

model. The battery capacity remains the dominant factor for boosting the driving range performance. The finding also revealed that optimizing motor and transmission performance is crucial to balance the energy consumption impact of EVs. Furthermore, the proposed predictive formulation offers a transferable framework that can be adapted to other EV models, serving as both a design-support tool and a performance evaluation guideline. Overall, this work provides a solid foundation for advancing EV powertrain optimization and supporting the global transition towards efficient transportation systems.

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Author's Declaration

Authors' contributions and responsibilities

S.F.Z.A Wrote the original paper, Review and editing manuscript, Funding acquisition; S.S and I.A.I Review manuscript, Visualisation; M.E.M and S.M.G Data Curation; Data Interpretation; M.A.A Wrote the revised manuscript; Data Curation; Visualization; Conceptualization.

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Availability of data and materials

All data are available from the authors.

Competing interests

The authors declare no competing interest.

Additional information

No additional information from the authors.

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Appendix

Table A1. EV vehicle body technical specifications.

Specification	unit	Hyundai Kona	Nissan Leaf
Vehicle mass	kg	1535	1580
Passenger and Cargo mass	kg	75	75
Vehicle drag coefficient	-	0.29	0.28
Vehicle frontal area	m^2	2.10	2.14
Vehicle wheelbase	m	2.60	2.69

Table A2. EV motor technical specifications.

Specification	unit	Hyundai Kona	Nissan Leaf
Electrical / brake power	kW	100	110
Base speed	rpm	1592	1592
Maximum rated power	kW	100	100
Brake torque	Nm	395	320

Table A3. EV battery technical specifications.

Specification	unit	Hyundai Kona	Nissan Leaf
Capacity	kWh	39.2	40
SOC	%	90	90
Material	-	Lithium-ion polymer	Laminated Lithium-ion
Voltage	Volt	327	350
Temparature	K	300	300

Table A4. EV tyres technical specifications.

Specification	unit	Hyundai Kona	Nissan Leaf
Tyre dimension	-	215/55R17	215/50R17
Explicit rolling radius	mm	324	324
Rolling resistance	-	0.01	0.01

Table A5. EV transmission technical specifications.

Specification	unit	Hyundai Kona	Nissan Leaf
In-Gear efficiency	%	95	95
Overall drive ratio		7.981	8.193

Table A6. Predicted driving range equation from simulation data under battery capacity criteria for EV models

Performance	EV model	Driving cycle	Trendline
Estimated Driving Range	Nissan Leaf	NEDC	$y = 7.8036x + 0.4286$
		WLTC	$y = 6.5536x - 0.7143$
	Hyundai Kona	NEDC	$y = 7.7856x + 0.1922$
		WLTC	$y = 6.5822x + 0.6347$

Table A7. Predicted acceleration time equation from simulation data under motor power performance criteria for EV models

Performance	EV model	Trendline
Acceleration time	Nissan Leaf	$y = 0.0009x^2 - 0.2579x + 26.536$
	Hyundai Kona	$y = 0.0010x^2 - 0.2780x + 27.133$

Table A8. Predicted driving range equation from simulation data under motor efficiency performance for EV models

Performance	EV model	Driving cycle	Trendline
Estimated Driving Range	Nissan Leaf	NEDC	$y = 525.58x - 139.0$
		WLTC	$y = 467.44x - 139.3$
	Hyundai Kona	NEDC	$y = 518.60x - 140.1$
		WLTC	$y = 437.21x - 117.8$

Table A9. Predicted energy consumption equation from simulation data under motor efficiency performance for EV models

Performance	EV model	Driving cycle	Trendline
Energy Consumption	Nissan Leaf	NEDC	$y = -25.535x + 34.796$
		WLTC	$y = -32.233x + 43.038$
	Hyundai Kona	NEDC	$y = -25.581x + 34.880$
		WLTC	$y = -30.186x + 41.222$

Table A10. Predicted driving range equation from simulation data under various final gear ratios for EV models

Performance	EV model	Driving cycle	Trendline
Estimated Driving Range	Nissan Leaf	NEDC	$y = -0.2857x^2 + 3.2817x + 304.46$
		WLTC	$y = -0.5410x^2 + 7.5634x + 237.13$
	Hyundai Kona	NEDC	$y = -0.4373x^2 + 6.5595x + 283.05$
		WLTC	$y = -0.3314x^2 + 4.0011x + 247.47$

Table A11. Predicted energy consumption equation from simulation data under various final gear ratios for EV models

Performance	EV model	Driving cycle	Trendline
Energy Consumption	Nissan Leaf	NEDC	$y = 0.0157x^2 - 0.2055x + 13.425$
		WLTC	$y = 0.0279x^2 - 0.3555x + 16.365$
	Hyundai Kona	NEDC	$y = 0.0207x^2 - 0.2891x + 13.828$
		WLTC	$y = 0.0207x^2 - 0.2551x + 15.893$