Sustainability of Electric Vehicles (EV)

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DOI : https://doi.org/10.51583/IJLTEMAS.2026.150100025

Received: 09 January 2026; Accepted: 15 January 2026; Published: 27 January 2026

ABSTRACT

The utilisation of electric vehicles (EVs) plays an integral role in the transition toward a more sustainable future in the automotive industry. The purpose of this review is to provide a structured and systematically organised analysis of EVs, focusing on the factors that encourage their usage and how these factors relate to the performance of the vehicles. With this structured overview, this review will improve the understanding of EV fundamentals and shed light on dubious or debated areas. By comparing and examining a range of research papers, this review singles out key correlations and insights to present the most reliable information. Ultimately, it not only enhances the overall understanding of electric vehicles but also offers a promising foundation for future research in this field.

Keywords Electric vehicles (EVs) ; Renewable energy ; Sustainable mobility

Graphical Abstract

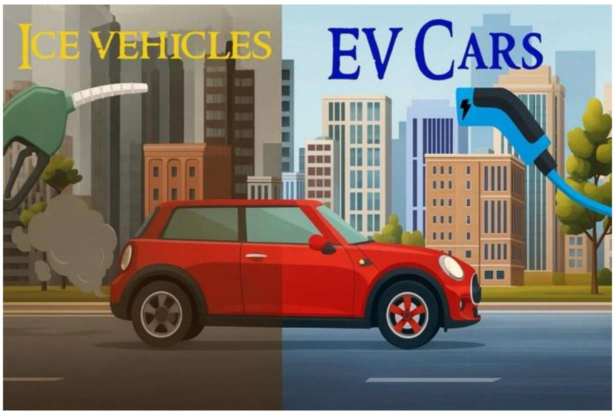

Figure 1

INTRODUCTION

The world as we know is no longer strangers to the term "Electric Vehicle" or more known as the term "EV". For short, EVs are vehicles powered by electricity rather than conventional fuel such as gasoline and diesel. These vehicles use electric motors which are fueled by rechargeable batteries making them a cleaner and more energy-efficient alternative to traditional internal combustion engine (ICE) vehicles. As the world shifts toward greener energy sources, electric vehicles are playing a pivotal role in reducing dependence on fossil fuels and promoting environmental sustainability. EVs are made of lithium-ion batteries which have a range up to 300 miles and 10 times the life, remaining functional through about 2000 deep cycles compared to its old lead-acid battery which was heavy and had a range less than 100 miles and only functioned through several hundred deep cycles. (constellation, no date) However, the production of these lithium-ion batteries requires raw materials such as lithium, cobalt, nickel and rare earth metals which requires extraction of these materials from the Earth itself. Recycling methods like pyrometallurgy, hydrometallurgy, and emerging direct recycling show

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue I, January 2026

promise but are energy intensive, chemically complex, and struggle with varied chemistries and pack designs. Advanced and emerging recycling technologies—robotic dismantling, AI sorting, deep-eutectic solvents, molten salt roasting—offer potential but remain at pilot or lab scale. (Safarzadeh and Di Maria, 2025) Another challenge for the increase in demand for EVs are the energy source for charging these vehicles which bring issues concerning the design and operation of power systems at both the transmission and distribution levels. Electric Vehicle Grid Integration, the process of integrating these vehicles into the electricity grid increases, calls for an increase in the demand for power grids as well which would also affect the grid infrastructure. (Singh *et al.*, 2024) With all these challenges and benefits coming from the increase in usage and demand for EVs, the question remains on whether EVs are sustainable for the long-term run. In this paper, we will be concluding just that according to a few factors which are comparing between an ICE vehicle and an EV, looking into depth the workings and the battery of an EV, its performance, challenges and impacts brought by EVs.

Comparison of Internal Combustion Engine (ICE) Vehicles to Electric Vehicles (EV)

In this section, we will be doing in-depth analysis for the comparison of these two vehicles from vehicle operation to driving behaviors. For an easier understanding and comparison to be done, we will be excluding Hybrid (HYB) Vehicles which can function on both electric and an internal combustion engine.

Vehicle Operation

The factors being put into place for vehicle operation are energy conversion, driving dynamics, braking, range and fueling and temperature sensitivity.

Energy Conversion

EVs

Electricity stored in the lithium-ion batteries are used by the motor to turn the wheels by using electromagnetic force. Around 85-90% of the electrical energy from the battery is converted into kinetic energy which makes it highly energy efficient. Its mechanical operation is also much simpler as it has less moving parts such as no usage of pistons or complex gear systems to move the wheels.

- ICE Vehicles

Power is generated by burning fuel within the engine’s cylinders which releases energy and is used to power the vehicle. Around only 20-30% of the energy from the fuel burned is converted into usable power while the remaining 70-80% is lost to heat in the exhaust, engine and transmission which makes it low energy efficient. The mechanical operations of this vehicle is very complex as it involves a lot of moving components such as pistons, camshafts, crankshafts and valves.

Driving Dynamics

EVs	FACTORS	ICE VEHICLES
Accelerate smoothly and quickly from stationary position. No delay or shifting needed	ACCELERATION AND POWER DELIVERY	Rely highly on its gearbox and clutch to navigate power. Have more gradual acceleration curve and noticeable delay as engine revs up before power is transmitted to the wheels for motion

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Do not require multi-gear transmission. A single-speed gearbox will be sufficient which makes the driving simpler and no gear shifting needed to be done (Lacock, du Plessis and Booysen, 2023)	SHIFTING GEARS	Require manual or automatic transmissions that shift gear to match its speed and engine load. Is a less smooth process
Quieter as the sound only comes from its wheels and wind	NOISE	Noisier especially when it comes to accelerating due to the engine noise and exhaust
Lack vibrations associated with the workings of an internal combustion engine	VIBRATION AND SENSATION	Vibration is experienced due to the engine and mechanical components such as its exhaust system

Table 2.1

Braking

EVs

EVs use a regenerative braking system where its electric motor works in reverse during the braking process to slow the vehicle down. This turns kinetic energy back into electrical energy which is then restored in its battery for later usage. Not only that, it also provides a different braking feel often described as “one-pedal driving”. Smoother deceleration occur and the usage of physical brakes is reduced significantly

ICE Vehicles

Braking involves friction between the brake pads and the discs which converts kinetic energy to heat energy which is lost greatly and no energy recovery is done in this process. The braking feels consistent and relies entirely on the friction-based system. The brake performance also reduces over time due to the wearing down of the brake pads. About **60–70%** of generated heat is conducted into the disc, destabilizing its structure and risking material failure. (Li *et al.*, 2020)

Range and Fueling

EVs

The range of an EV can vary widely as most can range up to 200-300 miles while long-range EVs can reach over 400 miles. Charging an EV can take over 30 minutes (fast charging) to several hours (standard charging) depending on the charger type and battery capacity.

ICE Vehicles

Conventional internal combustion engine (ICE) vehicles typically carry between **50–70 liters** of fuel. Combined with fuel efficiencies of **25–40 MPG,** this results **in 400–600 miles (≈640–965 km)** of range on a full tank—a level of consistency that ICE vehicles are known for. Its range is typically 400-600 miles on a full tank of fuel and is relatively consistent. Refueling is straightforward and is a very quick process which only takes up about a few minutes at any gas station.

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Temperature Sensitivity

EVs

Can be affected in cold weathers as battery performance can drop in low temperatures, reducing its range and charging efficiency. Charging in this type of weather could be very slow and can shorten the battery's lifespan over time.

ICE Vehicles

Engine thermal efficiency is significantly reduced during warm-up, with **fuel economy penalties up to ~7%** and emissions spikes of **up to ~40%** due to suboptimal lubricant and component temperatures. Frictional losses in a cold engine can be **110–150% greater** than during normal operation, significantly reducing performance until oil and coolant reach operating temperatures. (Roberts, Brooks and Shipway, 2014) Generally unaffected in cold weather except needing to warm up the engine in extremely cold conditions before use. Battery performance is also unaffected. Fueling in cold weathers could be a problem as the diesel or gasoline might not be in liquid form for it to be passed through in the piston system of the vehicle.

Summary of Key Differences Between ICE Vehicle and EVs From Vehicle Operation

FACTORS	ICE VEHICLES	EVs
Power Source	Gasoline or diesel fuel	Electricity from battery
Energy Efficiency	20-30% efficiency (lots of energy lost as heat)	85-90% efficiency (most energy is used for driving)
Transmission	Multi-gear system, complex operation	Single-speed transmission, smoother operation
Acceleration	Gradual, dependent on engine revs	Instant torque, smooth and rapid acceleration
Braking	Standard friction-based braking	Regenerative braking, recovering energy
Fueling/Charging	Fast refueling at gas stations	Charging time can range from 30 minutes to hours
Range	Typically 400-600 miles per tank	Typically 200-350 miles per charge

Table 2.2

Driving Behaviours

EVs are designed to have lower mileages than ICE vehicles such as less harsh acceleration, smoother braking maneuvers, less harsh cornering and speed violations. Even with these advantages, EV cars have recorded a higher percentage in first-party damage costs compared to ICE vehicles even though ICE vehicles have a higher probability for this to occur. The workings of the vehicles does not guarantee a reduction in accident rates caused by the driver of the vehicle itself when compared between EVs and ICE vehicles. (McDonnell *et al.*, 2024)

When we analyze through the aspect of switching from an ICE vehicle to an EV, this might be due to the unfamiliarity of the vehicle controls and drastic change in driving style and behavior for the driver. EV drivers claim that they feel more safe driving an EV after they are familiar with its controls and are more experienced with the vehicle.

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Trip distances are also a playing factor in the increasing number of at-fault claim likelihood. More road exposure experienced by EV drivers greatly increases its risks compared to an ICE driver. EVs have shorter achievable driver distance due to battery limitations and lower mileage than ICE vehicles which causes EV drivers to have a higher likelihood at causing at-faults claim with less mileage than ICE vehicles.

From here, we can conclude that even though EVs are designed to have safer and smoother driving experience features, the high number in accidents caused by EVs compared to ICE vehicles is highly because of the unfamiliarity to the controls and workings of the EV itself.

III. The Role of Batteries in Electric Vehicles (EVs)

The battery serves as a critical component in electric vehicles (EVs), accounting for approximately one-third of the total vehicle cost. Its performance directly influences the efficiency, range, and overall usability of EVs. The Battery Management System (BMS) plays an essential role in optimizing battery performance. (Waseem et al., 2023) It ensures key functions such as state of charge estimation, cell balancing, fault diagnosis, and thermal monitoring. Together, the battery and BMS form the backbone of EV technology, making advancements in this area vital for the industry's growth.

IV. Dominance of Lithium-Ion Batteries

Current EV battery technology predominantly relies on lithium-ion (Li-ion) batteries due to their superior characteristics, including high energy density, long lifespan, and cost-effectiveness. (Waseem *et al.*, 2023) Li-ion batteries have largely replaced older technologies like lead-acid and nickel-based batteries. Their long cycle life, low discharge rates, and high-power density make them ideal for automotive applications, power tools, and portable electronics. Researchers anticipate further energy density improvements, with predictions of reaching approximately 500 Wh/kg, enabling longer ranges and higher performance. (Waseem *et al.*, 2023)

V. Advantages of Secondary Batteries

Electric vehicles use rechargeable secondary batteries, which are favored over non-rechargeable primary batteries. Secondary batteries such as lithium-ion, lead-acid, nickel-cadmium (NiCd), and nickel-metal hydride (NiMH) offer significant advantages, including extended cycle life, higher power density, and improved safety features (Waseem et al., 2023). Among these, lithium-ion technology stands out as the most widely adopted solution in EVs, contributing to increased efficiency and reliability.

VI. Challenges Facing Li-ion Technology

Despite their advantages, lithium-ion batteries face several challenges that affect their longevity and performance. These include the loss of active anode and cathode materials, reduced lithium inventory, and decreased conductivity in both electrodes and the electrolyte. (Waseem et al., 2023) Addressing these limitations is crucial to enhancing the durability and efficiency of Li-ion batteries in real-world conditions.

VII. The Promise of Solid-State Batteries

Future innovations, such as solid-state batteries, offer potential breakthroughs in energy storage technology. Solid-state batteries, particularly those utilizing lithium as the anodic metal, promise significantly higher energy densities—up to 900 Wh/L—and improved stability. (Waseem et al., 2023) However, practical challenges, including low coulombic efficiency and limited life cycles, remain barriers to widespread adoption. Ongoing research aims to overcome these issues to unlock the full potential of solid-state batteries.

VIII. Artificial Intelligence in EV Battery Management

Artificial Intelligence (AI) is revolutionizing the EV sector, particularly in battery management and vehicle operation. AI applications optimize charging schedules, analyze driving patterns, and adjust vehicle performance to enhance energy efficiency. (Amer et al., 2024) Additionally, AI-driven systems enable advanced autonomous driving capabilities and vehicle-to-grid communication, creating smarter and more sustainable EV ecosystems. (Amer *et al.*, 2024)

IX. The Future of Wireless Charging

Another significant advancement in EV infrastructure is the development of wireless charging technology. Utilizing inductive and magnetic resonance methods, wireless charging systems offer superior convenience and flexibility compared to traditional plug-in charging solutions. (Amer et al., 2024) While still in development, these systems hold great promise for enhancing user experience, sustainability, and widespread adoption of EVs.

X. Challenges in Electric Vehicle (EV) Adoption

The growing demand for electric vehicles (EVs) places immense stress on existing electric power networks. Increased charging demand (CD) can cause voltage instability, harmonic distortion, and grid overloads, which compromise reliability and efficiency. Significant investments in upgrading transmission and distribution (T&D) systems are necessary to handle the added energy load. (Tuffour and Ewing, 2024) However, planning remains challenging due to uncertainties in determining accurate EV load profiles. Without integrated capacity expansion, widespread EV adoption could face serious setbacks.

XI. Strain on Energy Supply and Critical Materials

The study highlights concern about energy supply capacity at household and regional levels. Rapid EV adoption risks straining residential electricity supply and existing grid infrastructure. Projections suggest that global demand for EV batteries will triple by 2030, potentially leading to shortages of critical materials like cobalt and lithium. This material scarcity not only increases production costs but also raises concerns about long-term sustainability for the EV industry. (Waseem *et al.*, 2023)

XII. Charging Infrastructure (CI) Limitations

One of the major challenges in EV adoption is the availability and accessibility of charging infrastructure. Expanding CI requires overcoming obstacles such as ensuring access to multi-tenant buildings, managing power network connections, and securing sufficient charging slots. (Amer et al., 2024) Fast-charging technologies, essential for larger EV batteries, further strain weak power grids, necessitating infrastructure improvements. Moreover, the lack of uniform communication protocols between EVs and charging apparatus manufacturers risks incompatibilities and inefficiencies. (Waseem et al., 2023)

XIII. Battery Degradation and Vehicle-to-Grid (V2G) Feasibility

Battery degradation (BD) is another obstacle impacting EV adoption and V2G systems. High costs, limited battery life, and life-cycle concerns restrict the financial benefits of intelligent charging systems. Uncoordinated charging exacerbates grid instability, causing power disturbances and voltage fluctuations. (Waseem *et al.*, 2023) Both daytime and nighttime charging present challenges: daytime usage risks grid overloads, while nighttime charging relies heavily on time-of-use pricing to balance demand.

XIV. Safety Concerns in EV Batteries

Battery safety remains a critical challenge, particularly for lithium-ion (Li-ion) technology. Li-ion batteries are prone to overcharging, combustion risks, and thermal expansion during charging, as seen in incidents involving Tesla and Boeing. (Waseem *et al.*, 2023) Issues like leakage and thermal effects pose additional risks, though innovations, such as Stanford University's nanosphere layer technology, offer promising solutions for better heat and volume management.

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XV. Energy Conversion Efficiency

Electric vehicles (EVs) excel in energy conversion efficiency, typically converting 70–95 % of electrical energy stored in the battery into mechanical power (Liu, Shafique and Luo, 2024). This is a great contrast to internal combustion engine (ICE) vehicles, which lose much of their energy as heat in the engine and drivetrain. In EVs, several components enhance this efficiency: the electric motor, capable of achieving up to 95 % conversion efficiency; regenerative braking, which recovers kinetic energy; and optimized transmissions ranging from single speed to multi-speed gearboxes designed to keep the motor operating in its most efficient range(Liu, Shafique and Luo, 2024). Environmental factors like ambient temperature further influence this efficiency; cold weather stiffens battery performance and increases losses, while warmer conditions generally improve it, though prolonged heat can accelerate battery degradation. Finally, smart charging strategies such as aligning charging times with periods of low-grid-carbon intensity further reduce carbon footprint and energy losses. Factors such as motor, regeneration, transmission design, temperature, and charging time play a crucial role in maximizing BEV efficiency across varying conditions.

XVI. Battery Degradation

Battery degradation is a key challenge facing EVs, especially in applications like vehicle-to-grid (V2G) systems. Elevated temperature accelerates chemical reactions and capacity fade, while low temperatures slow reactions, reducing available capacity. Cycling repeated charging and discharging induces mechanical and chemical stress, particularly at high C-rates, which damages internal structures and hastens degradation. Depth of discharge (DoD) also matters deep cycling strains battery chemistry and shortens lifespan, whereas partial cycling can prolong it (Izquierdo-Monge et al., 2025b). In microgrid and V2G use, frequent shallow discharges may mitigate wear compared to deep cycles, but this balance depends on usage patterns. As batteries age, reduced capacity affects range and performance, leading to higher costs for replacements or degradation mitigation strategies. To address these challenges, it’s crucial to optimize thermal control, cycle rates, DoD limits, and charging profiles in EV battery management systems ensuring durability, reliability, and affordability over a battery’s operational lifetime.

XVII. Energy Consumption

Real-world energy consumption in EVs aligns closely with controlled testing when accounting for external factors like temperature, driving style, topography, and auxiliary loads. Ambient temperature plays a major role: consumption nearly doubles at −15 °C compared to 24 °C due to increased internal resistance and heating demands. Optimal efficiency is achieved around 18–20 °C. Above that, moderate increases have a modest effect, but efficiencies decline below 10 °C (Lee et al., 2024). Driving behavior such as speed and braking intensity also influences consumption; eco-driving can mitigate these effects, especially when paired with regenerative braking. Auxiliary demands like heating/cooling and lighting further impact energy use, especially in colder climates. Road gradient and driving mode selection influence consumption. In summary, while laboratory-rated ranges provide a useful baseline, actual consumption depends on complex real-world variables. EV designers and users must consider these factors for accurate range estimation, battery sizing, and energy optimization in various environments and use cases.

XVIII. Battery Thermal & Energy Management

Efficient battery thermal and energy management is essential for optimizing range, charging performance, and battery longevity. Recent ScienceDirect reviews highlight active thermal systems such as liquid cooling, heat pumps, and phase-change materials paired with model-predictive control for dynamically managing temperature during driving and charging. Smart strategies include pre-conditioning the battery before charging to minimize losses and reducing charging time by up to 44 % through optimized route and temperature control (Seo et al., 2025). In colder climates, pre-heating reduces energy loss; in heat, cooling prevents thermal runaway and degradation. Integration with eco-driving further enhances benefits by reducing peak thermal stress, extending lifespan, and reducing grid energy demand. Overall, combining advanced thermal systems, intelligent control, and proactive charging strategies boosts performance, reduces energy waste, and ensures safe, reliable operation across diverse climates.

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XIX. Powertrain & Transmission Efficiency

Innovations in powertrain and transmission systems enhance both the efficiency and driving dynamics of EVs. ScienceDirect studies demonstrate that multi-speed transmissions such as 2-speed gearboxes can improve motor efficiency by 2–5% through tailored gear ratios and shift patterns ((Biswas, Rathore and Emadi, 2023). Multi-objective optimization methods align gear shifts with torque demands, improving performance and reducing losses. Electronic management systems (EMS) enable coordinated clutch control and seamless shifting, enhancing both drivability and energy efficiency. Studies also explore continuously variable transmissions (CVTs) and mechanical AMTs, which allow the electric motor to remain in its optimal efficiency zone across varied speeds. These integrated powertrain architectures deliver smoother acceleration, better high-speed efficiency, and improved overall range key advantages for heavy-duty or performance-oriented EVs.

XX. Greenhouse Gas Emissions

Life-cycle analyses show BEVs generally produce lower greenhouse gas (GHG) emissions than ICE vehicles, though outcomes depend heavily on electricity generation sources. Battery manufacturing is a significant contributor to BEV GHG emissions, but with renewable or low-carbon grids, BEVs can achieve substantial savings over their operational life. As grid decarbonization advances, higher shares of solar, wind, or nuclear BEVs' relative advantage grow. Therefore, accelerating EV adoption must be coupled with transitioning to clean energy sources to fully realize emissions reduction benefits.

XXI. Resource Consumption

Compared to ICE vehicles, EVs require significantly more raw materials, especially for battery production. Critical minerals such as lithium, cobalt, nickel, and manganese are essential components in modern battery chemistry. Mining and processing these materials often result in substantial environmental impacts, including water pollution, habitat destruction, and high energy consumption. (Dolganova *et al.*, 2020)

For example, lithium extraction from brine sources can consume millions of liters of water per ton, which raises sustainability concerns in arid regions. Demand for these materials is projected to rise sharply in the coming decades, placing even more pressure on ecosystems and supply chains. To address this, manufacturers and policymakers are investing in material recycling, the development of alternative battery chemistries, and the improvement of supply chain transparency. Circular economy strategies and responsible sourcing practices are critical to reducing the environmental footprint of EVs while maintaining their long-term viability(Dolganova *et al.*, 2020)

XXII. Toxicity in the EV Lifecycle

The EV lifecycle involves potential human and environmental toxicity risks, particularly during battery production and end-of-life management. The extraction and refinement of battery materials can release harmful substances, including heavy metals and solvents, into the air, water, and soil. Manufacturing facilities may also emit volatile organic compounds (VOCs) and other toxic byproducts if not properly regulated. ((Mrozik *et al.*, 2021)

Battery recycling can recover valuable materials and reduce waste, but it too poses risks if managed poorly. Exposure to toxic substances such as fluorine compounds, acids, and metal dust during disassembly or smelting processes can endanger workers and local environments (Shu *et al.*, 2021). However, second-life applications and closed-loop recycling systems offer promising solutions to reduce these impacts. Research into safer materials and improved handling protocols is ongoing. By investing in safer technologies and enforcing strict environmental controls, the toxicity footprint of EVs can be significantly reduced.

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XXIII. Industrial Inertia

The existing automotive industry is heavily invested in ICE technology and supply chains. For over a century, manufacturers have built factories, tooling, and supplier networks around engines, transmissions, and fuel systems.

From a supply-chain perspective, ICE vehicles have one of the longest and most complex supply chains for any product. [1] An ICE car requires thousands of engine components, all supplied by a vast ecosystem of parts makers. By contrast, EVs have much simpler drivetrains and far fewer moving parts. [1] Transitioning to EVs therefore renders many legacy suppliers obsolete. Firms with large sunk investments in ICE parts, (e.g. precision casting, injection molding for engines) face losses if demand dries up.

Automakers cannot instantly repurpose an engine factory into a battery plant; new facilities must be built or heavily modified. Investment cycles in auto plants are long (often decades), so firms cautiously phase out EV capacity while leveraging existing ICE lines as long as possible. In effect, the high sunk cost in ICE manufacturing locks in production capacity and raises the risk for firms shifting too rapidly.

Moreover, dealerships and maintenance networks specialize in ICE cars. Service centers must invest in new equipment and training for EV repairs. Until these networks adapt, consumers may perceive higher difficulty in EV ownership.

XXIV. Job Displacement

Similar to point 1, transitioning to EV has significant labor implications. EVs are simpler to build, requiring far less assembly labor than ICE vehicles. Automakers and analysts note that producing an EV involves roughly 30–40% fewer manufacturing steps than an ICE car. [1] Key components like internal-combustion engines, fuel systems, and exhaust assemblies simply do not exist in EVs. As a result, the labor input and components required to produce an EV could be significantly lower than for a comparable ICE car.

In Europe, for example, more than 14½ million people (7% of the workforce) depend directly or indirectly on the automotive industry. (’Cohen, 2022)[1] In Germany, autos make up ~12% of jobs and 20% of manufacturing. If EV production rises to 100%, many workers currently focused on ICE parts could see their skills become obsolete. Studies suggest that without new job creation, this could impose significant adjustment costs on workers and regions. Workers in engine machining or transmission assembly may not easily switch to battery or electric motor work without retraining.

However, the transition also creates new opportunities. EVs generate demand for battery manufacturing, electric powertrain assembly, and charging infrastructure construction. These new plants may be built in different locations, potentially creating jobs in regions not traditionally automotive hubs. Indeed, governments like the U.S. (via the Inflation Reduction Act) and EU (via the Chips Act and Green Industrial plans) are offering incentives to attract EV and battery factories. Such industrial policy aims to mitigate job losses by re-shoring parts of the supply chain.

Nonetheless, the mismatch in skill requirements can be stark. Some analyses (e.g. from the IMF) warn that a large fraction of auto workers in ICE-related industries could be displaced. Auto manufacturers are beginning to address this (e.g. Cadillac’s EV factory training), but the scale of the change – in Europe and Asia as well as the U.S. – means sustained policy attention will be needed to avoid painful labor disruptions. [1]

XXV. Consumer Behavior

Consumer attitudes and habits significantly shape EV uptake. Surveys and studies consistently find that many potential buyers are “range-anxious” or worried about charging availability. Many consumers fear being stranded if the battery runs out. High upfront cost, unfamiliar technology, and doubts about reliability also deter many buyers.

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In effect, the decision to buy an EV is not based solely on economics; it involves psychological and social factors. For example, one study found that consumers who resisted buying EVs cited not only cost and range but also a lack of appeal compared to traditional vehicles. [2] Demographics also matter. Research in the U.S. finds that EV ownership skews toward higher-income, well-educated, homeowner demographics. In California's rebate program, nearly 80% of EV buyers had household income over $100,000. Low-income and disadvantaged communities see much lower adoption: one study showed that new EVs accounted for only 5.7–8.7% of sales in poor California neighborhoods, and those who did adopt tended to be comparatively affluent within those communities. [2] Additionally, some buyers worry about practicality: EVs have historically offered fewer models (especially in trucks and larger SUVs), and longer charging times compared to filling a tank. Thus, despite the long-run savings, many consumers treat EVs as a risky choice relative to the known convenience of ICE vehicles.

XXVI. Government Policy

On one hand, many developed countries use subsidies, tax credits, and regulatory mandates to encourage EV adoption. For example, China has offered purchase subsidies, tax exemptions, free license plates, and even HOV-lane access or free parking for EVs. (Alanazi, 2023). Such measures have sharply boosted EV sales; in China the NEV (new energy vehicle) market share reached nearly 30% by 2022, aided by these incentives. Similarly, parts of Europe and North America provide purchase grants or tax rebates, and stricter fuel-economy/CO_2 standards that effectively penalize ICE vehicles. These policies reduce the effective upfront cost of EVs and raise the cost of gasoline cars. However, government policy also works against EVs. Many governments continue to subsidize gasoline and diesel consumption (through tax breaks, price controls, or direct subsidies). Global fossil-fuel subsidies are still measured in hundreds of billions annually. For example, IEA data indicates that even after oil price crashes, fossil consumption subsidies were about USD 180 billion in 2020. ('Muta *et al.*, 2021) [4] These subsidies keep fuel prices artificially low in many markets, undermining the relative economics of EVs. In effect, drivers in subsidizing countries pay less at the pump, blunting one of the EV's long-term cost advantages.

XXVII. A Conclusion to Electric Vehicles

Electric vehicles are not a flawless solution, but they are a meaningful step toward more sustainable transportation. They offer real improvements over internal combustion engine cars in areas like energy efficiency, smoother driving experience, and reduced greenhouse gas emissions. With technologies like regenerative braking and intelligent battery management, EVs continue to prove that clean driving can also be highly performing. Battery technology sits at the heart of this progress. While lithium-ion remains the standard, its limitations, such as degradation, sourcing issues, and safety concerns, are still real. However, research into solid-state batteries and smarter energy systems shows strong potential to overcome these hurdles. Innovations like wireless charging and AI integration suggest that EVs will only become more practical with time. That said, the journey isn't easy. Charging infrastructure is still lacking in many regions, especially for those without access to home charging. Electricity grids will need upgrading to support widespread adoption. On top of that, concerns about battery waste, mineral extraction, and long-term environmental costs deserve serious attention. The economic side is also mixed. EVs can save money in the long run, but their high upfront costs still turn many buyers away. Industry transition is slow, and some jobs in traditional automotive sectors may be at risk as the market shifts. Supportive government policies and public willingness to adapt will play a key role in shaping what happens next. Overall, EVs are not perfect, but they're promising. Considering the environmental impact, performance, and future potential, it is clear that EVs represent a better path forward. With the right balance of innovation, investment, and policy, EVs can help build a more sustainable future. The road ahead is still under construction, but the direction is clear.

Funding and Grants

This reseach did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue I, January 2026

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