

The Influence of Improved Petrol Vehicle Features on a Sustainable Automotive Marketplace in Malaysia

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ABSTRACT

This study examines how enhanced features of petrol-powered vehicles can influence the creation of a sustainable automotive market in Malaysia. With the automotive sector moving to a greener form of transportation, petrol-driven cars will not be ignored as they are cheap and have a highly developed, robust refueling infrastructure. This paper is concerned with the measurement of fuel efficiency improvements, emission reduction technologies, and hybrid and environmentally friendly integration systems as independent variables. Quantitative research was adopted through a structured questionnaire that was administered to 300 respondents in central region of Malaysia. Statistical analysis was conducted using SPSS Version 25 to perform descriptive analysis, Pearson correlation, and multiple linear regression on the collected data. The findings indicate that there exist strong, positive correlations between the independent variables and the sustainable automotive marketplace ($r = 0.668$ to $r = 0.752$, $p < 0.01$). According to regression analysis, the overall fit of the model ($F = 181.211$, $p < 0.001$) explains 64.7% of the variance ($R^2 = 0.647$). The strongest predictor of a sustainable automotive marketplace was hybrid and eco-friendly integration technology ($\beta = 0.419$, $p < 0.001$), followed closely by emission reduction technology ($\beta = 0.274$, $p < 0.001$) and fuel efficiency improvements ($\beta = 0.205$, $p < 0.001$). These results demonstrate that petrol engine innovations serve as a critical bridging solution towards a more sustainable automotive future in Malaysia.

Keywords: Petrol engine vehicle, improved features, integrated technology, sustainable marketplace, automotive industry.

INTRODUCTION

The impact of vehicle technology advancements on market structure supports the automotive sector's ability to attain global economic growth (Owoso et al., 2024). The rising popularity of electric vehicles (EVs) is challenging but still rivaling conventional petrol-powered vehicles as the primary choice for consumers due to their cost advantages, performance, and extensive existing fuel infrastructure (Togun et al., 2024). However, growing environmental concerns and stringent emission regulations (De Wilde et al., 2023) have forced manufacturers to improve petrol-powered vehicle systems to achieve significantly higher fuel efficiency and environmental sustainability.

The integration of fuel-saving technologies with mild hybrid systems, direct fuel injection, and turbocharging in modern petrol engines is able to greatly improve vehicle performance where thermal and mechanical energy losses are minimized (Moradi et al., 2024). Therefore, this alternative can satisfy consumers who want conventional vehicles that comply with clean and strict environmental regulations. In addition, emission control systems such as petrol (gasoline) particulate filters (GPFs) and three-way catalytic converters are also

effective in offsetting the carbon footprint and particulate emissions of these petrol vehicles (Fayyazbakhsh et al., 2022).

In terms of marketing, consumers still continue to choose petrol vehicles due to affordability, low maintenance costs, and high resale prices. For developing countries, advanced petrol engines are more pragmatic and suitable for existing road networks. The lack of extensive grid capacity and charging infrastructure hinders the transition to large-scale electric vehicles (Mohamed, 2024). Therefore, manufacturers and regulatory authorities must understand the consumer perspective on purchasing power constraints and the need for a fundamental technological transition that should be realistically regulated towards automotive sustainability (Zhang et al., 2024).

This article particularly examines the extent to which modern petrol-powered cars have created sustainable progress in the Malaysian automotive industry in line with technological developments. These engines remain important based on the latest features implemented including fast refueling systems, improved acceleration, and smooth driving style. The extraordinary advances over the past two decades have also seen the development of emission control systems, engine cooling and fuel injection technologies that have resulted in vehicles with higher thermal efficiency and greater environmental friendliness (Fayyazbakhsh et al., 2022).

Problem Statement And Research Questions

The global automotive industry is undergoing rapid technological transformations, driven primarily by the urgent mandate to adopt environmentally friendly transportation systems. Amidst this shift, conventional vehicle manufacturers are aggressively developing advanced petrol powertrains capable of delivering exceptional fuel economy and minimized environmental footprints without compromising consumer performance demands (Joshi, 2020). Through critical technological innovations such as direct fuel injection, turbocharging, and variable valve timing (VVT), modern internal combustion engines can drastically reduce their carbon output (Ferrari et al., 2024). However, a critical macro-environmental challenge persists within the domestic sector regarding how to ensure long-term environmental sustainability as petrol-engined vehicles continue to dominate the marketplace. Conventional powertrains remain a primary source of urban carbon pollution and fossil fuel dependency (Reddy et al., 2024). In Malaysia, this issue is further compounded by a complex regulatory landscape, where inconsistent policy frameworks and fragmented fiscal incentives leave both consumers and manufacturers hesitant to commit fully to sustainable transportation paradigms (Ngu et al., 2020). Consequently, optimal vehicle emission management remains unrealized, posing a direct threat to Malaysia's strategic roadmap toward a low-carbon transportation ecosystem.

Hence, this study investigates the intersection of advanced propulsion engineering and market dynamics to establish a multi-dimensional sustainability framework for the Malaysian automotive sector. While substantial literature focuses on macro-level electric vehicle transitions, a clear research gap exists concerning how the continuous engineering optimization of petrol vehicles can be leveraged as an immediate, viable transition strategy. Specifically, there is a lack of empirical clarity on how consumer perceptions align with these engineering breakthroughs and what specific regulatory or operational coordinating factors are required to drive widespread market compliance. This structural uncertainty highlights an urgent need to identify the dominant technical characteristics of modern petrol powertrains that can simultaneously guarantee economic competitiveness for manufacturers and sustainable affordability for consumers. By isolating these critical variables, this research addresses the foundational gaps preventing the harmonization of ecological practices and continued internal combustion vehicle usage within developing automotive markets.

To address the aforementioned research problems, this study formulates the following three fundamental research questions (RQ):

RQ1: How does advanced petrol engine technology impact the multi-dimensional sustainability of the Malaysian automotive market?

RQ2: What specific features of advanced petrol vehicles are most appropriate for securing long-term marketplace sustainability within the Malaysian automotive sector?

RQ3: To what extent do the dominant technical characteristics of petrol-engined vehicles serve as primary contributors to sustainability within the local automotive industry?

Significance Of Study

The practical and theoretical significance of this research lies in its capacity to evaluate the real-world efficacy of advanced petrol-powered vehicles as an immediate vehicle for environmental sustainability. While macro-level discourse emphasizes complete electric vehicle (EV) adoption, the reality of developing automotive landscapes like Malaysia dictates that conventional and hybridized internal combustion engines remain widely preferred across both urban and suburban areas. This sustained reliance is primarily driven by persistent infrastructure limitations, such as an underdeveloped public charging network, combined with high upfront EV acquisition costs. Consequently, this study fills a critical gap by shifting focus toward internal combustion optimization as a pragmatic, cost-effective transitional alternative. By identifying how advanced engineering enhancements satisfy immediate ecological mandates, the findings provide a structured roadmap for policymakers and manufacturers to manage automotive carbon emissions effectively without inducing premature consumer or industrial disruption.

LITERATURE REVIEW

Fuel Efficiency Improvements

Growing environmental concerns and consumer demand for cost-effective transportation have triggered strict regulatory frameworks, positioning fuel efficiency as a paramount priority in automotive engineering. To achieve exceptional fuel economy, modern vehicle design leverages an array of interconnected technological systems that optimize combustion, reduce parasitic energy losses, and minimize thermal waste (Reitz et al., 2020; Jiaqiang et al., 2021). A foundational strategy in this effort is engine downsizing, which reduces displacement and cylinder count to decrease moving parts and mechanical friction losses (Namar et al., 2021; Wang et al., 2021). To compensate for reduced engine displacement without diminishing power output, manufacturers integrate advanced turbocharging technology. By capturing high-velocity exhaust gases to drive a compressor, turbochargers force packed air into the combustion chamber, enabling smaller engines to achieve highly complete, responsive fuel combustion (Di Battista et al., 2022; Shahariar et al., 2022).

Complementing these fundamental structural adjustments are sophisticated fuel management strategies and anti-idling innovations. Direct Fuel Injection (DFI) plays a critical role by pumping high-pressure fuel directly into the combustion chamber, allowing for meticulous air-fuel mixture control (Zhu et al., 2022). This technique effectively improves cooling within the cylinder head and piston, lowers overall heat loss, and enables stratified charge combustion under light operating loads (Kalwar et al., 2021). Alongside DFI, modern start-stop systems eliminate unnecessary idle fuel waste by automatically shutting off the engine when the vehicle is stationary and rapidly restarting it upon acceleration (Romano et al., 2021; Romero et al., 2024). To prevent premature wear on the primary starter motor, these setups utilize dedicated heavy-duty starter-generators and auxiliary battery systems.

Beyond thermodynamic and combustion optimization, structural weight reduction serves as a vital mechanical pillar for modern fuel economy. Replacing heavy cast iron components within the engine block and cylinder heads with advanced lightweight materials such as aluminum, magnesium alloys, and composite materials significantly decreases total vehicle mass (Romero et al., 2024; Zhang et al., 2022). This structural reduction directly minimizes rolling resistance and decreases the absolute energy required during vehicle acceleration. Consequently, vehicles benefit from a dual advantage: significantly enhanced handling dynamics and sustained, long-term reductions in fuel consumption.

Emission Reduction Technologies

Escalating global environmental challenges have created an urgent national need to mitigate hazardous gaseous emissions from road transport (Nunes et al., 2023). While global benchmarks shift toward Euro 6 and Euro 7 frameworks, markets like Malaysia focus on progressively tightening emission baselines, primarily

driven by the national rollout of Euro 5 fuel specifications. To comply with these advancing localized standards without sacrificing vehicle performance, modern petrol models rely on an array of integrated exhaust treatment technologies. A central component in this effort is the three-way catalytic converter, which utilizes precious metals like platinum, rhodium, and palladium to transform toxic carbon monoxide, nitrogen oxides (NO_x), and unburned hydrocarbons into harmless carbon dioxide, nitrogen, and water vapor (Lejda et al., 2021). To ensure peak conversion efficiency, the system continuously relies on oxygen sensor feedback to maintain an exact stoichiometric air-fuel ratio (Huang et al., 2022). This chemical process is directly supported by Exhaust Gas Recirculation (EGR) systems, which route a precise portion of inert exhaust gas back into the intake manifold to dilute the air-fuel mixture, effectively lowering peak combustion temperatures and suppressing NO_x formation (Kumar et al., 2022; Joshi et al., 2020).

Alongside gaseous chemical conversion, managing particulate matter remains a critical priority for direct-injection engines that inherently produce higher soot emissions. To address this, Petrol Particulate Filters (GPFs) are increasingly integrated into vehicle exhaust tracts, utilizing a porous ceramic honeycomb substrate to trap fine soot particles before they exit the tailpipe. To maintain long-term functionality and comply with particulate count standards, the filter periodically undergoes passive or active regeneration to burn off the trapped soot (Valverde et al., 2020; Awad et al., 2020). Through this synergetic combination of chemical conversion, temperature regulation, and physical filtration, contemporary vehicles significantly mitigate their overall environmental footprint even when operating in regions with developing regulatory timelines.

Integration Technologies

Vehicle hybridization serves as an essential technological bridge between conventional internal combustion engines (ICE) and fully electric drivetrains, optimizing both the environmental footprint and operational performance of petrol vehicles (Reitz et al., 2020). A critical mechanism within mild and full-hybrid architectures is regenerative braking, which captures kinetic energy during deceleration that would otherwise be dissipated as wasted heat through the brake pads (Hamada et al., 2022). This system converts the captured kinetic energy into electrical energy, storing it in an auxiliary battery to power an electric starter-generator that actively assists the engine during high-load acceleration. This electric assistance works in tandem with eco-friendly engine designs, which utilize low-friction coatings on pistons and cylinders to minimize internal mechanical losses (Şener et al., 2021; Zhang et al., 2022). Furthermore, optimized combustion chamber geometries and elevated static compression ratios promote complete fuel burn, while advanced thermal management networks precisely regulate operating temperatures to maximize thermodynamic efficiency.

Sustaining these physical and mechanical optimizations requires sophisticated, data-driven engine monitoring and control systems. Advanced Engine Control Units (ECUs) utilize an extensive network of electronic sensors to monitor critical parameters such as coolant temperature, throttle position, exhaust oxygen levels, and air intake volume in real time (Li et al., 2023). By analyzing this continuous stream of data, the ECU dynamically recalculates and adjusts fuel injection timing, ignition maps, and variable valve timing (VVT) parameters. This continuous electronic calibration ensures that the powertrain consistently operates within its peak efficiency window across all driving cycles and load conditions. Through this integration of kinetic energy recovery, minimized friction, and real-time electronic governance, hybridized powertrains achieve substantial reductions in fuel consumption and tailpipe emissions.

Sustainable Automotive Marketplace

The sustainable automotive marketplace is an emerging, multi-dimensional sector focused on environmental preservation, energy resource efficiency, economic stability, and consumer inclusivity (Agarwal et al., 2020). For petrol-engined vehicles, marketplace sustainability is primarily anchored in environmental impact reduction and economic continuity. Technological advancements in fuel economy and exhaust after-treatment significantly lower localized and global emissions, allowing internal combustion engines to comply with increasingly stringent environmental baselines (Wellbrock et al., 2020). Simultaneously, maintaining a clean, highly efficient petrol-engined segment protects the financial health of local automotive suppliers, manufacturers, and labor forces (Mishra et al., 2022; Mattioli et al., 2020). This balances environmental goals

with industrial stability, preventing severe economic disruption during the broader macro-economic transition toward full electrification.

Furthermore, advanced petrol and hybridized powertrains act as a critical technological and socio-economic bridge for mass-market consumers. Mild-hybrid architectures and integrated energy management features serve as an essential transitional step, conditioning consumer driving behaviors toward energy-efficient habits, such as utilizing eco-modes, prior to full electric vehicle (EV) ownership (Singh et al., 2024). This transition is vital given that battery electric vehicles still carry high upfront purchase premiums that effectively exclude lower- and middle-income demographics. Consequently, advanced petrol vehicles enhanced with integrated green technologies represent an accessible, low-operating-cost option for mass-market buyers (Tarei et al., 2021; Waseem et al., 2023). This inclusivity is especially critical in developing automotive markets and rural regions that currently lack widespread public charging infrastructure.

Beyond short-term consumer accessibility, long-term resource efficiency and circular economy principles underpin the sustainability of modern petrol-engined vehicles. Contemporary powertrains utilize higher-strength materials and smart monitoring systems that substantially extend the operational lifespan of the vehicle (Yang et al., 2022; De Abreu et al., 2022). By prolonging vehicle longevity, this durability directly slows vehicle replacement cycles, which in turn conserves critical manufacturing raw materials and reduces industrial factory energy expenditure. Ultimately, optimizing the lifecycle of advanced petrol vehicles prevents premature scrappage, supports sustainable consumption patterns, and ensures that resource efficiency is maintained throughout the automotive value chain.

METHODOLOGY

Research Design

To empirically evaluate the conceptual framework, this study deployed a quantitative, cross-sectional survey design to capture immediate trends, perceptions, and statistical relationships within a defined research timeframe (Maier et al., 2023; Neale et al., 2020). The empirical investigation was anchored in central region of Malaysia, a place that serves as an ideal research site due to its highly established automotive manufacturing sector, exceptionally high vehicle ownership rates, and evolving regulatory framework aimed at shifting toward localized environmental sustainability. To gather data across this landscape, a probability sampling strategy specifically simple random sampling was used to collect data from a geographically dispersed target population comprising Malaysian vehicle owners, regular drivers, and potential car buyers with direct experience in petrol-powered vehicles (Lohr et al., 2021). Grounded in the sample size determination guidelines established by Krejcie and Morgan (1970), a minimum baseline of 383 respondents was targeted to ensure reliable, generalizable results at a 95% confidence level with a 5% margin of error for an undefined or large population exceeding 10,000 individuals.

Primary data collection was facilitated through a highly structured survey questionnaire organized into three distinct operational sections as follow.

Section A captured demographic profiles, detailing respondent characteristics such as gender, age, occupation, monthly income bracket, and petrol vehicle ownership status.

Section B operationalized the independent variables, using 5 items each to measure consumer perceptions regarding Fuel Efficiency Improvements, Emission Reduction Technologies, and Integration Technologies.

Section C assessed user perceptions of the central dependent variable, the Sustainable Automotive Marketplace, through a dedicated 5-item construct. To ensure high measurement precision, all items within Sections B and C were evaluated using a standardized 5-point Likert scale ranging from 1 (Strongly Disagree) to 5 (Strongly Agree), a configuration widely validated for capturing nuanced behavioral and attitudinal variances (Sekaran & Bougie, 2010; Dillman et al., 2014).

Prior to full-scale field distribution, the structural clarity, legibility, and initial reliability of the questionnaire were verified through a rigorous pilot study executed with 30 randomly selected respondents (Wadood et al., 2021). Feedback from this preliminary phase guided minor refinements, which included simplifying complex technical jargon, rephrasing ambiguous items, and optimizing the logical sequence of the questions to enhance respondent comprehension. The internal consistency of the instrument was statistically validated through Cronbach's alpha analysis, where all underlying constructs exceeded the universally accepted reliability threshold of 0.70, thereby confirming the suitability of the research instrument for deployment in the main data collection phase (Teresi et al., 2022; Aithal et al., 2020).

Following the full field administration of the survey, the quantitative datasets were processed utilizing the Statistical Package for the Social Sciences (SPSS) Version 25 software platform (Cooksey et al., 2020). The statistical analysis pipeline commenced with descriptive statistics, applying frequency distribution tables and percentage breakdowns to systematically summarize the demographic background of the sample. To ensure the dataset satisfied the assumptions necessary for parametric testing, normality was strictly evaluated through an inspection of Skewness and Kurtosis metrics, followed by a secondary reliability check recalculating Cronbach's alpha coefficients across the full sample. Subsequently, inferential statistical analyses were performed to test the research hypotheses. Pearson correlation analysis was first utilized to determine the strength and direction of the linear bivariate relationships existing between the individual independent variables and the dependent variable. Finally, to evaluate the collective predictive capacity of the framework, a Multiple Linear Regression analysis was conducted to examine the overall model fit via the coefficient of determination (R^2 or R squared), validate model significance using analysis of variance (ANOVA F-test), and isolate the unique predictive weight of each technology dimension through standardized beta coefficients (β or beta) and corresponding t -values (James et al., 2023).

RESULTS AND DISCUSSION

Descriptive Analysis

Table 1: Demographic Profile of Survey Respondents (N = 300)

Demographic Category	Sub-Group	Frequency (N)	Percentage (%)
Gender	Male	158	52.7%
	Female	142	47.3%
Age	Below 20 years old	13	4.3%
	21 – 25 years old	126	42.0%
	26 – 30 years old	56	18.7%
	31 – 35 years old	40	13.3%
	36 years old and above	65	21.7%
Occupation	Government employee	71	23.7%
	Private sector employee	93	31.0%
	Self-employed	49	16.3%
	Student	84	28.0%
	Unemployed	3	1.0%

Monthly Salary	Below RM1,500	86	28.7%
	RM1,501 – RM3,000	46	15.3%
	RM3,001 – RM4,500	56	18.7%
	RM4,501 – RM6,000	48	16.0%
	Above RM6,000	64	21.3%
Vehicle Ownership	Yes	250	83.3%
	No	50	16.7%

The demographic characteristics of the 300 respondents are detailed in the above Table 1. Although the initial distribution targeted 383 respondents, the final analytical sample comprises 300 fully completed and usable surveys (a 78.33% response rate). This sample yields a 5.66% post-hoc margin of error at a 95% confidence level. Falling well within the conventional 5% to 7% threshold for social sciences, this minor variance preserves the data's statistical integrity and generalizability. The sample displays a balanced gender representation, with 158 males (52.7%) and 142 females (47.3%). The largest age group is young adults aged 21–25 years old (42.0%), reflecting Malaysia's active car-buying demographic. In terms of occupation, the private sector represents the largest segment (31.0%), followed by students (28.0%) and government sector employees (23.7%). Monthly income is widely distributed, with 28.7% earning below RM1,500, and 21.3% earning above RM6,000, representing diverse socioeconomic backgrounds. Crucially, 83.3% of the respondents own or drive a petrol-engined vehicle, ensuring direct personal experience with the study's subject matter.

Normality Testing

To verify that the dataset is appropriate for parametric statistical analyses (Pearson correlation and multiple regression), Skewness and Kurtosis were calculated for all 20 key items. According to Hair et al. (2022), Skewness values between -1 and +1 are considered excellent, and values between -2 and +2 indicate an acceptable normal distribution. Similarly, Kurtosis values between -2 and +2 are acceptable. For this dataset, the Skewness statistics ranged from -0.336 to -0.746, and the Kurtosis statistics ranged from -0.421 to -1.076. This confirms that all variables lie well within the acceptable normality band, displaying slight left skewness and a slightly flatter (platykurtic) shape, indicating stable distributions with minimal outlier effects.

Construct Reliability Testing

To confirm internal consistency, Cronbach's Alpha coefficients were calculated for the constructs. The results are summarized in Table 2. As established by Lee J. Cronbach (1951), an alpha coefficient above 0.70 is acceptable, above 0.80 is good, and above 0.90 is excellent. Fuel Efficiency Improvements ($\alpha = 0.726$) displays acceptable reliability, while Emission Reduction Technologies ($\alpha = 0.873$) and Integration Technologies ($\alpha = 0.836$) exhibit good internal consistency. The Sustainable Automotive Marketplace construct ($\alpha = 0.907$) exhibits excellent reliability. Since all constructs exceed the 0.70 threshold, the research instrument has proven highly reliable and suitable for hypothesis testing.

Table 2: Construct Reliability Analysis (N = 300)

Construct Variable	Number of Items	Cronbach's Alpha (α)	Internal Consistency Status
Fuel Efficiency Impr (IV1)	5	0.726	Acceptable Reliability
Emission Reduction Tech (IV2)	5	0.873	Good Reliability



Integration Tech (IV3)	5	0.836	Good Reliability
Sustainable Auto Market (DV)	5	0.907	Excellent Reliability

Pearson Correlation Analysis

Pearson correlation was performed to measure the bivariate linear relationships between the variables. The outputs in Table 3 indicate that all independent variables are positively and significantly correlated with the dependent variable at the 0.01 level (2-tailed). A strong positive correlation exists between Fuel Efficiency Improvements (IV1) and the Sustainable Automotive Marketplace (DV) ($r = 0.668$, $p < 0.01$). Emission Reduction Technology (IV2) also shares a strong positive relationship with the DV ($r = 0.713$, $p < 0.01$). The strongest correlation was observed between Integration Technologies (IV3) and the DV ($r = 0.752$, $p < 0.01$). Moderate positive correlations were also recorded among the independent variables themselves (ranging from $r = 0.663$ to $r = 0.716$), showing that while they are related, there is no risk of multicollinearity.

Table 3: Pearson Correlation Matrix (N = 300)

Construct	Fuel Efficiency (IV1)	Emission Reduction (IV2)	Integration Tech (IV3)	Sustainable Market (DV)
Fuel Efficiency Impr (IV1)	1.000	0.676**	0.663**	0.668**
Emission Reduction Tech (IV2)	0.676**	1.000	0.716**	0.713**
Integration Tech (IV3)	0.663**	0.716**	1.000	0.752**
Sustainable Auto Market (DV)	0.668**	0.713**	0.752**	1.000

**. Correlation is significant at the 0.01 level (2-tailed).

Multiple Linear Regression Analysis

Multiple linear regression was conducted to determine the combined predictive effect of the independent variables on the Sustainable Automotive Marketplace. The model summary (Table 4) reveals an R coefficient of 0.805, indicating a strong positive relationship. The R Square (R^2) is 0.647, indicating that the independent variables jointly account for 64.7% of the variance in the sustainable automotive marketplace. The remaining 35.3% is explained by other external factors not included in this study, such as vehicle pricing, national carbon policy incentives, and consumer green awareness.

Table 4: Model Summary (SPSS Regression Output)

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.805a	.647	.644	.53004

To evaluate the overall significance of the regression model, the ANOVA F-test was utilized. As displayed in Table 5, the model generated an F-value of 181.211 with a significance value of 0.000 ($p < 0.05$). This indicates that the regression model is statistically highly significant, confirming a robust linear relationship between the independent variables and the dependent variable, allowing for a confident rejection of the null hypothesis.

Table 5: ANOVA Result of the Regression Model

Model 1	Sum of Squares	df	Mean Square	F	Sig.
Regression	152.727	3	50.909	181.211	.000b
Residual	83.158	296	.281		
Total	235.885	299			

To determine the individual predictive strength of each independent variable, standard regression coefficients were calculated (Table 6). The unstandardized coefficient B reveals the quantitative change in the DV per unit change of the IV, while the standardized coefficient Beta (β) permits comparison of relative predictive importance.

Table 6: Standard Regression Coefficients of Predictor Variables

Model 1	Unstandardized β	Std. Error	Standardized Beta (β)	t-value	Sig.
(Constant)	0.377	0.141		2.668	0.008
Fuel Efficiency Impr (IV1)	0.212	0.051	0.205	4.113	0.000
Emission Reduction Tech (IV2)	0.267	0.052	0.274	5.103	0.000
Integration Tech (IV3)	0.414	0.052	0.419	7.951	0.000

Based on Table 6, the regression equation is established as:

$$Y = 0.377 + 0.212(IV1) + 0.267(IV2) + 0.414(IV3)$$

All three predictor variables exhibit statistically significant positive effects on the Sustainable Automotive Marketplace ($p = 0.000 < 0.05$). The standardized coefficients demonstrate that Integration Technologies (IV3) is the strongest predictor ($\beta = 0.419$, $t = 7.951$), followed by Emission Reduction Technologies (IV2) ($\beta = 0.274$, $t = 5.103$), and Fuel Efficiency Improvements (IV1) ($\beta = 0.205$, $t = 4.113$).

RESULTS DISCUSSION

The empirical findings strongly support the theoretical linkages established in the literature. The balanced demographic profile (52.7% male, 47.3% female) ensures that consumer perceptions are gathered equally from both genders. The predominance of young adults aged 21–25 years old (42.0%) is highly relevant, as this younger demographic represents Malaysia's primary future vehicle-buying cohort. They are highly receptive to environmental sustainability but are simultaneously constrained by initial financial capital (with 28.7% earning below RM1,500/month) and a lack of residential charging infrastructures.

Therefore, advanced technologies that improve the fuel efficiency of conventional engines (IV1) represent an immediate, accessible value proposition for budget-conscious consumers, allowing them to participate in sustainability while achieving operational fuel savings. Similarly, emission control innovations like catalytic converters and GPFs (IV2) allow consumers to dramatically reduce their carbon footprint and localize toxic output (NOx, soot) in their daily commutes (83.3% vehicle owners). The dominant predictive power of Integration Technologies (IV3) ($\beta = 0.419$) reflects consumer enthusiasm for mild-hybrid designs and smart electronic engine management. These systems allow partial electrification and energy reclamation (such as regenerative braking) without requiring charging grids, offering a perfect transitional alternative in developing markets like Malaysia.

CONCLUSION AND RECOMMENDATIONS

Achievements of Research Questions

All three research questions outlined were successfully achieved:

Achievement of RQ1: The study confirms that improved petrol engine technologies exert a statistically highly significant positive impact on the sustainability of the Malaysian automotive market. The overall model fit is strong, explaining 64.7% of marketplace outcomes.

Achievement of RQ2: The strong pairwise correlations among the independent variables $r = 0.663$ to 0.716 mathematically confirm that these technologies do not operate in isolation; instead, they function as mutually reinforcing factors. By demonstrating that any two features are deeply synchronized, this pairwise connectivity proves a balanced alternative, lowers operational costs and reduces urban emissions significantly.

Achievement of RQ3: The study analyzed the key improved features of petrol engines, identifying that Integration Technologies (IV3) acts as the most dominant contributor ($\beta = 0.419$), followed by Emission Reduction Technologies (IV2) ($\beta = 0.274$) and Fuel Efficiency Improvements (IV1) ($\beta = 0.205$).

Achievements of Research Hypotheses

The empirical validation of the research hypotheses is decisively established by the robust t -values derived from the multiple linear regression analysis, which confirm that the selected independent variables do not act as competing alterations but as highly significant, complementary drivers of the Sustainable Automotive Marketplace. The individual predictive significance of each dimension is underscored by its respective t -statistic, led by Integrated Technologies (IV3) ($t = 7.951$, $p < 0.05$), followed by Emission Reduction Technologies (IV2) ($t = 5.103$, $p < 0.05$), and Fuel Efficiency Improvements (IV1) ($t = 4.113$, $p < 0.05$). Every calculated t -value comfortably exceeds the standard critical threshold of ± 1.96 , mathematically proving that the positive relationship hypothesized for each individual engineering component is highly significant and immune to random sampling error. This inferential robustness mirrors the tight pairwise correlations recorded among the predictor pairs ($r = 0.663$ to 0.716), where thermodynamic advancements physically reduce downstream after-treatment loads, and real-time electronic oversight (IV3) acts as the primary mechanism required to synchronize these systems. Ultimately, these elevated t -values provide definitive empirical verification for the acceptance of H1, H2, and H3, demonstrating that a sustainable automotive market relies entirely on this precisely integrated technological ecosystem.

Significant Contributions of the Study

Contributions to the Body of Knowledge: This study expands the available literature on automotive sustainability by shifting the academic focus from an all-or-nothing transition to electric vehicles. It empirically demonstrates that optimizing existing combustion engine technologies is a highly viable and scientifically sound pathway to sustainability in developing nations, successfully bridging the theoretical gap between conventional vehicle engineering and green marketplace frameworks.

Practical Contributions to Industry: For automotive manufacturers, the results validate continued investment in mild-hybridization, DFI, and advanced exhaust filtering, particularly in markets where EV charging infrastructure is underdeveloped. For policymakers, it demonstrates that sustainable mobility goals can be reached realistically by offering transitional incentives for clean, high-efficiency petrol and hybrid vehicles, maintaining economic viability for both manufacturers and mass-market consumers.

Limitations and Future Research Directions

Despite its contributions, several limitations must be addressed. First, the study utilized self-administered questionnaires, which are susceptible to subjective response biases. Second, the geographical focus was restricted to central region of Malaysia, potentially limiting direct generalizability to markets with higher EV

penetration or different carbon regulation levels. Third, the cross-sectional design restricts observation of overtime changes in customer perceptions

To address these limitations, future research should:

- Incorporate external market variables, such as vehicle price, direct government subsidies, and localized fuel price fluctuations.
- Utilize larger, multi-national samples to compare consumer behaviors across Southeast Asian developing countries.
- Adopt a longitudinal research approach to map long-term shifts in consumer trust and environmental adaptation over several years.

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REFERENCES

1. Agarwal, J., Sahoo, S., Mohanty, S., & Nayak, S. K. (2020). Progress of novel techniques for lightweight automobile applications through innovative eco-friendly composite materials: A review. *Journal of Thermoplastic Composite Materials*, 33(7), 978–1013. [Sage Journals Portal](#)
2. Aithal, A., & Aithal, P. S. (2020). Development and validation of survey questionnaire & experimental data—A systematical review-based statistical approach. *International Journal of Management, Technology, and Social Sciences (IJMTS)*, 5(2), 233–251. [SSRN Scholarly Network](#)
3. Alita, D., Putra, A. D., & Darwis, D. (2021). Analysis of classic assumption test and multiple linear regression coefficient test for employee structural office recommendation. *IJCCS (Indonesian Journal of Computing and Cybernetics Systems)*, 15(3), 295–306. [UGM Journal Repository](#)
4. Almalki, F. A., Alsamhi, S. H., Sahal, R., Hassan, J., Hawbani, A., Rajput, N. S., ... & Breslin, J. (2023). Green IoT for eco-friendly and sustainable smart cities: Future directions and opportunities. *Mobile Networks and Applications*, 28(1), 178–202. [SpringerLink Portal](#)
5. Awad, O. I., Ma, X., Kamil, M., Ali, O. M., Zhang, Z., & Shuai, S. (2020). Particulate emissions from petrol direct injection engines: A review of how current emission regulations are being met by automobile manufacturers. *Science of the Total Environment*, 718, Article 137302. ScienceDirect Database
6. Cooksey, R. W. (2020). Descriptive statistics for summarising data. *Illustrating Statistical Procedures: Finding Meaning in Quantitative Data*, 61–139. [SpringerLink Portal](#)
7. De Abreu, V. H. S., Da Costa, M. G., Da Costa, V. X., De Assis, T. F., Santos, A. S., & D'Agosto, M. D. A. (2022). The role of the circular economy in road transport to mitigate climate change and reduce resource depletion. *Sustainability*, 14(14), Article 8951. [MDPI Open Access](#)
8. De Wilde, L., Keserü, I., Macharis, C., & Vanhaverbeke, L. (2023). Finding alternatives for the traditional diesel-powered company car: A conjoint analysis approach. *Frontiers in Sustainability*, 4, Article 1114437. Frontiers Media Platform
9. Di Battista, D., Di Bartolomeo, M., & Cipollone, R. (2022). Full energy recovery from exhaust gases in a turbocharged diesel engine. *Energy Conversion and Management*, 271, Article 116280. ScienceDirect Database
10. Fayyazbakhsh, A., Bell, M. L., Zhu, X., Mei, X., Koutný, M., Hajinajaf, N., & Zhang, Y. (2022). Engine emissions with air pollutants and greenhouse gases and their control technologies. *Journal of Cleaner Production*, 376, Article 134260. ScienceDirect Database
11. Ferrari, A., Gurri, S., & Vento, O. (2024). Injected fuel mass and flow rate control in internal combustion engines: A systematic literature review. *Energies*, 17(24), Article 6455. [MDPI Open Access](#)

12. Gao, J. (2024). R-Squared (R^2)—How much variation is explained?. *Research Methods in Medicine & Health Sciences*, 5(4), 104–109. Sage Journals Portal
13. Gaur, P. S., Zimba, O., Agarwal, V., & Gupta, L. (2020). Reporting survey-based studies—A primer for authors. *Journal of Korean Medical Science*, 35(45), Article e398. JKMS Official Portal
14. Hamada, A. T., & Orhan, M. F. (2022). An overview of regenerative braking systems. *Journal of Energy Storage*, 52, Article 105033. ScienceDirect Database
15. Huang, Y., Lee, C. K., Yam, Y. S., Zhou, J. L., Surawski, N. C., Organ, B., ... & Shon, H. K. (2022). Effective emissions reduction of high-mileage fleets through a catalytic converter and oxygen sensor replacement program. *Science of the Total Environment*, 850, Article 158004. ScienceDirect Database
16. James, G., Witten, D., Hastie, T., Tibshirani, R., & Taylor, J. (2023). Linear regression. In *An Introduction to Statistical Learning: with Applications in Python* (pp. 69–134). Springer, Cham. [SpringerLink Book Portal](#)
17. Jiaqiang, E., Ding, J., Chen, J., Liao, G., Zhang, F., & Luo, B. (2021). Process in micro-combustion and energy conversion of micro power system: A review. *Energy Conversion and Management*, 246, Article 114664. ScienceDirect Database
18. Johari, N. A., & Yusoff, R. (2026). Analysing the economic and environmental impact of electric vehicle diffusion on the Malaysian economy. *International Journal of Energy Economics and Policy*, 16(2), 394–402. EconJournals Portal
19. Joshi, A. (2020). Review of vehicle engine efficiency and emissions. *SAE International Journal of Advances and Current Practices in Mobility*, 2(2020-01-0352), 2479–2507. SAE Mobilus Portal
20. Kalwar, A., & Agarwal, A. K. (2021). Lean-burn combustion in direct-injection spark-ignition engines. *Alternative Fuels and Advanced Combustion Techniques as Sustainable Solutions for Internal Combustion Engines*, 281–317. SpringerLink Portal
21. Karunarathna, I., Gunasena, P., Hapuarachchi, T., & Gunathilake, S. (2024). The crucial role of data collection in research: Techniques, challenges, and best practices. *Uva Clinical Research*, 1, 1–24. ResearchGate Profile Repository
22. Koohestanian, E., & Shahraki, F. (2021). Review on principles, recent progress, and future challenges for oxy-fuel combustion (CO_2) capture using compression and purification unit. *Journal of Environmental Chemical Engineering*, 9(4), Article 105777. ScienceDirect Database
23. Kumar, M. V., Babu, A. V., Reddy, C. R., Pandian, A., Bajaj, M., Zawbaa, H. M., & Kamel, S. (2022). Investigation of the combustion of exhaust gas recirculation in diesel engines with a particulate filter and selective catalytic reactor technologies for environmental gas reduction. *Case Studies in Thermal Engineering*, 40, Article 102557. ScienceDirect Database
24. Lejda, K., Jaworski, A., Mądziel, M., Balawender, K., Ustrzycki, A., & Savostin-Kosiak, D. (2021). Assessment of petrol and natural gas vehicle carbon oxides emissions in the laboratory and on-road tests. *Energies*, 14(6), Article 1631. [MDPI Open Access](#)
25. Lelkes, Y., Marx, D., & Park, B. (2012). Complete anonymity compromises the accuracy of self-reports. *Journal of Experimental Social Psychology*, 48(6), 1291–1299. ScienceDirect Database
26. Li, J., Zhou, Q., He, X., Chen, W., & Xu, H. (2023). Data-driven enabling technologies in soft sensors of modern internal combustion engines: Perspectives. *Energy*, 272Block, Article 127067. ScienceDirect Database
27. Lohr, S. L. (2021). *Sampling: Design and Analysis* (3rd ed.). CRC Press. [Routledge Product Page](#)
28. Maier, C., Thatcher, J. B., Grover, V., & Dwivedi, Y. K. (2023). Cross-sectional research: A critical perspective, use cases, and recommendations for IS research. *International Journal of Information Management*, 70, Article 102625. ScienceDirect Database
29. Mattioli, G., Roberts, C., Steinberger, J. K., & Brown, A. (2020). The political economy of car dependence: A systems of provision approach. *Energy Research & Social Science*, 66, Article 101486. [ScienceDirect Database](#)
30. Mishra, R., Singh, R. K., & Rana, N. P. (2022). Developing environmental collaboration among supply chain partners for sustainable consumption & production: Insights from an auto sector supply chain. *Journal of Cleaner Production*, 338, Article 130619. ScienceDirect Database
31. Mohajan, H. K. (2020). Quantitative research: A successful investigation in natural and social sciences. *Journal of Economic Development, Environment and People*, 9(4), 50–79. [MPRA Repository Platform](#)

32. Mohammed, A., Saif, O., Abo-Adma, M., Fahmy, A., & Elazab, R. (2024). Strategies and sustainability in fast charging station deployment for electric vehicles. *Scientific Reports*, 14(1), Article 283. [Nature Portfolio Platform](#)
33. Moradi, J., Banagar, I., Mehranfar, S., Andwari, A. M., Könnö, J., & Gharehghani, A. (2024). Advancing combustion technologies and alternative fuels in hybrid electric vehicles: A pathway to high-efficiency, low-emission propulsion systems. *Future Technology*, 3(1), 42–54. [Future Tech Journal Page](#)
34. Mruzek, M., Gajdosik, T., & Kučera, L. (2024). Strategies for reducing automobile fuel consumption through advanced powertrain and tribological optimizations. *Applied Sciences*, 14(2), Article 910. [MDPI Open Access](#)
35. Namar, M. M., Jahanian, O., Shafaghat, R., & Nikzadfar, K. (2021). Engine downsizing; global approach to reduce emissions: A world-wide review. *HighTech and Innovation Journal*, 2(4), 384–399. [HTIJ Repository Portal](#)
36. Neale, B. (2020). *Qualitative Longitudinal Research: Research Methods*. Bloomsbury Publishing. [Bloomsbury Product Page](#)
37. Ngu, H. J., Lee, M. D., & Osman, M. S. B. (2020). Review on current challenges and future opportunities in Malaysia sustainable manufacturing: Remanufacturing industries. *Journal of Cleaner Production*, 273Blocks, Article 123071. [ScienceDirect Database](#)
38. Nunes, L. J. (2023). The rising threat of atmospheric CO_2 : A review on the causes, impacts, and mitigation strategies. *Environments*, 10(4), Article 66. [MDPI Open Access](#)
39. Owoso, J. O., & Hodonu-Wusu, O. J. (2024). Harnessing globalization, information science and technological innovations in automobile industry into the transportation systems in Nigeria. *Industrial Technology Education Research Journal*, 7(1), 198–213. [ResearchGate Portal](#)
40. Pistoia, G. (Ed.). (2010). *Electric and Hybrid Vehicles: Power Sources, Models, Sustainability, Infrastructure and the Market*. Elsevier. [Elsevier Book Webpage](#)
41. Rahman, M. M. (2023). Sample size determination for survey research and non-probability sampling techniques: A review and set of recommendations. *Journal of Entrepreneurship, Business and Economics*, 11(1), 42–62. [JEBE Journal Portal](#)
42. Reddy, V. J., Hariram, N. P., Maity, R., Ghazali, M. F., & Kumarasamy, S. (2024). Sustainable vehicles for decarbonizing the transport sector: A comparison of biofuel, electric, fuel cell and solar-powered vehicles. *World Electric Vehicle Journal*, 15(3), Article 93. [MDPI Open Access](#)
43. Reitz, R. D., Ogawa, H., Payri, R., Fansler, T., Kokjohn, S., Moriyoshi, Y., ... & Zhao, H. (2020). IJER editorial: The future of the internal combustion engine. *International Journal of Engine Research*, 21(1), 3–10. [Sage Journals Platform](#)
44. Romano, M. H. K., Zanotto, T. T., de Lima Nogueira, S. C., & Szejka, A. L. (2021, July). Application of engine intelligent start-stop system technology for heavy vehicle fuel saving. In *IFIP International Conference on Product Lifecycle Management* (pp. 200–214). Cham: Springer International Publishing. [SpringerLink Lecture Notes](#)
45. Romero, C. A., Correa, P., Ariza Echeverri, E. A., & Vergara, D. (2024). Strategies for reducing automobile fuel consumption. *Applied Sciences*, 14(2), Article 910. [MDPI Open Access](#)
46. Şener, R., & Gül, M. Z. (2021). Optimization of the combustion chamber geometry and injection parameters on a light-duty diesel engine for emission minimization using multi-objective genetic algorithm. *Fuel*, 304, Article 121379. [ScienceDirect Database](#) [[1](#), [2](#), [3](#), [4](#)]
47. Sekaran, U., & Bougie, R. (2010). *Research Methods for Business: A Skill-Building Approach* (5th ed.). Haddington: John Wiley & Sons. [Wiley Product Webpage](#)
48. Shahariar, G. H., Bodisco, T. A., Zare, A., Sajjad, M., Jahirul, M. I., Van, T. C., ... & Brown, R. J. (2022). Impact of driving style and traffic condition on emissions and fuel consumption during real-world transient operation. *Fuel*, 319, Article 123874. [ScienceDirect Database](#)
49. Sher, F., Chen, S., Raza, A., Rasheed, T., Razmkhah, O., Rashid, T., ... & Erten, B. (2021). Novel strategies to reduce engine emissions and improve energy efficiency in hybrid vehicles. *Cleaner Engineering and Technology*, 2, Article 100074. [ScienceDirect Database](#)
50. Singh, V. P., Kumar, A., Meena, C. S., & Dwivedi, G. (Eds.). (2024). *Energy Efficient Vehicles: Technologies and Challenges*. CRC Press. [Routledge Book Portal](#)

51. Sürücü, L., & Maslakci, A. (2020). Validity and reliability in quantitative research. *Business & Management Studies: An International Journal*, 8(3), 2694–2726. BMIJ Online Index
52. Tarei, P. K., Chand, P., & Gupta, H. (2021). Barriers to the adoption of electric vehicles: Evidence from India. *Journal of Cleaner Production*, 291, Article 125847. [ScienceDirect Database](#)
53. Teresi, J. A., Yu, X., Stewart, A. L., & Hays, R. D. (2022). Guidelines for designing and evaluating feasibility pilot studies. *Medical Care*, 60(1), 95–103. Lippincott Wolters Kluwer Portal
54. Valverde, V., & Giechaskiel, B. (2020). Assessment of gaseous and particulate emissions of a Euro 6d-temp diesel vehicle driven > 1300 km including six diesel particulate filter regenerations. *Atmosphere*, 11(6), Article 645. [MDPI Open Access](#)
55. Wadood, F., Akbar, F., & Ullah, I. (2021). The importance and essential steps of pilot testing in management studies: A quantitative survey results. *Journal of Contemporary Issues in Business and Government*, 27(5), 18–29. JCIBG Archive Site
56. Wang, Y., Cao, Z., & Liu, J. (2024). A systematic review on sustainability assessment of internal combustion engines: Identifying frameworks, gaps, and emerging technologies in developing transport sectors. *Journal of Cleaner Production*, 441, Article 141444. [ScienceDirect Database](#)
57. Wang, Z., Shuai, S., Li, Z., & Yu, W. (2021). A review of energy loss reduction technologies for internal combustion engines to improve brake thermal efficiency. *Energies*, 14(20), Article 6656. [MDPI Open Access](#)
58. Waseem, M., Sher, F., & Raza, A. (2023). Cost efficiency and lifecycle carbon analysis of fuel saving engines in developing countries. *Cleaner Logistics and Supply Chain*, 6Block, Article 100095. ScienceDirect Database
59. Wellbrock, W., Ludin, D., Röhrle, L., & Gerstlberger, W. (2020). Sustainability in the automotive industry, importance of and impact on automobile interior—insights from an empirical survey. *International Journal of Corporate Social Responsibility*, 5, Article 10. SpringerOpen Platform
60. William, F. K. A. (2024). Mastering validity and reliability in academic research: Meaning and significance. *International Journal of Research Publications*, 144(1), 287–292. IJRP Article Webpage
61. Xin, L., Ahmad, M., & Khattak, S. I. (2023). Impact of innovation in hybrid electric vehicles-related technologies on carbon dioxide emissions in the 15 most innovative countries. *Technological Forecasting and Social Change*, 196, Article 122859. ScienceDirect Database
62. Yang, Z., Huang, H., & Lin, F. (2022). Sustainable electric vehicle batteries for a sustainable world: Perspectives on battery cathodes, environment, supply chain, manufacturing, life cycle, and policy. *Advanced Energy Materials*, 12(26), Article 2200383. Wiley Online Library
63. Yu, Z., Guindani, M., Grieco, S. F., Chen, L., Holmes, T. C., & Xu, X. (2022). Beyond t test and ANOVA: Applications of mixed-effects models for more rigorous statistical analysis in neuroscience research. *Neuron*, 110(1), 21–35. [Cell Press / ScienceDirect](#)
64. Zhang, W., & Xu, J. (2022). Advanced lightweight materials for Automobiles: A review. *Materials & Design*, 221, Article 110994. ScienceDirect Database
65. Zhang, X., & Dong, F. (2020). Why do consumers make green purchase decisions? Insights from a systematic review. *International Journal of Environmental Research and Public Health*, 17(18), Article 6607. [MDPI Open Access](#)
66. Zhu, Y., & Fan, L. (2022). Fuel delivery system for alternative fuel engines: A review. Potential and Challenges of Low Carbon Fuels for Sustainable Transport, 67–95. [SpringerLink Book Chapter](#)