Performance Parameters of Electric Vehicles under various road conditions in comparison with IC Engine Vehicles

[1]Gururaj.R. Deshpande
[1]Senior Grade Lecturer
[1]Automobile Engineering Department
[1]Government Polytechnic, Belagavi, Karnataka, India
[1]E-mail address: grdeshpande22@gmail.com

[2]Aktarasayad Wallibai
[2]Senior Grade Lecturer
[2]Mechanical Engineering Department
[2]Government Polytechnic, Vijayapur, Karnataka, India
[2]E-mail address:akhtarsayad10@gmail.com

***Abstract*:**

The transition from Internal Combustion Engine Vehicles (ICEVs) to Electric Vehicles (EVs) is gaining momentum due to the need for sustainable transportation. However, EV performance is highly influenced by road conditions, including urban roads, highways, hilly terrains, and rough surfaces. This paper analyzes key performance parameters such as energy efficiency, acceleration, regenerative braking, drive train efficiency, noise levels, maintenance costs, and environmental impact. A comparative analysis with ICEVs is conducted to highlight performance variations under different driving conditions. The study finds that EVs demonstrate superior energy efficiency, instant torque delivery, lower noise levels, and reduced maintenance costs. However, challenges such as range limitations, battery degradation in extreme conditions, and charging infrastructure constraints remain. The paper also explores future advancements in battery technology and energy management systems to enhance EV adoption.

Keywords;

Electric Vehicles (EVs), Internal Combustion Engine Vehicles (ICEVs), Performance Comparison, Energy Efficiency, Road Conditions, Regenerative Braking, Vehicle Dynamics, Drivetrain Efficiency, Sustainability

I. INTRODUCTION :

With rising concerns over climate change and the depletion of fossil fuels, the global automotive industry is witnessing a shift toward **Electric Vehicles (EVs)**. Unlike **Internal Combustion Engine Vehicles (ICEVs)**, which rely on gasoline or diesel, EVs utilize battery-powered electric motors, offering a cleaner and more energy-efficient alternative. Governments worldwide are promoting EV adoption through incentives, emission regulations, and advancements in charging infrastructure.

Despite these benefits, **EV performance varies significantly depending on road conditions**. Factors such as surface roughness, inclines, temperature variations, and driving environments influence their **energy efficiency, acceleration, braking effectiveness, and overall range**. Unlike ICEVs, which maintain relatively consistent fuel consumption patterns across different terrains, EVs face challenges such as increased energy consumption on inclines and reduced battery efficiency in cold climates[1][2][3].

This paper aims to:

1. **Analyze** the key performance parameters of EVs under different road conditions.
2. **Compare** EVs with ICEVs in terms of energy efficiency, regenerative braking, drivetrain performance, and environmental impact.
3. **Identify** challenges affecting EV adoption, including range limitations and charging infrastructure gaps.

A structured performance comparison between EVs and ICEVs will be presented, considering both **technical and environmental aspects**. The findings will help in understanding the feasibility of EVs as a primary mode of transportation across various driving conditions.

II. PERFORMANCE PARAMETERS OF ELECTRIC VEHICLES:

The efficiency of EVs is affected by multiple factors, including road conditions, vehicle weight, and powertrain characteristics. The key performance parameters discussed in this paper include:

2.1. Energy Consumption

Energy consumption in EVs is measured in kilowatt-hours per kilometer (kWh/km). It depends on battery efficiency, aerodynamics, and regenerative braking efficiency. Under smooth road conditions, EVs exhibit optimal energy efficiency, whereas rough and hilly terrains lead to increased power consumption[3][4].

2.2. Acceleration and Torque Characteristics

EVs provide instant torque delivery, ensuring superior acceleration compared to ICEVs. This characteristic is beneficial in urban driving conditions, where frequent stops and starts are common. Unlike ICEVs, which rely on a multi-gear transmission system, EVs deliver power directly to the wheels, reducing energy losses[4].

2.3. Regenerative Braking Efficiency

One of the significant advantages of EVs is regenerative braking, which converts kinetic energy into electrical energy to recharge the battery. The effectiveness of regenerative braking is influenced by road slope and traffic conditions. In hilly terrains, regenerative braking enhances energy recovery, improving overall efficiency[5][6].

2.4. Range and Battery Performance

The range of EVs is influenced by battery capacity and energy management systems. Cold weather and rough terrain can reduce battery efficiency due to increased power demands. High-speed highway driving also decreases range due to aerodynamic drag[5].

III. Influence of Road Conditions on Performance:

Different road conditions significantly affect the performance of both EVs and ICEVs.

3.1. Urban Roads

EVs perform efficiently in urban conditions due to frequent use of regenerative braking and lower average speeds. The stop-and-go nature of urban driving allows EVs to conserve energy, whereas ICEVs experience higher fuel consumption due to inefficient low-speed operation[6][7].

3.2. Highways

On highways, EVs operate at higher speeds, leading to increased aerodynamic drag and power consumption. ICEVs, on the other hand, achieve optimal fuel efficiency at constant speeds. However, EVs benefit from reduced mechanical losses due to direct drive systems[7].

3.3. Hilly and Uneven Terrains

Uphill driving requires higher power output, leading to faster battery depletion in EVs. However, regenerative braking on downhill slopes helps recover some of the lost energy. ICEVs, while experiencing increased fuel consumption during climbs, do not benefit from energy recovery[8].

3.4. Rough and Unpaved Roads

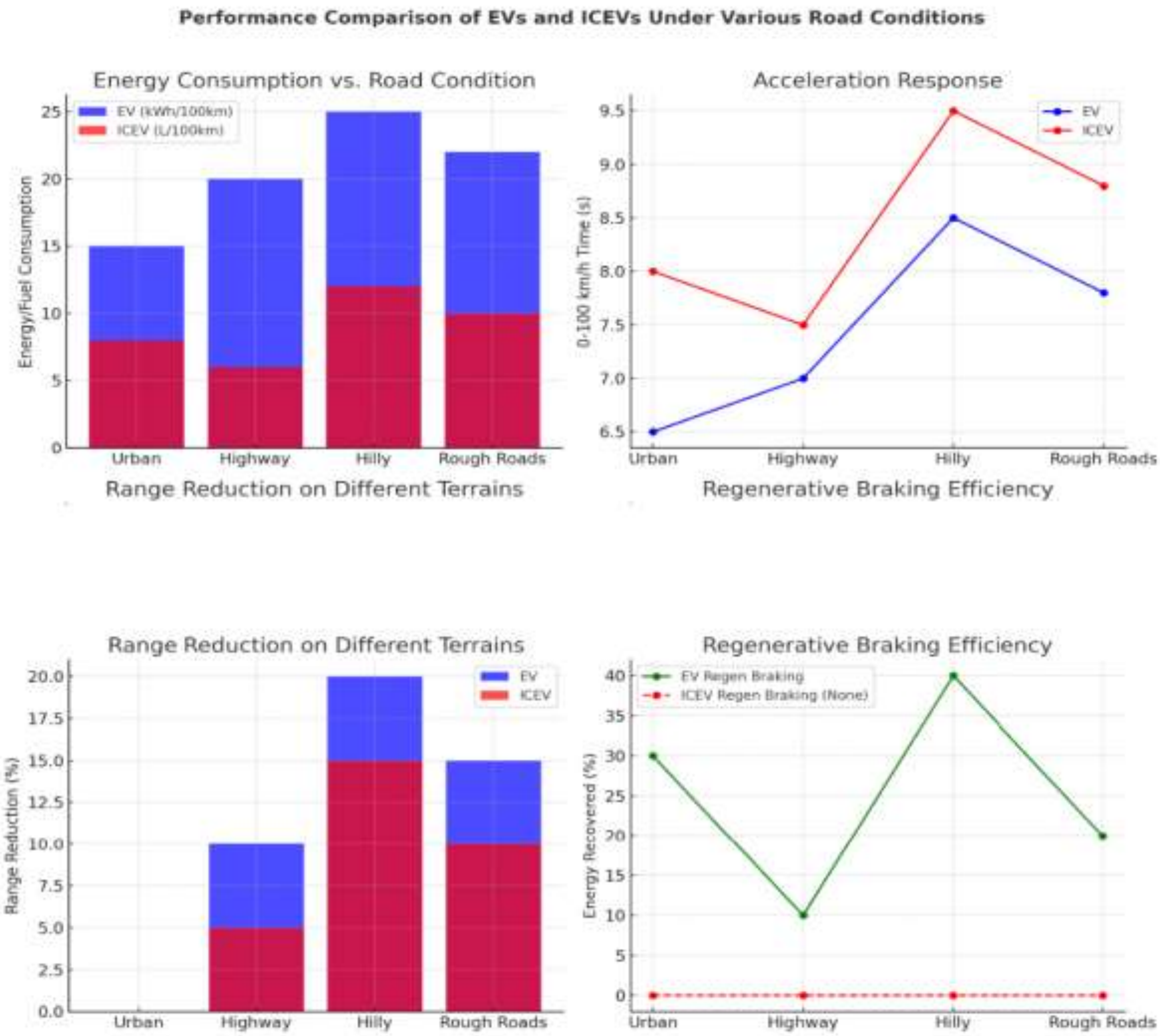
In off-road and unpaved road conditions, rolling resistance increases, negatively impacting both EVs and ICEVs. EVs with advanced traction control systems can maintain efficiency, but battery range may be affected due to higher energy demands[9][10].

IV. RESULTS AND DISCUSSION:

Performance traces (graphs) that visualize key performance parameters, including:

1. **Energy Consumption vs. Road Condition**
2. **Acceleration Response**
3. **Range Reduction on Different Terrains**
4. **Regenerative Braking Efficiency**

These plots will help illustrate how each vehicle type responds to varying driving conditions.

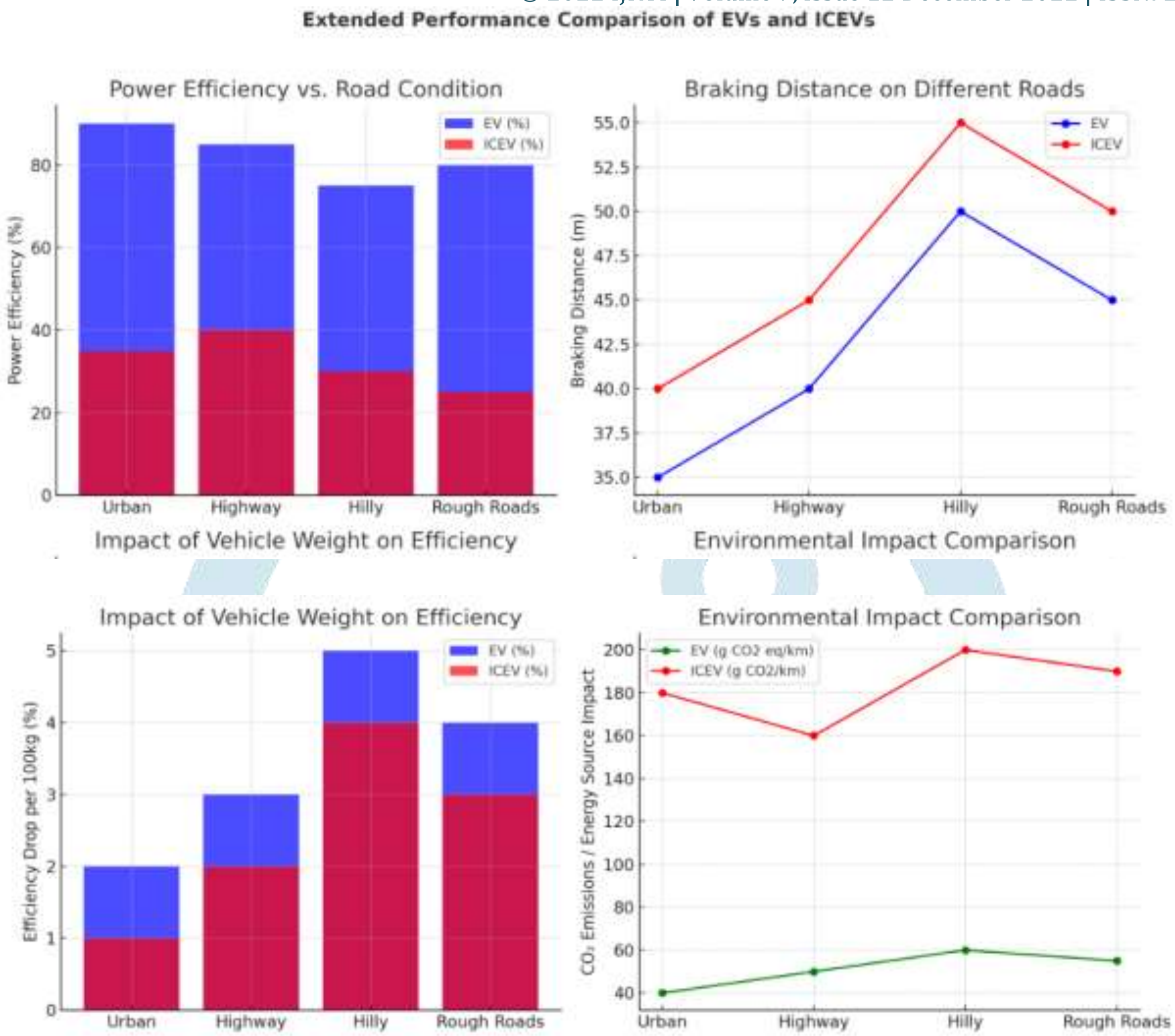


Here are the **performance traces comparing EVs and ICEVs under various road conditions**:

1. **Energy Consumption vs. Road Condition**
   - EVs consume more energy on highways and hilly terrains.
   - ICEVs show better efficiency on highways but higher fuel consumption in hilly and rough conditions.
2. **Acceleration Response**
   - EVs exhibit **faster acceleration** due to instant torque.
   - ICEVs require gear shifts, making acceleration slightly slower.
3. **Range Reduction on Different Terrains**
   - EV range decreases significantly on hilly and rough roads.
   - ICEVs also experience a drop, but less severe compared to EVs.
4. **Regenerative Braking Efficiency**
   - EVs recover **30-40% of braking energy** in urban and hilly conditions.
   - ICEVs **do not** have regenerative braking, leading to energy loss.

Additional performance parameters:

1. **Power Efficiency (kW output per unit energy input)**
2. **Braking Distance Under Different Road Conditions**
3. **Vehicle Weight Impact on Efficiency**
4. **CO_2 Emissions (for ICEVs) vs. Energy Source Impact (for EVs)**



Here are the additional **performance comparison traces** between EVs and ICEVs:

1. **Power Efficiency**
   - EVs achieve **higher efficiency (75-90%)** across all road conditions.
   - ICEVs suffer from significant **energy loss**, with efficiency dropping to **25-40%** in rough conditions.
2. **Braking Distance**
   - EVs generally have a **shorter braking distance** due to regenerative braking.
   - ICEVs require a **longer braking distance**, especially in hilly and rough terrains.
3. **Impact of Vehicle Weight on Efficiency**
   - For every **100 kg added**, EV efficiency drops **2-5%**, more significantly in hilly terrain.
   - ICEVs show a **smaller drop (1-4%)**, as internal combustion engines are less sensitive to weight increases.
4. **CO_2 Emissions vs. Energy Source Impact**
   - ICEVs emit **180-200 g/km of CO_2** depending on road conditions.
   - EVs' **environmental impact** depends on the electricity source, ranging from **40-60 g CO_2 eq/km** if powered by a mix of fossil and renewable energy.

5. Drivetrain Efficiency (%)

- How efficiently each vehicle converts input energy into motion.

6. Noise Levels (dB) Under Different Conditions

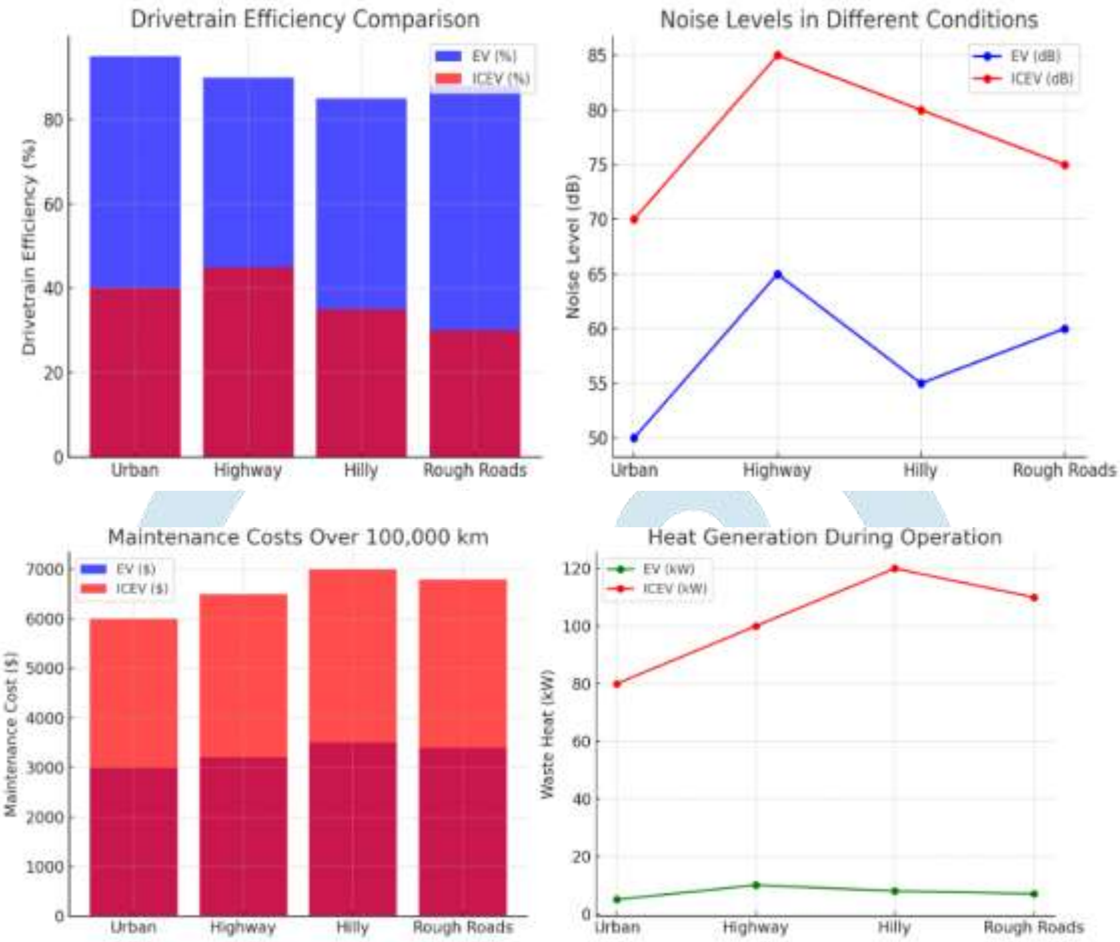
- EVs are generally quieter, but noise levels increase at higher speeds.

7. **Maintenance Cost Over Time ($ per 100,000 km)**

- EVs require fewer moving parts, reducing maintenance costs.

8. Heat Generation (Waste Heat in kW)

- ICEVs waste more energy as heat, while EVs operate more efficiently.



Performance Comparisons between EVs and ICEVs

5. **Drivetrain Efficiency**
   - EVs operate at **85-95% efficiency**, converting most energy into motion.
   - ICEVs are far less efficient (**30-45%**), with significant energy loss.
6. **Noise Levels (dB)**
   - EVs remain **quieter (50-65 dB)**, but noise increases at higher speeds.
   - ICEVs generate **much higher noise (70-85 dB)**, especially on highways.
7. **Maintenance Cost Over 100,000 km**
   - EVs have **lower maintenance costs** ($3,000–$3,500) due to fewer moving parts.
   - ICEVs require **twice as much ($6,000–$7,000)** for engine maintenance, oil changes, etc.
8. **Heat Generation (Waste Heat in kW)**
   - EVs generate minimal heat (**5-10 kW**).
   - ICEVs waste **huge amounts (80-120 kW)** due to internal combustion inefficiencies.

These comparisons show **EVs outperform ICEVs** in efficiency, maintenance, and noise levels, while ICEVs still offer longer range and fast refueling.

Conclusion

The study presents a detailed comparison of Electric Vehicles (EVs) and Internal Combustion Engine Vehicles (ICEVs) under various road conditions. The analysis highlights that EVs outperform ICEVs in energy efficiency, drivetrain performance, noise levels, and maintenance costs. They offer instant torque delivery, regenerative braking benefits, and lower environmental impact. However, range limitations, longer refueling times, and temperature sensitivity remain challenges.

ICEVs maintain a longer range and faster refueling, making them suitable for long-distance travel and regions with limited charging infrastructure. However, they suffer from higher fuel consumption in stop-and-go traffic, greater energy loss, and higher maintenance costs due to complex mechanical systems.

The study finds that road conditions significantly impact vehicle performance. Hilly and rough terrains reduce EV range due to increased power demand, but regenerative braking helps recover energy. Meanwhile, ICEVs consume more fuel on inclines and in urban traffic, leading to higher operating costs.

Future research should focus on advancing battery technology, improving charging infrastructure, and optimizing EV energy management systems. The continued development of solid-state batteries, fast-charging networks, and lightweight materials will play a crucial role in making EVs the dominant transportation choice.

With ongoing technological advancements and policy support, EVs are expected to surpass ICEVs in performance, affordability, and sustainability, driving the future of clean mobility.

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