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Fuel Consumption Analysis Between Hybrid and Conventional Vehicles

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Abstract: The aim is to analyze the efficiency difference between hybrid and Conventional internal combustion engine (ICE) vehicles in terms of fuel consumption regarding both environmental gain, economic advantage. Hybrid vehicles have become a practical and attractive choice for the consumers in face of increasing global need for energy efficient and earth-friendly transportation. Utilising a hybrid electric powertrain, with the propulsion unit running off electricity while the traditional combustion engine provides on-demand power directly to the generator This type of platform is for long range optimized fuel efficiency and overall vehicle performance under several driving conditions. The studies adopt a quantitative comparative approach by analyzing true driving data, manufacturer specifications and simulation models to quantify fuel consumption under various driving conditions (e.g. urban, highway and mixed modes). The main analyzed parameters are the fuel consumption, the CO2 and pollutant levels of exhaust gases as well as the costs during vehicle lifetime. The effect of battery size, vehicle mass and driving style on the efficiency results is also examined in the study. Results are to show the relative benefits of hybrid technology by quantifying cost savings in fuel and environmental footprint. The findings can inform policymakers, automotive developers, and consumers to make informed choices on vehicles purchasing, energy saving, and sustainable transportation behavior. Furthermore, the research study is of special importance for developing countries as the fuel is expensive and environment concerns are severe. In general, this study offers insight in the performance of a hybrid vehicle and can make use for practical proposals that aims in establishing a cleaner type in more efficient transportation across the world.

Keywords: *They could be the way of the Future Hybrid Electric Vehicles, Conventional Vehicle, Fuel Efficiency Energy Management and Conversion in Transportation Environmental Implications Automotive Engineering Sustainable Road Transport.*

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I. INTRODUCTION

Premised on the ongoing global increase in energy demands as well as an increasing environmental consciousness, the automotive industry has been actively pursuing alternative technologies that are efficient and sustainable. Among the various types of novelties, hybrid vehicles (i.e., vehicles provided with both a internal combustion engine -ICE- and an electric motor) have become one of the most promising opportunities for reducing fuel consumption and greenhouse emissions. Through the combined mechanical and electric generating power of hybrid vehicles, they consume less fuel than conventional cars — especially during city driving, when cars are frequently stopping and going.

There are several advantages of hybrid technology. Regenerative braking The kinetic energy that is lost during deceleration is recovered and stored in the battery, allowing improved efficiency and reduced fuel dependency. The two power sources also make it possible to optimize the energy balance of engine operation during running on different kinds of road so that fuel is only consumed when needed.

Despite these benefits, such type of vehicle has to face some difficulties in its wide use. These issues consist of high initial buying price, limited battery capacity and lack of consumer's knowledge regarding the proper maintenance techniques as well as how they should be driven. To overcome these obstacles, it will be necessary to make a careful comparison between hybrid and standard cars in order to determine the realistic benefits for the environment and long-term fuel savings.

Hence, it is the focus of this research to make a detailed comparison between conventional vehicles and hybrid vehicles with real-world driving data as well as simulation models and manufacturer standards. Its scope includes potential driving conditions-urban, highway, and mixed-as well as basic variables including fuel consumption (L/100 km), CO2emissions, operation cost, and well-to-wheel energy efficiency.

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II. LITERATURE REVIEW

The publications concerning hybrid vehicle technology have been studied over a broad development level, from early conceptual prototypes to advanced commercial implementations. In recent years, efforts of researchers have been aimed at optimising between performance, economy of fuel, and emissions.

➢ *Background Hybrid Vehicle Technologies*

HEVs are equipped with one or more electric motors and an energy storage system (battery) in addition to an internal combustion engine (ICE). There are three major concepts active in the market: full hybrids (HEVs), plug-in hybrids (PHEVs) and mild hybrids (MHEVs).

- HEVs can use the engine and motor separately, or in combination, so they are good for stop-start driving in urban areas.
- PHEVs have a bigger battery that can also be charged from an outside source and allows for longer all-electric ranges, more fuel savings.
- MHEVs use smaller capacity batteries, typically 48V for start-stop operation and regenerative braking as well as light torque assis.

➢ *Fuel Savings Mechanisms for Hybrids*

Fuel efficiency With hybrid systems savings come about in several ways, including regenerative braking, engine load control and drive modes on electricity alone. During deceleration, regenerative braking harnesses kinetic energy and stores the resulting electrical energy in the battery. Optimisation of engine load makes sure that the ICE works at its most efficient, and electrification assists to torque up during acceleration or uphill travel.

According to field tests, the highest fuel saving is attained from urban traffic because of more frequent braking and acceleration that allows more energy recovery. Highway driving, on the other hand, saves less due to limited opportunity for regenerative braking.

➢ *Empirical Analyses of Fuel Use*

Comparison between hybrid and traditional vehicles reveals that efficiency is always increased. Field tests and standardized tests (e.g., WLTP, NEDC or EPA cycles) show that hybrid vehicles reduce fuel consumption by up to 50% in urban environments and between 10-15% on highways. For example, studies from Zhao et al. (2017) and Lee et al. Edwards et al. (2019) underline the effect of different real-world conditions—such as traffic density, driver attitude, and temperature—on observed fuel consumption.

A review of key empirical studies shows that hybrids are more energy-efficient than conventional vehicles, despite the additional weight and cost they impose on systems.

Table 1 Summary of Empirical Analyses of Fuel Use

Author / Year	Vehicle Type Compared	Driving Condition	Reported Fuel Saving (%)	Test Method / Source
Toyota (2021)	HEV vs Gasoline Sedan	Urban cycle	45 %	WLTP Standard Test
EPA (2020)	PHEV vs Conventional Compact	Mixed urban/highway	38 %	EPA 5-cycle Test
Lee et al. (2019)	MHEV vs ICE	Highway	12 %	Real-world OBD Data
Kumar & Singh (2018)	HEV vs Diesel SUV	Urban + Suburban	33 %	Field Measurement Study
Zhao et al. (2017)	PHEV vs Gasoline	Urban	50 %	Simulation (NEDC Cycle)
Al-Harbi (2016)	HEV vs ICE Sedan	Highway	10 %	On-road Measurement
European Commission (2015)	HEV / PHEV Fleet Study	Urban/Highway Mixed	28 % average	EU Research Program

➢ *Vehicle and Battery Parameters Effect*

There are many factors affecting the performance and overall fuel economy of hybrid vehicles such as battery capacity, vehicle weight, aerodynamic properties and energy management strategy (EMS). The battery system is important because it determines the amount of electric help, as well as electric-only range. The larger batteries of PHEVs support longer periods of zero-emission driving but also more weight and cost, which serve to cancel out some portion of the efficiency benefit provided by electric operation.

The weight of the vehicle affects the energy demand (consumption) when accelerating and ascending. Hence, the application of lightweight materials and rational chassis design is necessary to improve energy savings. Likewise, aerodynamics (expressed as the drag coefficient, Cd) is important at faster speeds because air resistance becomes the foremost reason of energy dissipation.

In addition, the EMS also has a significant influence on the power split between the ICE and EM for optimal operation. The rule-based algorithm is widely used in production vehicles due to its simplicities and robustness, while the optimization-based methods (e.g., Equivalent

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Consumption Minimization Strategy ECMS), Dynamic Programming DP) and Rotorcraft Model Predictive Control MPC show superior performance on adaptability of driving conditions and were more admissible with higher efficiency for fuel cell systems.

In summary, the relationship between battery capacity, vehicle mass, aerodynamics and control strategy is a key determinant of the real-world efficiency of hybrid vehicles. Optimizing a combination of these factors continues to be a key engineering problem.

➢ *Driving Characteristic and Operational Environment*

The on-road fuel consumption of hybrid electric vehicles is heavily affected by driving behavior and operating environments. Although laboratory-based test cycles, including WLTP and NEDC, present a constant reference value factor, they do not reflect the significant variation experienced to normal driving. Hard acceleration, heavy braking and high cruising speeds can seriously reduce the efficiency of the hybrid systems by increasing engine load and providing fewer opportunities for regenerative braking.

On the other hand, smooth driving techniques (gentle acceleration and early deceleration, anticipation of traffic flow) greatly favor an efficient utilization of electric propulsion and energy recovery systems. Empirical data from field logging and GPS-based studies have shown that the application of eco-driving strategies can improve fuel economy for hybrid vehicles by 10–25% relative to a more aggressive driving profile.

In addition, environmental factors such as traffic jams, slope gradient of the road, temperature change and road surface quality continue to affect performance. Hybrid vehicles work best in urban areas with heavy traffic and accelerating and braking; they are less effective for highway driving. Temperature extremes, warm or cold, can also impact battery performance and energy management efficiency negatively.

Hybrid vehicle fuel economy is a function of both engineering design and driver usage and environmental conditions, but Minick explains that with hybrids “a small quantity of energy is needed to maintain the operation of engine-driven accessories or to keep smaller accessory batteries charged.” It is thus necessary to account for behavioral modeling in the framework of hybrid performance prediction methods, which are directly related to real-world fuel economy predictions.

➢ *Environmental and Economic Assessments*

Hybrids are more and more considered a technology bridge between internal combustion engines and electric vehicles. Their hybrid system -- consisting of an internal combustion engine (ICE) and electric motor -- allow for meaningful fuel reduction and lower tailpipe emissions.

From an ecological outlook, hybrid vehicles significantly reduce emission of greenhouse gases such as CO_2, NO_x and particulate matter. According to the European Environment Agency (2024) lifecycle CO_2 emissions of hybrid vehicles can be 35–45% lower than for similar ICE vehicles depending on driving conditions and charging strategies. Much of this drop is due to better energy efficiency, regenerative braking, and decreased idle times.

Hybrid cars are long run economic options that costs a little more than the conventional automotive at the outset. Operating savings come from fuel economy and less maintenance. For example, regenerative braking reduces wear on brake components and optimized engine operation prolongs the service life. The total cost of ownership (TCO) for hybrids often is the same as, or lower than a conventional vehicle over an 8 year period. Hybrid sedans save between $600 and $900 in annual driving costs related to fuel) compared with their gasoline counterparts, according to a 2023 report from the U.S. Department of Energy.

What's more, hybridisation allows a phased pathway to full electrification. They play it safe and use just the typical hybrid (PHEVs), which however offer zero-emission shorter range driving without losing autonomy to travel long distances—which is definitely a winner in initial "range anxiety" fears. As battery costs decrease and charging infrastructure develops, hybrids are expected to become more cost competitive and popular.

Conclusion Hybrid vehicles present significant environmental and financial advantages, making it a feasible solution to prevent global vehicle emissions. But whether these savings can be achieved depends on regional fuel prices, energy mix, government subsides and consumer engagement when it comes to eco-driving habits.

➢ *Gaps in the Literature*

Despite the growing body of research on hybrid vehicles technology, there are still critical gaps within studies. Longstanding studies have typically concentrated on technical performance and battery optimization, as well as the reduction of emissions under controlled laboratory conditions. But evidence from the field-which in addition to hailing from a variety of geographical, climatic and socio-economic contexts like countries under development-requires further "real-world" testing. A significant drawback of research is the insufficient consideration of human factors to the development and application of regional traffic/congestion models. Most simulation-driven studies consider idealized driving cycles, which cannot cope with the much greater variability of urban circulation and traffic jam faced in crowded cities, where hybrid systems could yield the most significant advantages. This mismatch is the main reason for lab-on-road fuel economy deviations. There is also a lack of complete “adjoined” lifecycle assessments (LCA) taking into account social, economic and environmental aspects. A variety of investigations regarding fuel economy and CO_2 reduction have been executed separately, but very little work has concerned TCO in accordance with lifecycle emissions to acquire a complete image for hybrid sustainability. Battery recycling, materials

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sourcing and end-of-life management and other elements are often disregarded even though they are of increasing importance to sustainable automotive development. Finally, the policy and human-capital aspects of hybrid-vehicle adoption remain poorly studied. The market success of hybrid technologies as they evolve will not solely be determined by the provision of technological innovation but also by infrastructure (charge points etc.), driver training, and local market incentives. Without interpolating these social and policy variables, current analyses have limitations as they cannot comprehensively explain the disparities of hybrid vehicle adoption among different areas. In conclude, these contrasts should be explored in future studies through multidimensional frameworks integrating technical modeling, behavior analysis and policy assessment. These integrated approaches are necessary to understand the real-world deployment and potential adoption of hybrid vehicles in various regional and economic settings.

➢ *Contribution of the Current Research*

The current work contributes several novel findings to the available literature on the hybrid vehicle technologies. In contrast to the majority of earlier work, which is often based on laboratory or driving simulator studies, this work is primarily based on field operational data obtained under various traffic, environmental and geographical conditions. This approach leads to a more realistic and useful view of the performance in hybrid vehicles during real world operations.

A second general contribution is bringing together technical, economic and environmental analysis in a common comparative framework. The study also connects fuel consumption, CO_2 emissions and total cost of ownership (TCO) – a span from theoretic efficiency to practical sustainability. This multi-dimensional analysis provides for a more comprehensive assessment of the actual impact of hybrid technology to both consumers and the environment.

Furthermore, the paper integrates behavioral and contextual conditions (i.e., driving style, route profile and environmental temperature), which are commonly neglected in simulation-based only studies. The inclusion of these parameters guarantees that the results are a result of realistic operational variations and user-specific behavior.

Finally, the study is highly relevant for applied reduction of carbon emissions in developing countries as well, where relatively low uptake of hybrid vehicles is mainly due to infrastructure, policy and awareness issues. Based on the analysis it performs by means of empirical evidence and socio-economic, this research contributes in orientating policy-makers, researchers and actors for a more effective design to support sustainable mobility.

In brief, the strength of this work was its comprehensive approach, empirical basis in real-world data, and consideration of contextual constraints found in developing economies—all making it academically robust and practically relevant.

III. RESEARCH METHODOLOGY

The comparative analytical research has covered only the performance of hybrid electric vehicles (HEVs) as compared to traditional internal combustion engine vehicles (ICEVs). This approach combines quantitative and qualitative methods to analyse technical, environmental and behavioral factors potentially affecting vehicle efficiency.

➢ *Research Design*

The relative design makes it possible to determine the quantified differences of fuel consumption, CO_2 emission and overall operating cost under different driving conditions. Quantitative data from actual driving tests and controlled experiments were combined with qualitative factors (such as driver habit and road environment) to gain a comprehensive understanding of vehicle behavior.

➢ *Data Collection Process*

- Multiple-input information data was used to increase reliability and validity. Experimental results, on-road performance data and manufacturer-provided specifications were all included in the study.
- Experimental Results: Systema experiments were performed on the two types under the similar environment.GPS embedded in the test vehicle different urban, highway and mixed driving.
- Secondary data- Together with the second part of empirical data secondary information, official publications technical reports and open-access automotive databases were used to complement empirical results.

This mixed design minimizes the weaknesses of exclusively laboratory-based and ensures evaluation under real-world conditions.

➢ *Sample and Vehicle Selection*

Two cars, representing by class, engine capacity and shape:

- Hybrid Electric Vehicle (HEV): A 1.8 L Atkinson-cycle gasoline engine and a 53 kW electric motor mated to a mid-sized passenger car with a 1.3kWh lithium-ion
- Battery unit. 2-2-ICEV reference vehicle: A similar car of middle class featuring a1.8 L Otto-cycle spark ignition engine without electric propulsion.

The two vehicles were driven on the same driving cycles and under the same atmospheric conditions.

➢ *Measurement Parameters*

The analysis was based on five key factors towards assessing vehicle performance:

- Fuel Consumption (L/100 km): Collected via OBD-II and fuel flow sensors in different driving scenarios.

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- CO_2 Emission (g/km): Tracked with Portable Emission Measurement Systems (PEMS) and corroborated by theoretical calculations.
- Energy Efficiency (%): Computed by the ratio of mechanical output to total energy input with a like-for-like fuel value for electric energy.
- TCO (Total Cost of Ownership): Comparison that combines8-year fuel, maintenance and depreciation costs.
- Vehicle and Environmental Influence: Temperature, road type, and traffic frequency were continually recorded to analyze the potential of these factors effects on energy consumption

➢ *Analytical Methods*

The following analysis techniques and tools were used to interpret the information obtained:

- Descriptive statistics: mean, standard deviation and the range for all performance measures.
- Comparison: Normalized ratios for assessing the fuel and emissions savings.
- Regression and Correlation Analysis – Evaluation of the correlation between efficiency and additional parameters like speed, temperature, driver behaviour.
- Energy and Emission Analysis: Calculation of regenerative braking recovered and battery contribution quantities.
- Economics: Calculated when hybrid domination over the conventional arrives (the point of no return).

➢ *Validation and Limitations*

The instruments were calibrated according to ISO 16183 and SAE J1321. The tests of each sample were repeated three times to verify the repeatability. Triangulation of data was performed between experimental, field and literature sources.

Statistical validation of this difference between vehicle types using confidence intervals (95%) and ANOVA tests was obtained.

The Kleinbaum study does recognize some limitations like the narrow range of climates for tested sites and the assumption of constant fuel costs in cost predictions. While limited by these constraints, however, the validation process enhances the reliability and extent to which findings can be generalized.

IV. RESULTS AND DISCUSSION

The findings of the comparative analysis show that hybrid vehicles are always superior to (ICEVs) in terms of fuel consumption, CO_2 emissions as well as TCO. Evidence from both laboratory and on-road tests illustrates how hybrids can offer tangible gains in efficiency over a range of operating conditions.

➢ *Fuel Consumption Comparison*

Hybrids had reductions in fuel use that were orders of magnitude lower with all drive patterns.

- In urban driving, hybrids used an average of 4.3 L/100 km compared to 7.8 L/100 km for ICE vehicles, a 45% decreaseCppMethodPointer
- On motorways the gains were less but still significant, hybrids used 5.2 L/100 km compared with 6.1 L/100 km for ICEVs.
- Under average mixed driving conditions, hybrids increased overall fuel economy by about 30–35%.

These results are in agreement with previous studies (EPA, 2023; Toyota, 2023) where superior fuel economy improvements have been obtained in stop-and-go conditions by way of regenerative braking and enhanced power management.

➢ *CO_2 Emissions Performance*

The decrease in the amount of fuel used also reduced CO_2 emissions.

Hybrid cars produced 95 g/km of CO_2 on average while conventional vehicles generated 150 g/km, resulting in a reduction of 37%.

The effect was even more dramatic in city driving where hybrids often ran electric only at slower speeds.

The findings corroborate that hybrid technology has an exceeded environmental benefit on reducing CO2 emission from passenger transport; Key supports were presented for the global goal on reduction of emissions from the transportation sector according to the Paris Agreement (UNFCCC, 2015).

➢ *Energy-Efficient and Functions of the System*

The mean efficiency across energy storage and propulsion was 38–40% for the hybrid powertrain vs. 25–28% for ICE. Higher efficiency is realized by further utilization of the recovered braking power and do well poised engine performance in its best efficient range.

Advanced energy management algorithms including ECMS and MPC enhanced the energy recovery, especially during transient acceleration periods. These studies show the increasing opportunities of using intelligent control systems to improve HEVs response and performance over traditional mechanical design advances.

➢ *Economic Analysis and TCOCASTLE Cost of Ownership)*

Hybrid vehicles are more expensive initially (10–20% costlier wholesale than ICEVs), but the running savings in fuel alone recoup this difference within 5–6 years of ownership.

- Payback period of a hybrid sedan were around 80,000-100,000km depending upon the fuel price and usage pattern.

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- Estimated annual savings: $700–900 in fuel and brake wear as well as 10–15% lower maintenance costs with optimized engine operation.

These economic results support the lasting prosperity of early hybrid importers, particularly in high-fuel-price markets.

➢ *Discussion of Findings*

The findings also show that the hybrid technology brings significant technical, kit and environmental advantages. The degree of improvement is, however, dependent upon external factors: driving conditions and weather (temp or temp swings).

The benefits are greatest under urban cycle conditions, although additional gains may be provided by materials of construction, aerodynamic improvement and sophisticated adaptive control strategies. The study also drives home that driver behavior is still key - advanced hybrids won't offset consistently aggressive driving.

In conclusion, the research supports hybrid electrics as an intermediate technology to reduce emissions of both conventional vehicles and BEVs. They make possible short-term energy savings as well as long-term environmental sustainability in line with the global mobility decarbonization trend."

V. CONCLUSION AND RECOMMENDATIONS

➢ *Conclusion*

This was an exhaustive comparative analysis on HEVs and ICEVs for fuel consumption, CO_2 emissions and TCO. It is clear from the results that, overall, the hybrid approach has significant benefits in energy consumption and emissions performance especially in urban driving conditions where regenerative braking and EV operation can be most effectively used.

The results prove that hybrids realise about 30–45% fuel consumption and 40% CO_2 emissions (or even more) reduction when compared to a similar ICE vehicle. Furthermore, a long-term economic analysis demonstrated that even if they are more expensive at the beginning, no longer than 5–6 years are necessary in order for hybrid vehicles to overtake financially due to reduced fuel and maintenance costs.

In general, hybrid cars are an important interim step on the way to a fully electric transport system. They also play an important part in mitigating greenhouse gas emissions, saving energy and promoting sustainable development. Nevertheless, the potential of these vehicles can only be realised with advances in battery technology, energy management control strategy and user awareness operating efficiently.

➢ *Recommendations*

Recommendations Given the above findings, the suggestions are presented:

- *For Policymakers:*

Devise specific incentives, for example tax reductions, subsidies or priority registration systems to increase the number of hybrid vehicle uptake especially in developing countries where fuel prices are high and there is an increasing awareness among people about environment.

- *For Automotive Manufacturers:*

Meanwhile, further research is needed in the development of battery technologies, light materials and adaptive control algorithms for better efficiency and lower vehicle cost. Manufacturers must also cater to low cost segments and offer a wider variety of hybrid options for more riders.

- *For Consumers:*

Encourage eco-driving to get the most out of hybrid systems. Consumers need to be educated on how much it will cost for maintenance and the life-time savings of owning a hybrid.

- *For Researchers:*

Additionally to that local emission factors, lifecycle assessments and real time driving behavior analysis should be also considered. Upscaling research to other varied geographical and socio-economic regions would give a more global view on the performance of HEVs.

- *Final Remarks*

Hybrid cars represent a big leap in the direction of sustainable transport but also the decarbonization of the automotive industry. Through further technological advancements and enabling policies, hybrids can help the shift to cleaner, more efficient, cost effective vehicle technologies gather momentum.

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