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A COMPARATIVE ANALYSIS OF ENERGY CONSUMPTION AND CO2 EMISSIONS FOR ENERGY-EFFICIENT VEHICLES IN MALAYSIA

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ABSTRACT

Malaysia's road transport sector contributes significantly to national energy consumption and CO_2 emissions. This study develops a simplified comparative model to assess the operational energy use and CO_2 emissions of gasoline internal combustion engine vehicles (ICEVs), hybrid electric vehicles (HEVs), and electric vehicles (EVs) under Malaysian passenger-car conditions. Useful traction energy was estimated at 13.76%, 23.48%, and 69.19% for ICEVs, HEVs, and EVs, respectively. Compared with ICEVs, HEVs and EVs reduced annual operational CO_2 emissions by 38.69% and 45.96%, respectively, although EV performance remains strongly dependent on the electricity-generation mix. Scenario analysis indicates that electrification alone is unlikely to deliver rapid transport-sector decarbonisation without aggressive adoption, grid decarbonisation, and supporting infrastructure. HEVs and improved ICEV technologies can provide short- to medium-term transition benefits, while EVs offer stronger long-term potential with the expansion of renewable electricity, charging infrastructure, and clear policy support. The findings support a balanced transition strategy that combines electrification, vehicle efficiency improvements, and power-sector decarbonisation.

KEYWORDS

Energy-efficient vehicles; vehicle energy consumption; hybrid electric vehicles; electric vehicles; CO_2 emissions; Malaysia

INTRODUCTION

Climate change and global warming remain major global concerns due to the continued increase in anthropogenic greenhouse gas emissions. The combustion of fossil fuels is a major contributor to the rising concentration of carbon dioxide (CO_2) in the atmosphere, which has been linked to long-term changes in global temperature and climate patterns [1]. As a result, many countries have introduced policies to reduce carbon emissions, improve energy efficiency, and accelerate the transition towards low-carbon transportation systems.

The transport sector plays an important role in national decarbonisation strategies because of its high dependence on fossil fuels. In Malaysia, the transportation sector is among the major contributors to greenhouse gas emissions [2]. Transport accounted for a significant share of Malaysia's final energy consumption, with road transport representing the dominant contributor within the sector [3]. Therefore, reducing energy consumption and CO_2 emissions from road vehicles is essential for supporting Malaysia's low-carbon mobility agenda.

At the international level, the Paris Agreement has placed strong emphasis on the need for climate action across all sectors, including transport [4]. Malaysia has also committed to reducing its greenhouse gas emissions intensity relative to gross domestic product by 2030 compared with the 2005 level [5]. Although this national commitment is expressed at the economy-wide level, the transport sector is expected to contribute meaningfully through improved vehicle efficiency, cleaner energy use, and the gradual adoption of low-carbon vehicle technologies.

In response to these challenges, several ASEAN countries have introduced policies and programmes to encourage more environmentally friendly vehicles. Thailand has implemented the Eco-Car Programme, Indonesia has promoted low-cost green cars, while Malaysia has introduced the Energy-Efficient Vehicle (EEV) policy. In Malaysia, EEV development has become a key direction for the automotive industry, particularly through the promotion of efficient internal combustion engine vehicles (ICEVs), hybrid electric vehicles (HEVs), and electric vehicles (EVs).

However, the transition towards electrified mobility in Malaysia requires careful evaluation. Although EVs produce zero tailpipe emissions, their overall operational CO_2 emissions depend strongly on the electricity generation mix. Similarly, HEVs can reduce fuel consumption and emissions compared with conventional ICEVs, but their effectiveness depends on vehicle efficiency, driving conditions, and the extent of hybridisation. Therefore, a direct comparison between ICEVs, HEVs, and EVs under Malaysian operating conditions is necessary to understand their relative energy and emissions performance. Recent work has also examined EV adoption in Malaysia using behavioural and predictive modelling approaches, highlighting the importance of consumer readiness, charging infrastructure, and policy support in achieving national EV adoption targets [6].

Previous studies have discussed vehicle energy consumption, transport-related emissions, and energy losses in passenger vehicles [2,7,8]. However, there remains a need for a simplified comparative framework to evaluate the operational energy consumption and CO_2 emissions of ICEVs, HEVs, and EVs, using consistent Malaysian assumptions. In particular, the gradual adoption of EEVs and their potential contribution to transport-sector decarbonisation require further assessment.

Therefore, this study aims to develop a comparative energy consumption model for ICEVs, HEVs, and EVs under Malaysian passenger-car conditions. The objectives are to determine the energy consumption breakdown of each vehicle type, estimate the corresponding operational CO_2 emissions, and evaluate the potential implications of different EEV adoption scenarios in Malaysia. The findings are expected to provide a clearer understanding of the short- and long-term roles of HEVs and EVs in supporting Malaysia's transition towards lower-carbon road transport.

Although previous studies have examined vehicle energy consumption, EV adoption, transport emissions, and friction-related energy losses, most of these works treat these topics separately. The present study differs in that it develops a simplified comparative framework that evaluates ICEVs, HEVs, and EVs under a consistent set of Malaysian passenger-car assumptions. In addition, the study combines vehicle-level energy breakdowns, operational CO_2 emissions, EEV adoption scenarios, and technology improvement strategies for ICEVs and HEVs within a single framework.

METHODOLOGY

This study focuses on gasoline-fuelled passenger vehicles, as gasoline or petrol is the dominant fuel used in Malaysian passenger cars [5]. Simplified energy consumption models were first developed for internal combustion engine vehicles (ICEVs), hybrid electric vehicles (HEVs), and electric vehicles (EVs). These models were then used to estimate the corresponding carbon dioxide emissions under different vehicle adoption scenarios. The overall methodological framework is summarised in Figure 1. It should be noted that the study focuses only on operational energy consumption and operational CO_2 emissions. Manufacturing emissions, battery production, infrastructure development, maintenance, vehicle disposal, and other life-cycle stages were not included.

An average vehicle model was adopted to represent typical passenger vehicles used in Malaysia and to simplify the energy consumption analysis. The vehicle specifications and input parameters were obtained from previous studies and representative average passenger-car data. These parameters include vehicle mass, fuel consumption, electricity consumption, drivetrain efficiency, rolling resistance coefficient, aerodynamic drag coefficient, frontal area, average vehicle speed, annual mileage, and regenerative braking factor, as summarised in Appendix A.

The parameters were selected to represent a simplified average Malaysian passenger-car model. Where Malaysia-specific values were unavailable, representative values from vehicle specifications, literature, and standard engineering assumptions were used. The purpose of the parameter set is not to represent a specific vehicle model but to provide a consistent basis for comparing the operational energy consumption of ICEV, HEV, and EV under the same annual mileage and driving assumptions.

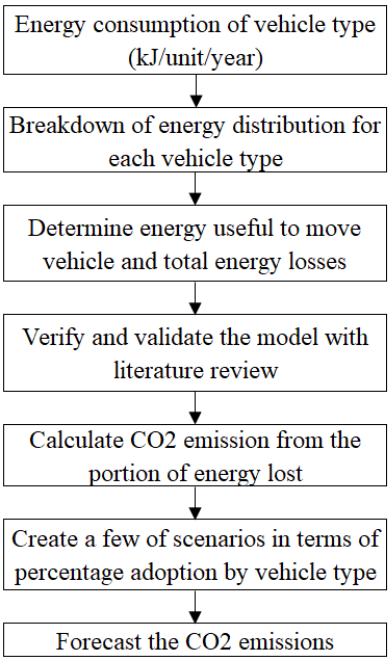

Figure 1: Flow chart for the methodology to develop a vehicle energy consumption model

The annual energy consumption of ICEVs and HEVs was calculated using Equation (1), which relates fuel consumption to fuel energy content. Since EVs are powered entirely by electricity and do not consume gasoline during operation, their annual energy consumption was calculated using Equation (2), which relates electricity consumption to annual mileage.

$$\begin{aligned} &EC_{ICEV\ or\ HEV} \\ &= Fuel\ consumption_{ICEV\ or\ HEV} \\ &\times Fuel\ density \times D_a \\ &\times Fuel\ lower\ heating\ value \end{aligned} \qquad (1)$$

$$EC_{EV} = 3600 \times power\ consumption \times D_a \qquad (2)$$

The energy consumption model was developed based on the vehicle's longitudinal dynamics. The traction force required to propel a vehicle is determined by the main resistive forces acting against its motion, namely rolling resistance, aerodynamic drag, grade resistance, and inertial/braking losses. The energy required to overcome these components is called traction energy, which represents the useful energy for vehicle propulsion. These formulations served as the basis for estimating the energy consumption of ICEVs, HEVs, and EVs The corresponding energy components were calculated using the equations below:

$$E_{Rolling\ resistance} = mvgC_r \times \frac{D_a}{v} \qquad (3)$$

$$E_{air\ drag} = \frac{\rho C_d}{2} \times A_f \times v^3 \times \frac{D_a}{v} \qquad (4)$$

$$E_{potential} = mgv\ \sin\theta \times \frac{D_a}{v} \qquad (5)$$

$$E_{kinetic\ or\ inertia} = \frac{1}{2} mv^3 \times \frac{D_a}{v} \times n \qquad (6)$$

where n is the number of acceleration events. Under real driving conditions, the number of acceleration events from rest to a specified velocity is difficult to determine. Therefore, the inertial energy associated with acceleration was assumed to be equivalent to the braking energy loss [7]. This assumption implies that the energy required to accelerate the vehicle from rest to a given speed equals the energy dissipated during deceleration from that speed to rest. Based on the braking energy loss framework adapted from Chong et al. [8], the braking loss was calculated as follows:

$$E_{braking} = 0.2 \times P_{out} \times \frac{D_a}{v} \qquad (7)$$

Mechanical power losses include rolling resistance, braking losses, engine frictional losses, and transmission losses. Since rolling resistance and braking losses have already been accounted for in the vehicle dynamics model, this section focuses on engine and transmission frictional losses. Based on the method proposed by Chong et al. [8], these losses were calculated using the following equations:

$$Engine\ frictional\ losses = n_{th} \times EC - P_{out} \times \frac{D_a}{v} \qquad (8)$$

$$Transmission\ losses = (1 - n_{tr}) \times P_{out} \times \frac{D_a}{v} \qquad (9)$$

In ICEVs, braking energy is dissipated as heat and is therefore treated as a loss. In contrast, HEVs and EVs can recover a portion of this braking energy through regenerative braking, in which the motor-generator converts kinetic energy into electrical energy, which is stored in the battery and later reused for propulsion. Yang et al. [9] defined the regenerative braking factor, k, as the percentage of total braking energy that can be recovered by the motor-generator.

$$k = \begin{cases} 0.5 \times \frac{v}{5}\, for\ v < 5m/s \\ 0.5 + 0.3 \times \frac{v-5}{20}\, for\ v \geq 5m/s \end{cases} \qquad (10)$$

Once the regenerative braking factor is determined, the amount of energy recovered through regenerative braking can be obtained by multiplying the braking loss in Equation (7) by the regenerative braking factor.

$$E_{regen} = k \times E_{braking} \qquad (11)$$

Similar regenerative braking modelling has also been reported, where an integrated EV model and regenerative braking system were simulated to evaluate battery recharging behaviour and state-of-charge response under different operating conditions [10].

For ICEVs and HEVs, CO_2 emissions are produced directly from gasoline combustion. In contrast, EVs do not consume gasoline during operation and therefore produce no tailpipe CO_2 emissions. However, their indirect emissions must be considered because electricity generation in Malaysia remains partly dependent on fossil fuels. Therefore, the CO_2 emissions of EVs were estimated using the vehicle's electricity consumption and the grid's emission factor. The CO_2 emission conversion factors used in this study are summarised in Table 1.

Table 1: CO_2 emission conversion factor for ICEV, HEV, and EV

Vehicle Type	CO_2 emission	Sources
ICEV and HEV	2.3 kg CO_2 per liter gasoline	[11]
EV	0.57 kg CO_2e/kWh	[12]

This study evaluates the gradual introduction of EEVs in Malaysia through several vehicle adoption scenarios. Since the transition from conventional ICEVs to HEVs and EVs cannot occur immediately, scenario analysis was used to examine the potential impact of different EEV adoption rates on future CO_2 emissions. The projected emissions were then compared to an indicative transport-sector reduction benchmark to assess the potential contribution of EEV adoption to Malaysia's low-carbon mobility pathway. The scenarios considered in this study are summarised in Table 2.

The adoption percentages in Table 2 were developed as exploratory scenario assumptions rather than official forecasts. The BAU case represents the continuation of current adoption patterns, while the moderate and aggressive cases represent progressively stronger EEV penetration. The extreme HEV and EV cases were included as boundary cases to illustrate the maximum theoretical effect of full replacement with HEV or EV under the assumptions used.

RESULTS AND DISCUSSION

Figures 2–4 show the energy distribution for ICEVs, HEVs, and EVs, respectively. Useful energy refers to the portion of total energy consumption used for vehicle traction, while energy losses include heat losses, frictional losses, braking losses, drivetrain losses, and auxiliary losses. The model estimates that useful traction energy accounts for 13.76%, 23.48%, and 69.19% of the total energy consumed by ICEVs, HEVs, and EVs, respectively. This indicates that EVs convert a substantially higher proportion of input energy into useful propulsion energy than ICEVs and HEVs, which incur greater losses due to combustion, mechanical friction, and drivetrain inefficiencies.

Table 3 compares the annual energy consumption and operational CO_2 emissions of the three vehicle types. The estimated annual energy consumption of a single ICEV is 46,416 MJ/year, while HEVs and EVs consume 28,463 MJ/year and 10,652 MJ/year, respectively. Compared with ICEVs, EVs reduce annual energy consumption by 77.05%. However, the corresponding reduction in operational CO_2 emissions is lower, at 45.96%, because EV emissions are indirectly associated with electricity generation. Although EVs produce no tailpipe emissions during operation, Malaysia's electricity generation mix remains partly dependent on fossil fuels. Therefore, the CO_2 emissions of EVs were estimated using the vehicle's electricity consumption and Malaysia's grid emission factor. In comparison with HEVs, EVs provide only an additional CO_2 reduction of approximately 7 percentage points under the assumptions used in this study.

Table 2: Various scenarios for EEV introduction in Malaysia

Scenarios	Assumptions
Business-as-Usual (BAU)	Assume the percentage adoption of EEVs is the same in 2030 and 2040 as of now.

Moderate	**2030** : 75% ICEV; 15% HEV; 10% EV **2040** : 50% ICEV; 30% HEV; 20% EV
Aggressive	**2030** : 50% ICEV; 25% HEV; 25% EV **2040** : 0% ICEV; 50% HEV; 50% EV
Extreme HEV	**2030** : 0% ICEV; 100% HEV; 0% EV
Extreme EV	**2030** : 0% ICEV; 0% HEV; 100% EV

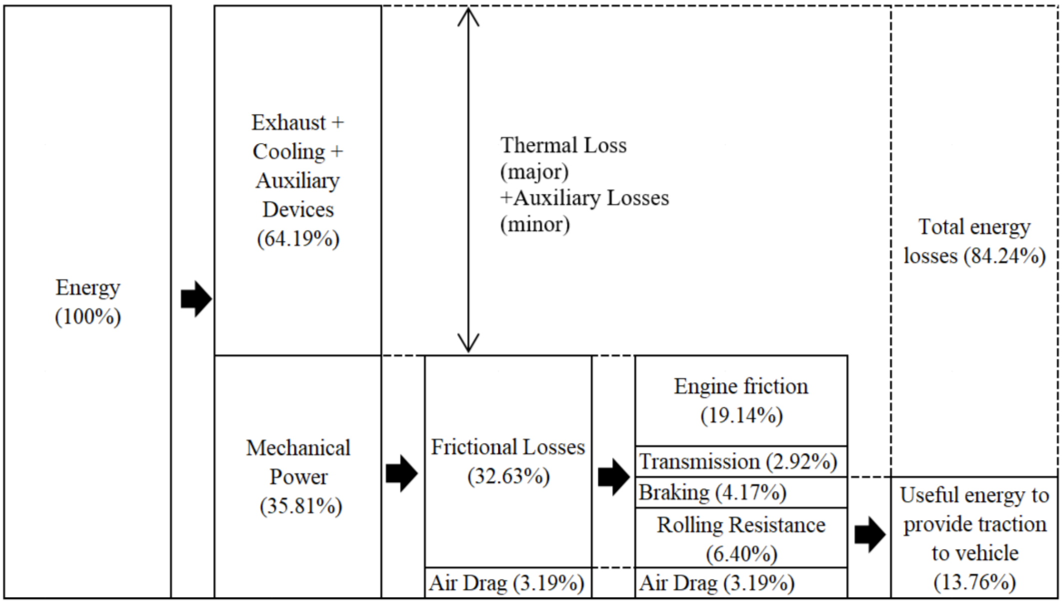

Figure 2: Energy distribution for a gasoline Internal Combustion Engine Vehicle (ICEV)

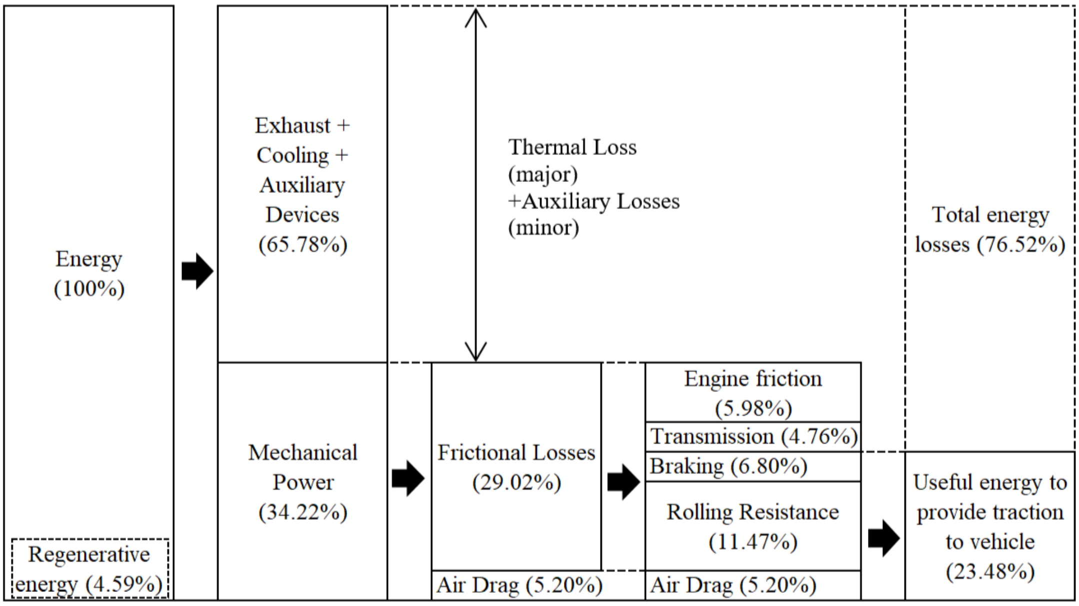

Figure 3: Energy distribution for a Hybrid Electric Vehicle (HEV)

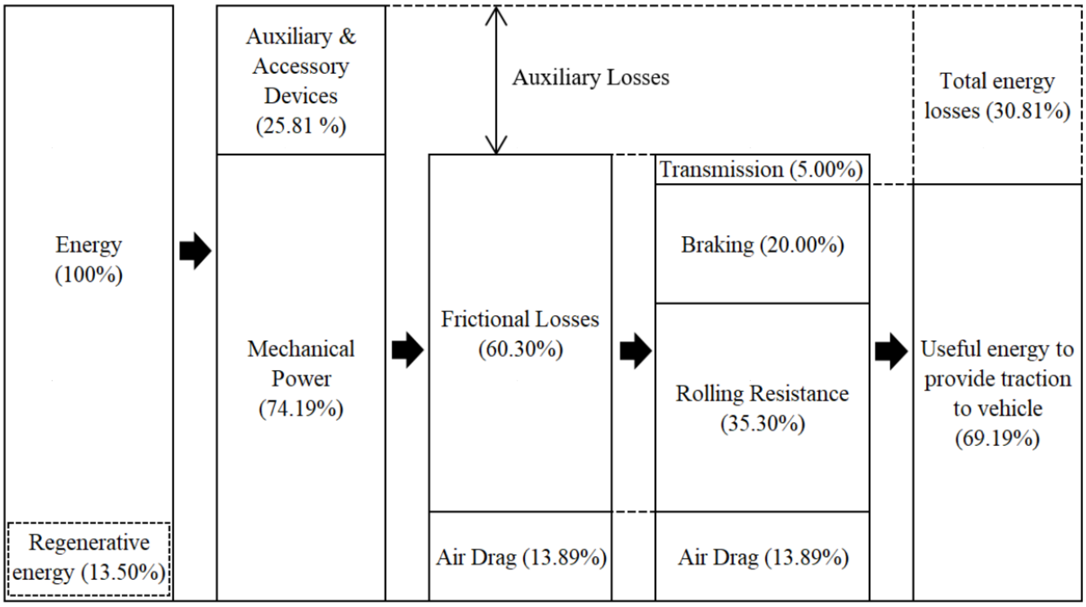

Figure 4: Energy distribution for an Electric Vehicle (EV)

Table 3: The percentage of energy consumption and CO2 emission reduction in HEV and EV

	Annual energy consumption (MJ/vehicle/year)	Annual CO_2 emissions (kg CO_2/vehicle/year)	Energy consumption difference compared to ICEV	Energy consumption difference compared to ICEV (%)	CO_2 emission Difference Compared to ICEV	CO_2 reduction compared to ICEV (%)
ICEV	46,416	3,122	-	-	-	-
HEV	28,463	1,914	-17,953	-38.68%	-1208	-38.69%
EV	10,652	1,687	-35,764	-77.05%	-1435	-45.96%

Table 4: CO_2 emission from different scenarios when compared to CO2 emission on 2005

Year / Scenario	2020	2030	2040
BAU	-0.29%	-23.00%	-23.07%
Moderate	-0.29%	-30.93%	-39.19%
Aggressive	-0.29%	-39.60%	-56.57%
Extreme HEV	-0.29%	-38.68%	N/A
Extreme EV	-0.29%	-45.97%	N/A

Scenario analysis was conducted to evaluate the effect of different EEV adoption rates on future CO_2 emissions. Since Malaysia's transition from ICEVs to HEVs and EVs is expected to occur gradually, several adoption scenarios were considered to examine potential emissions reductions at different levels of vehicle electrification. The projected emissions were compared with an indicative 45% reduction benchmark relative to the 2005 level to assess the transport sector's potential contribution to Malaysia's broader national emissions-reduction pathway. The 45% reduction benchmark was used as an indicative reference point because Malaysia has committed to reducing national greenhouse gas emissions intensity relative to GDP by 45% by 2030 compared with the 2005 level. However, this benchmark is not a direct transport-sector emission target. In this study, it is used only as a reference for discussing the potential contribution of the passenger-car technology transition to Malaysia's broader low-carbon pathway.

Table 4 shows that increasing the adoption of HEVs and EVs reduces CO_2 emissions in all scenarios. This is mainly because replacing ICEVs with HEVs and EVs lowers the average operational emissions per vehicle. However, the magnitude of reduction depends strongly on the level of EV adoption.

Under the assumptions used in this study, the BAU, moderate, and aggressive scenarios are insufficient to reach the indicative 45% reduction benchmark by 2030. Only the extreme EV scenario, which assumes 100% EV adoption by 2030, achieves a reduction close to this benchmark. However, this scenario is unlikely to be practical in the short term due to challenges such as vehicle affordability, charging infrastructure, grid readiness, and the time required for fleet replacement. Therefore, the results suggest that EEV adoption alone may not be sufficient for rapid transport-sector decarbonisation unless it is supported by stronger electrification policies, grid decarbonisation, and continued improvements in vehicle efficiency.

Technology Improvement Strategies for CO_2 Emission Reduction

Given that the rapid elimination of ICEVs is not practical in the short term, CO_2 emissions can also be reduced through improvements in vehicle and engine technologies. In this study, three technology improvement strategies were considered: (i) reduction of mechanical power losses and improvement of thermal management systems, (ii) engine downsizing and efficiency improvement through turbocharging, and (iii) advanced combustion using dilute lean-burn technology.

Table 5: CO_2 emission reductions of ICEVs and HEVs under different technology improvement strategies

	ICEV CO_2 emission (kg CO_2/unit/year)	ICEV reduction compared with original (%)	HEV CO_2 emission (kg CO_2/unit/year)	HEV reduction compared with original (%)
Original	3122	-	1914	-
Improvement 1	2691	-13.80%	1696	-11.39%
Improvement 2	2410	-22.80%	1524	-20.38%
Improvement 3	1755	-43.80%	1122	-41.38%

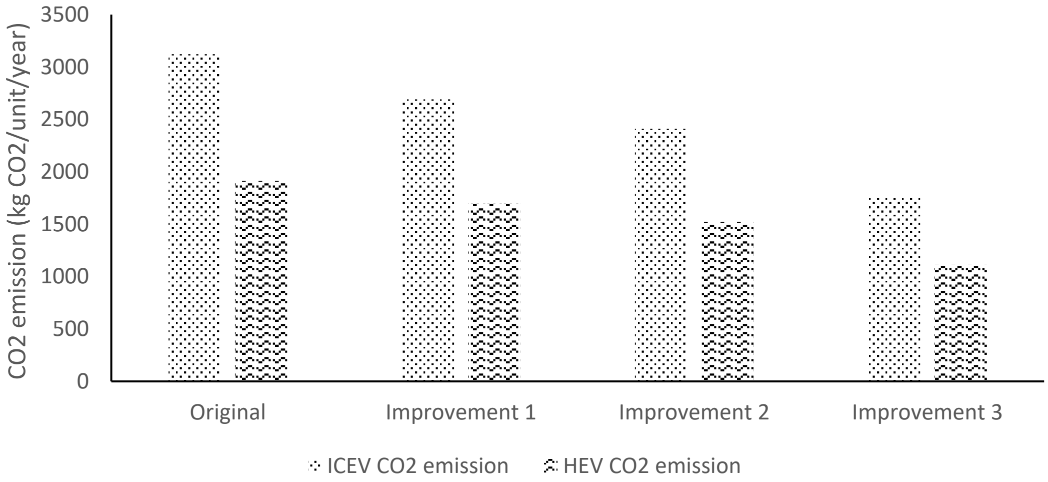

Figure 5: Comparison of CO2 emission ICEV and HEV after improvement

Table 6: Effect of technology improvement strategies on CO_2 emissions relative to the 2005 level under different adoption scenarios

Improvement Type	Scenario	2020	2030	2040
Improvement 1	BAU	-0.29%	-14.03%	-14.07%
	Moderate	-0.29%	-23.35%	-33.02%
	Aggressive	-0.29%	-33.72%	-53.81%
Improvement 2	BAU	-0.29%	-23.00%	-23.07%
	Moderate	-0.29%	-30.93%	-39.19%

	Aggressive	-0.29%	-39.60%	-56.57%
Improvement 3	BAU	-0.29%	-43.94%	-44.07%
	Moderate	-0.29%	-48.61%	-53.59%
	Aggressive	-0.29%	-53.32%	-63.03%

The reduction values for the technology improvement strategies were treated as indicative improvement cases. Improvement 1 represents the reduction of vehicle mechanical losses and the enhancement of thermal management systems. This includes improvements in bearing technology, engine lubrication, low-rolling-resistance tyres, aerodynamic components, and thermal management. Improvement 2 includes the measures in Improvement 1, with the additional application of turbocharged engine technology. Improvement 3 also includes the measures in Improvement 1, but replaces the turbocharged engine strategy with dilute lean-burn combustion technology.

As shown in Table 5, Improvement 1 reduces CO_2 emissions by 13.80% for ICEVs and 11.39% for HEVs. With the addition of turbocharging in Improvement 2, the CO_2 reduction increases to 22.80% for ICEVs and 20.38% for HEVs. Improvement 3 provides the largest reduction, with CO_2 emissions decreasing by 43.80% for ICEVs and 41.38% for HEVs. These results suggest that while improvements in mechanical losses and thermal management provide moderate benefits, advanced combustion strategies have greater potential to reduce CO_2 emissions from gasoline-based vehicle technologies.

Table 6 summarises the effect of these technology improvement strategies under different EEV adoption scenarios. Improvements 1 and 2 reduce CO_2 emissions but are insufficient to reach the indicative 45% reduction benchmark by 2030 under the scenarios considered. In contrast, Improvement 3 enables the moderate and aggressive adoption scenarios to exceed the benchmark by 2030, while the BAU scenario approaches the target. These findings indicate that advanced combustion technologies, combined with the gradual adoption of HEVs and EVs, may provide an important transitional pathway to reduce transport-related CO_2 emissions in Malaysia.

Challenges for the Implementation of EEVs in Malaysia

The implementation of EEVs in Malaysia faces several technical, economic, and policy-related challenges. For ICEVs and HEVs, further improvement through technologies such as turbocharging may be limited by consumer concerns regarding maintenance cost, long-term reliability, and engine durability. Retrofitting turbocharging systems into older vehicles may also require extensive modifications and may increase the risk of component failure if not properly designed and calibrated. Therefore, turbocharging is more suitable as a factory-integrated technology in new vehicles rather than as a retrofit solution for the existing vehicle fleet.

For HEVs, the main challenges are related to cost, maintenance, and consumer confidence. Since HEVs combine an internal combustion engine with an electric motor, battery pack, and additional power electronics, their maintenance requirements may be perceived as more complex than those of conventional ICEVs. Battery durability, replacement cost, and long-term reliability remain important concerns among consumers. In addition, the reduction or removal of government incentives, such as tax exemptions or other ownership-related benefits, may reduce consumer interest in HEVs, particularly if the purchase price remains higher than that of conventional vehicles.

EV adoption in Malaysia also faces several barriers. One of the main challenges is the availability and accessibility of charging infrastructure. Compared with conventional refuelling, EV charging generally requires a longer time, which may affect consumer acceptance, especially for users without access to home or workplace charging. Affordability is another major concern, as many EV models currently available in Malaysia are still priced in the higher-end segment. Wider availability of affordable EV models, including potential development by national manufacturers, such as Proton and Perodua, could help improve market acceptance and support the development of the local automotive industry.

In addition, EV adoption depends strongly on long-term policy clarity, investment planning, and grid readiness. A clear national roadmap for charging infrastructure, vehicle incentives, renewable electricity integration, and local EV production would help reduce uncertainty for consumers, manufacturers, and investors. Without these supporting measures, the transition towards HEVs and EVs may remain gradual despite their potential to reduce operational CO_2 emissions.

This study is subject to several limitations. The analysis is based on simplified average-vehicle assumptions and focuses only on operational energy consumption and CO_2 emissions. It does not include vehicle manufacturing emissions, battery production, end-of-life impacts, regional grid variations, detailed driving-cycle effects, or changes in future vehicle ownership. Therefore, the results should be interpreted as indicative scenario-based estimates rather than full life-cycle emissions predictions.

The scenario results show that high EV adoption is required to approach the indicative 45% reduction benchmark by 2030. However, the practical discussion above indicates that such rapid adoption is constrained by affordability, charging availability, grid readiness, and policy continuity. Therefore, the moderate and aggressive scenarios may be more realistic in the short- to medium-term, while the extreme EV scenario should be interpreted as a theoretical upper bound rather than a practical near-term pathway.

CONCLUSION

This study analysed the operational energy consumption and CO_2 emissions of energy-efficient vehicles in Malaysia using simplified vehicle energy consumption models for ICEVs, HEVs, and EVs. The model estimated that useful traction energy accounts for 13.76%, 23.48%, and 69.19% of total energy consumption in ICEVs, HEVs, and EVs, respectively. In terms of operational CO_2 emissions, HEVs and EVs were estimated to reduce emissions by 38.69% and 45.96%, respectively, compared with ICEVs.

The scenario analysis showed that increasing the adoption of HEVs and EVs can reduce transport-related CO_2 emissions. However, under the assumptions used in this study, BAU, moderate, and aggressive adoption scenarios are insufficient to meet the indicative 45% reduction benchmark by 2030. Only the extreme EV scenario, which assumes 100% EV adoption by 2030, achieves a reduction close to this benchmark. Nevertheless, this scenario is unlikely to be practical in the short term due to limitations related to vehicle affordability, charging infrastructure, grid readiness, and fleet replacement time.

The results also indicate that improvements to ICEV and HEV technologies remain important during the transition period. Strategies such as reducing mechanical power losses, improving thermal management, adopting turbocharged engines, and applying dilute lean-burn combustion can further reduce CO_2 emissions. Among the technology improvement strategies considered, dilute lean-burn combustion showed the largest potential reduction. Therefore, while EVs offer the strongest long-term pathway for reducing operational emissions, HEVs and improved ICEV technologies can provide useful short- to medium-term contributions to Malaysia’s low-carbon mobility transition.

The findings should be interpreted as comparative operational-emission estimates rather than full life-cycle emission results. Future work should incorporate updated official Malaysian transport and energy data, including vehicle population, annual mileage, fleet composition, and grid emission factors. The model can also be expanded to include diesel vehicles, motorcycles, commercial vehicles, regional differences in electricity generation, and life-cycle emissions from vehicle and battery production. Such improvements would allow the framework to better support policy discussions on EEV adoption targets, vehicle technology development, and transport-sector decarbonisation in Malaysia.

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APPENDIX A: PARAMETERS USED FOR THE AVERAGE VEHICLE ENERGY CONSUMPTION MODELS

Specification	**ICEV**	**HEV**	**EV**	**Unit**
Engine Capacity	1500	1500	-	cc
Vehicle mass, *m*	1500	1650	1900	kg
Fuel Consumption, *FC*	0.106	0.065	-	liter/km
Electric power consumption, *PC*	-	-	0.22	kWh/km
Engine thermal efficiency, n_{th}	0.4	0.4	-	-
Transmission efficiency, n_{tr}	0.86	0.86	0.95	-
Average engine output power, P_{out}	12	12	-	kW
Average motor output power, P_{out}	-	-	13.2	kW
Rolling resistance coefficient, C_r	0.015	0.015	0.015	-
Drag coefficient, C_d		0.33		-
Frontal area, A_f		2		m^2
Average vehicle speed, *v*		60		km/h
Annual Mileage, D_a		13450		km
Regenerative braking factor, *k*	-	0.675	0.675	
Fuel Lower Heating Value	43.7			kJ/g
Gasoline Density	745			g/liter
Air Density, ρ	1.2			kg/m^3