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A Review of the Future Feasibility and Dynamics of the Indian EV Market; an Economic, Geopolitical, and Engineering Insight

Ishan Nafde[1], Tanmay Zade[2], Manaswi Patil[3], Sarthak Wankhade[4], Anurag Kadu[5]
[1]BE Student, Department of Mechanical Engineering, PRMIT&R
[2, 3, 4]BE Student, Department of Computer Science & Engineering, PRMIT&R
[5]BTech Student, Department of Information Technology, GCOEA

Abstract: In order to reduce air pollution and greenhouse gas emissions, India's rapidly expanding transportation sector requires a paradigm change toward sustainable energy choices. Fuel cell electric vehicles (FCEVs) and battery electric vehicles (BEVs) both provide advantages and disadvantages that make them viable options. The engineering elements of both technologies are thoroughly examined in this review study, with particular attention paid to driving range, energy density, resource requirements, and the condition of the refuelling infrastructure in the Indian context.

The limits of existing BEV technology are also severely examined in the report, with a focus on range anxiety resulting from slower charging periods as compared to FCEVs. On the other hand, FCEVs provide a longer driving range and quicker refuelling, simulating the operation of traditional gasoline cars. Moreover, the study delves into the resource limitations linked to lithium-ion batteries in battery-electric vehicles (BEVs) and highlights the possible advantages of fuel cell electric vehicles (FCEVs) concerning material accessibility, ecological durability, and diminished dependence on essential minerals.

A thorough examination of the country's current infrastructure indicates a notable discrepancy between the abundance of BEV charging stations and the small number of FCEV hydrogen refuelling stations in India. The "chicken-or-egg" conundrum impeding the mainstream adoption of FCEVs is acknowledged in the report, which also emphasizes the necessity of significant investment and technology improvements to close the infrastructural gap.

While both BEVs and FCEVs have the potential to help India meet its clean mobility targets, the study makes the case that FCEVs are a better option because of their longer range, quicker refuelling times, and possibly more sustainable resource profile. For them to be widely adopted, it is still necessary to overcome the infrastructure's present shortcomings for hydrogen refuelling. This analysis emphasizes the necessity of a multifaceted strategy that includes infrastructure development, technical developments, and deliberate governmental interventions in order to set the groundwork for India's transition to clean and sustainable transportation in the future.

Keywords: Battery Electric Vehicles (BEVs), Fuel Cell Electric Vehicles (FCEVs), Electric Vehicles (EVs), Clean Transportation, Air Pollution, Greenhouse Gas Emissions, Range Anxiety, Energy Density, Resource Constraints, Lithium-Ion Batteries, Hydrogen Refuelling Infrastructure, Infrastructure Development, Sustainable Transportation, India.

I. INTRODUCTION

India's transportation sector is currently undergoing remarkable expansion, playing a significant role in the economic advancement of the country. Nevertheless, this advancement is accompanied by an environmental toll. The increasing dependence on vehicles powered by fossil fuels has resulted in a surge in both air pollution and the emission of greenhouse gases, posing risks to public health and the sustainability of the environment. In order to tackle these issues, a fundamental shift towards clean energy alternatives is deemed necessary. Battery Electric Vehicles (BEVs) and Fuel Cell Electric Vehicles (FCEVs) have emerged as frontrunners in this transition, presenting a viable route towards a more environmentally friendly transportation landscape. While both technologies come with their own set of advantages, they also encounter distinct challenges that impede their widespread implementation. This analytical paper examines in depth the engineering aspects of BEVs and FCEVs, focusing specifically on their relevance within the Indian context. Key factors such as driving range, energy density, resource demands, and the status of refuelling infrastructure will be thoroughly investigated.

Firstly, an in-depth analysis will be conducted on the constraints of existing BEV technology, with a specific focus on the issue of "range anxiety" resulting from prolonged charging durations compared to traditional gasoline vehicles. Following this, an evaluation will be made on the capacity of FCEVs to mitigate this concern by virtue of their enhanced range and efficient refuelling capabilities, thereby replicating the user experience provided by conventional gasoline vehicles.

Moreover, this study will delve into the limitations posed by lithium-ion batteries in BEVs and spotlight the advantages offered by FCEVs in terms of raw material accessibility and ecological sustainability. Additionally, an assessment will be carried out on the current status of refuelling infrastructure in India, shedding light on the disparity between the widespread presence of BEV charging stations and the limited availability of hydrogen refuelling stations for FCEVs.

The study recognizes the complex "chicken-or-egg" predicament impeding the extensive integration of FCEVs and stresses the necessity for substantial investments and technological progress to bridge the existing infrastructure gap. Finally, we will argue that while both BEVs and FCEVs possess the potential to contribute to India's clean mobility goals, FCEVs offer a compelling alternative due to their extended range, rapid refuelling, and a potentially more sustainable resource profile. However, overcoming the limitations in hydrogen refuelling infrastructure remains crucial for their widespread adoption.

This review paper concludes by emphasizing the need for a multi-pronged approach encompassing technological advancements, infrastructure development, and strategic policy interventions to pave the way for a clean and sustainable transportation future in India.

II. ENGINEERING FACTORS

India's automotive sector relies heavily on fossil fuels like petrol and diesel, which release harmful greenhouse gases (GHGs) into the atmosphere. These rising emissions are a major cause of climate change, leading to problems like extreme heat waves, rising sea levels, and stronger storms.

While we currently depend on fossil fuels, their use in internal combustion engine (ICE) vehicles is causing serious environmental issues. These vehicles emit a range of noxious gases like COx, SOx, NOx, and particulate matter, contributing significantly to air pollution. A report by the International Energy Agency (IEA) highlights that transportation is responsible for over 30% of global emissions, with on-road cars accounting for nearly 70% of that figure (Table 1 outlines the specific emissions and their health impacts). While battery-powered electric vehicles (EVs) are emerging as a potential solution, they still face challenges like range anxiety, energy density to name a few. Additionally, India has limited lithium resources, a key component in most EV batteries.

Fuel cell technology offers a promising alternative. These systems convert clean hydrogen fuel into electricity, with only water and heat as by-products. This makes them a reliable and potentially game-changing solution for the Indian automotive industry. We will take a look at the picture from an engineering perspective here.

Table-1 Type of air pollutant, major sources of emission and its health impact

Air Pollutant	Major source of Emission	Averaging Time	Standard Level	Health Impact and Target Organs
Particulate Matter, $PM_{2.5}$	Motor engines, industrial, smokes	24 Hr	35 µg/m3	Respiratory and Cardiovascular diseases, Central Nervous System and reproductive dysfunctions, Cancer
Particulate Matter, PM_{10}		24 Hr	150 µg/m3	
Ground level Ozone	Vehicular exhaust, industrial activities	1 Hr	0.12 mg/m3	Respiratory and Cardiovascular dysfunctions, eye irritation
Carbon monoxide	Motor engines, burning coal, oil and wood, industrial activities, smokes	1 Hr	35 mg/m3	Central Nervous System and Cardiovascular diseases
Sulphur dioxide	Fuel combustion, burning coal	1 Hr	75 µg/m3	Respiratory and Central Nervous System involvement, eye irritation
Nitrogen dioxide	Fuel burning, Vehicular exhaust	1 Hr	100 µg/m3	Damage to liver, lung, spleen, and blood
Lead	Lead smelting, industrial activities, leaded petrol	3 months average	0.15 µg/m3	CNS and hematologic dysfunctions, eye irritation
Polycyclic Aromatic hydrocarbons	Fuel combustion, wood fires, motor engines	1 Hr	1 ng/m3	Respiratory and Central Nervous System involvement, cancer

A. Battery Electric Vehicles

Battery Electric Vehicles (BEVs) are emerging as a powerful solution to the challenges posed by conventional gasoline-powered vehicles. Unlike their internal combustion engine (ICE) counterparts, BEVs rely solely on electric motors powered by rechargeable batteries, typically Lithium-ion based [1]. These batteries can be conveniently charged at home using a wall charger or, for faster charging, at public charging stations if available.

BEVs offer remarkable versatility, encompassing a wide range of vehicle types – from everyday hatchbacks and sedans to SUVs and even high-performance sports cars and motorcycles. Recent advancements have pushed the boundaries of range, with some models now exceeding 1,000 kilometres of range on a single charge [2]. Furthermore, BEVs

boast desirable handling characteristics due to the placement of batteries on the vehicle floor, resulting in a lower centre of gravity and improved stability. This translates to enhanced safety, as evidenced by their frequent achievement of 4-5 star ratings in crash tests [3]. Beyond safety, BEVs offer an engaging driving experience due to the instant torque delivery of electric motors, providing a significant advantage over traditional gasoline cars.

1) *Range:* While the average BEV offers a driving range of approximately 200 miles (322 km), certain high-end models, such as those from Tesla, boast EPA-estimated ranges exceeding 400 miles (644 km). This disparity originates from fundamental differences in energy storage mechanisms between batteries and fuel cells, despite their shared reliance on electrochemical principles for converting chemical energy into electricity. Both systems require specific criteria for ion and electron conduction within their electrolytes and electrodes [26].

   Figure 1 illustrates the significant gap in specific energy (energy per unit weight) between current battery technologies and fuel cells. Traditional deep-discharge lead-acid (PbA), nickel metal hydride (NiMH), and lithium-ion (LIB) batteries fall far short of the US ABC (Advanced Battery Consortium) target, while a PEM fuel cell system coupled with compressed hydrogen storage tanks demonstrates a clear advantage. Notably, the use of fiber-wrapped composite tanks for hydrogen storage at higher pressures (5,000 psi and 10,000 psi) presents a trade-off between pressure capacity and weight due to the increased fiber required for strength at higher pressures.

   The substantial weight difference between batteries and fuel cells is another crucial factor. Batteries typically weigh at least ten times more than fuel cells, resulting in a mass-based energy density in the range of 0.1 to 0.27 kWh/kg. This pales in comparison to gasoline (13 kWh/kg) and even compressed hydrogen gas (39.6 kWh/kg at 700 bars). Furthermore, BEVs typically consume between 0.24 kWh and 0.87 kWh of electricity per mile, with an average of around 0.33 kWh/mile [18]. In contrast, the Toyota Mirai FCEV achieves a range of 100 km (80 miles) on just 1 kg of hydrogen [27, 28]. These limitations highlight the ongoing challenge of achieving sufficient range with BEVs, particularly for applications requiring long-distance travel.

2) *Energy Density:* Energy density, expressed in kilowatt-hours per kilogram (kWh/kg), serves as a paramount metric for evaluating battery performance in Electric Vehicles (EVs). It quantifies the amount of energy a battery can store relative to its mass. Unfortunately, lithium-ion (Li-ion) battery technology, the current mainstay in BEVs, faces a significant constraint in this domain. As previously established, Li-ion batteries typically exhibit a mass-based energy density of merely 0.1 to 0.27 kWh/kg. This value falls demonstrably short of conventional gasoline, which boasts an energy density around 13 kWh/kg. This stark disparity translates into a fundamental challenge for BEVs: achieving driving ranges comparable to gasoline-powered vehicles. A BEV equipped with a battery of lower energy density necessitates a larger and consequently heavier battery pack to attain the same range as a gasoline vehicle. This, in turn, leads to a heavier overall vehicle weight, which exerts a detrimental effect on efficiency and performance. For example, a heavier vehicle demands more energy for acceleration and maintaining speed, resulting in a reduced range and potentially higher electricity consumption.

   Furthermore, the weight of the battery pack significantly influences factors beyond driving range. Payload capacity and cargo space are also impacted in BEVs. A car burdened with a large, heavy battery pack will offer less room for passengers and cargo compared to a gasoline-powered vehicle with a smaller fuel tank. This can pose a significant disadvantage for consumers requiring a vehicle for extended journeys or transporting large items.

   The limitations of current battery energy density extend beyond the immediate concerns of driving range and weight. The additional mass of a large battery pack can also influence the handling and dynamic characteristics of a BEV. A heavier vehicle may exhibit a higher centre of gravity, potentially compromising agility and stability during manoeuvres.

   The limited energy density of current battery technology presents a critical engineering bottleneck for widespread BEV adoption. Researchers are actively engaged in exploring avenues to enhance energy density, such as the development of novel electrode materials and innovative cell architectures. Significant advancements in this area are essential for BEVs to compete effectively with gasoline-powered vehicles and offer a truly compelling alternative for consumers.

3) *Materials and other Factors:* The widespread adoption of BEVs faces a significant challenge: the limited availability of critical materials for lithium-ion batteries. Lithium, nickel, and cobalt are essential components of these batteries, and while production is increasing, it may not keep pace with the projected demand, especially in a region like the Indian subcontinent [47].

Cathode materials play a crucial role in battery design, each offering unique advantages and disadvantages in terms of cost, safety, performance, and other factors (Figure 2). While Lithium Cobalt Oxide (LCO) is a mature cathode chemistry used in consumer electronics, it suffers from structural instability and is not suitable for EV applications due to over-delithiation [48, 49].

Resource availability, stable crystal structures, and affordability have led other cathode chemistries like Lithium Nickel Cobalt Aluminium Oxide (NCA), Lithium Manganese Oxide (LMO), Lithium Nickel Manganese Cobalt Oxide (NMC), and Lithium Iron Phosphate (LFP) to replace LCO as the preferred battery material for automotive applications (Figure 2 summarizes key features of these cathodes for automotive use).

However, concerns remain regarding safety and environmental impact during mining. A recent example is the halted $2.4 billion lithium project in Serbia, which some analysts believe could contribute to continued scarcity for years [47]. This scarcity fuels competition for battery materials between nations and companies, ultimately leading to price hikes for import-dependent countries with little control over production or pricing.

India's exploration of FCEVs stems partly from this resource constraint with lithium-ion batteries. Researchers around the world are also exploring alternative battery technologies that rely on less scarce resources. Lithium Iron Phosphate (LiFePO4) batteries, for instance, do not require nickel or cobalt and offer improved safety characteristics. Beyond lithium-ion, sodium-ion and zinc-air batteries hold promise due to the abundance of their constituent materials [51, 52, 53]. However, achieving acceptable performance, reliability, safety, and durability remains a challenge, and most of these technologies are still in the prototype or research stage, with potential market entry not expected before 2025 [50].

4) *Charging Infrastructure:* The widespread adoption of BEVs in India faces a significant challenge: the development of a robust and convenient charging infrastructure. While home charging offers a solution, its effectiveness is limited in high-density urban areas where secure off-street parking is often scarce. Therefore, the quantity and accessibility of public charging stations become a critical factor for BEV adoption.

The Indian government recognizes this challenge and has initiated efforts to address it. The National Hydrogen Mission (NHM) aims to leverage the potential of hydrogen as a clean alternative fuel. Power generation companies like NTPC Ltd. are exploring the establishment of green hydrogen production facilities. Additionally, the Ministry of Power has issued bids for electrolyser capacity, aiming to incentivize green hydrogen production and consumption through financial support and policy measures. These initiatives are encouraging signs for the future of hydrogen as a potential fuel source.

However, the current reality is that BEV charging infrastructure development is outpacing that of hydrogen refuelling stations. One reason for this disparity is the classic "chicken-or-egg" dilemma. Investors are hesitant to build hydrogen refuelling stations without a substantial number of FCEVs on the road, fearing the stations will be underutilized. Conversely, consumers are hesitant to adopt FCEVs due to the limited availability of refuelling infrastructure.

Another challenge for BEV infrastructure in India is grid resilience. Frequent power outages can deter potential EV owners, leading to hesitation in purchasing electric vehicles. To address this concern, initiatives like the Tata Motors and Indian Oil Corporation collaboration on solar-powered EV charging stations offer a promising solution by improving the resilience of charging infrastructure.

Standardization of battery technology is another crucial aspect for establishing a robust charging network. Furthermore, the development of a system for responsible and sustainable end-of-life battery disposal is essential.

While charging infrastructure development is ongoing, charging time remains a challenge for BEVs. Even the fastest charging options, like Tesla's Superchargers, require a minimum of 30 minutes, and frequent use of such high-speed charging can degrade battery life.

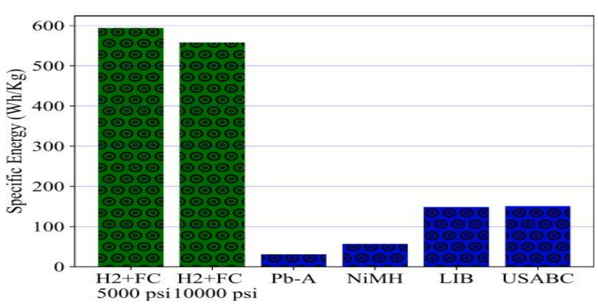

Fig. 1 The specific energy of various battery systems with that of hydrogen and fuel cell systems.

B. Fuel Cell Electric Vehicles

1) *Range:* One of the significant advantages of Fuel Cell Electric Vehicles (FCEVs) compared to BEVs lies in their potential for extended driving range. While the average BEV offers a range of approximately 200 miles (322 km), FCEVs boast the capability to travel considerably further on a single fill of hydrogen. For instance, the Toyota Mirai FCEV demonstrates a range of 100 km (80 miles) per kilogram of hydrogen [27, 28]. This translates to a potential range exceeding 400 km (250 miles) with a full hydrogen tank, depending on the vehicle's capacity. This advantage stems from the fundamental difference in energy storage mechanisms between batteries and fuel cells. As highlighted in Figure 1, compressed hydrogen gas boasts a superior energy density of 39.6 kWh/kg at 700 bars pressure. This dwarfs the typical mass-based energy density of Li-ion batteries used in BEVs, which falls within the range of 0.1 to 0.27 kWh/kg. In simpler terms, for the same weight, hydrogen can store significantly more energy than a battery, enabling FCEVs to achieve longer ranges without the need for a bulky, heavy battery pack. This extended range capability is particularly advantageous for applications requiring long-distance travel or frequent use, mitigating the range anxiety often associated with BEVs. Furthermore, FCEVs offer the potential for faster refuelling times compared to BEVs, further enhancing their suitability for long journeys.
2) *Energy Density:* Fuel cell technology presents a compelling alternative to battery storage in electric vehicles due to the high energy density of hydrogen fuel. As illustrated in Figure 1, compressed hydrogen gas at 700 bars boasts a remarkable energy density of 39.6 kWh/kg. This value stands in stark contrast to the comparatively low energy density of Li-ion batteries, which typically range from 0.1 to 0.27 kWh/kg. This disparity in energy density translates into several advantages for FCEVs. Firstly, FCEVs can achieve longer driving ranges on a single fill of hydrogen compared to BEVs with a full battery charge. This eliminates the need for frequent stops to recharge, improving overall convenience and practicality for long-distance travel. Secondly, the high energy density of hydrogen allows FCEVs to potentially have smaller and lighter onboard storage systems compared to BEVs with large battery packs. This can lead to weight savings and potentially improve vehicle performance and efficiency. However, it is crucial to acknowledge that the development of a robust and efficient hydrogen refueling infrastructure remains a challenge that needs to be addressed for widespread FCEV adoption. Additionally, the efficiency of converting hydrogen into electricity within the fuel cell itself plays a role in overall vehicle range.
3) *Materials and Other Factors:* Fuel Cell Electric Vehicles (FCEVs) present a compelling alternative to BEVs from a resource availability standpoint. The fuel source for FCEVs, hydrogen, holds a distinct advantage: it is the most abundant element in the universe [54]. This inherent ubiquity stands in stark contrast to the critical materials required for lithium-ion batteries in BEVs, such as lithium, nickel, and cobalt, whose limited supply and uneven geographical distribution pose a significant challenge for widespread BEV adoption, particularly in regions like the Indian subcontinent [47]. Beyond the abundance of hydrogen fuel, FCEVs benefit from the utilization of common materials in their construction, such as carbon, graphite, and stainless steel. While the catalyst electrode materials, particularly those employed in the cathode, can be expensive, they are generally not subject to the same level of resource constraints as the critical minerals essential for lithium-ion batteries. This translates into a more sustainable and secure supply chain for FCEVs compared to BEVs. Furthermore, FCEVs offer inherent environmental advantages from a materials perspective. The fuel cell itself utilizes materials that are considered less hazardous to the environment compared to their lithium-ion counterparts. For instance, lithium mining has been associated with environmental concerns, and the halted $2.4 billion lithium project in Serbia serves as a recent example of potential disruptions in the supply chain that can exacerbate resource scarcity [47]. The hybrid architecture of FCEVs offers an additional benefit in terms of resource utilization. FCEVs can operate with smaller traction batteries compared to BEVs, as the primary energy conversion occurs within the fuel cell itself. This reduces the overall dependence on resource-intensive battery materials in FCEVs. The traction battery in an FCEV primarily serves to provide auxiliary power and support regenerative braking, meaning a smaller, less resource-intensive battery can suffice. FCEVs hold a significant advantage over BEVs in terms of resource availability and environmental sustainability. The ubiquity of hydrogen fuel, the use of common materials in FCEV construction, and the hybrid architecture that allows for smaller traction batteries all contribute to a more secure and environmentally friendly approach to electric mobility.
4) *Refuelling Infrastructure:* The nascent stage of FCEV adoption in India presents a significant challenge: the lack of a well-developed hydrogen refuelling infrastructure. Currently, India has only a single hydrogen refuelling station, located in Faridabad, compared to the far greater number of BEV charging stations available. The Indian government's National Hydrogen Mission (NHM) aims to address this disparity by promoting the development of a hydrogen economy. Initiatives include the exploration of green hydrogen production facilities and support for electrolyser capacity to facilitate hydrogen generation. These efforts aim to establish hydrogen as a viable and sustainable transportation fuel option.

However, the current state of FCEV infrastructure pales in comparison to that of BEVs. This disparity stems partly from the "chicken-or-egg" dilemma. Investors are hesitant to build hydrogen refuelling stations without a critical mass of FCEVs on the road, while consumers are hesitant to adopt FCEVs due to the limited availability of refuelling stations.

While some suggest using existing refuelling stations to generate hydrogen through reforming techniques as a potential cost-effective solution, this approach has implications for sustainability.

In contrast to BEVs, FCEVs offer the advantage of rapid refuelling times, similar to those of conventional gasoline vehicles. However, the overall well-to-wheel efficiency of FCEVs is currently lower than that of BEVs due to energy losses associated with hydrogen production through electrolysis.

The lack of a comprehensive hydrogen refuelling infrastructure presents a major hurdle for widespread FCEV adoption in India. While the Indian government's National Hydrogen Mission offers a roadmap for the development of a hydrogen economy, significant investment and technological advancements are necessary to overcome the existing infrastructure gap and establish FCEVs as a viable alternative to BEVs.

C. Comparison Between the Two

Table-2 Comparison of refuelling time (hours) between BEVs and FCEVs

Vehicle Range (km)	Energy required from grid (kWh)	BEV - Charging time				FCEV
		120 V, 20 A (1.9 kW)	240 V,40 A (7.7 kW)	480 V,3 ϕ (60 kW)	480 V,3 ϕ (150 kW)	Filling time
241	56	29.2	7.3	0.9	0.4	0.08
322	82	42.7	10.68	1.4	0.55	0.1
483	149	77.6	19.40	2.5	0.99	0.15

The table 2 compares the refuelling time (in hours) between BEVs and FCEVs [16]. It shows that BEVs take significantly longer to charge than FCEVs to refill. For example, a BEV with a 241 km range would take 29.2 hours to charge using a 120V outlet, whereas it would only take 0.08 hours to refill an FCEV with the same range. The refuelling time for FCEVs remains constant regardless of the distance travelled, whereas the charging time for BEVs increases with the driving range. Even with a 480V outlet, a BEV would still take 2.5 hours to travel 483 km, whereas an FCEV would only take 0.15 hours to refill for the same distance. The table also shows that the type of charging outlet used for a BEV can significantly affect the charging time. A BEV charged with a 480V outlet can achieve a much faster charging time than one charged with a 120V outlet

Table-3 Comparison of conversion energy loss for BEVs, FCEVs and ICE vehicles

		BEV	FCEV	ICE
100% Renewable electricity				
Well to tank	Electrolysis	–	30%	30%
	Co_2 air capture	–	–	37%
	Transport, storage& distribution	5%	26%	–
Fuel Production Efficiency		95%	52%	44%
Tank to Wheel	Inversion AC/ DC	5%	–	–
	Battery charge efficiency	5%	–	–
	H2 to electricity conversion	–	50%	–
	Inversion DC/AC	5%	5%	–
	Engine efficiency	10%	10%	70%
Overall efficiency		73%	22%	13%

The table 3 compares the conversion efficiency from well to tank (WTT) and well to wheel (WTW) for Battery Electric Vehicles (BEVs), Fuel Cell Electric Vehicles (FCEVs), and Internal Combustion Engine (ICE) vehicles [46].

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1) *BEVs:* Experience a 95% efficiency in fuel production and a round trip efficiency of 5% to 10% for battery inversion and charging. This results in an overall WTT to WTW efficiency of 73%.
2) *FCEVs:* Incur a 30% loss in efficiency during electrolysis (electricity to hydrogen) and a 37% loss for other processes involved in well-to-tank conversion. Additionally, there's a 5% loss in hydrogen conversion to electricity within the fuel cell and a further 5% loss for DC to AC conversion. The total efficiency for FCEVs is 22%.
3) *ICE Vehicles:* Have a mere 30% well-to-tank efficiency due to energy losses during fuel refining and transportation. They do, however, achieve a higher engine efficiency of 70% compared to FCEVs and BEVs. This translates to a total WTT to WTW efficiency of 21% for ICE vehicles

Table-4 Comparison of the state of the art BEV with FCEV

Parameters	BEVs (Tesla model 3 - 2023)	FCEVs (Toyota Mirai XLE - 2023)
Power conversion	Grid-Battery- Motor (Grid Dependent)	refueling-FC Stack-Motor
Curb Weight	2069 kg	1900 kg
Recharging/Refueling time	Normal charging (22 kW) – 5 h ; Supercharging (150 kW) – 25 min	3 min
Range	270/350 miles	>400 miles
Energy capacity	80 kWh	120 kWh (5.6 kg of H2)
Cost	42 k/53.2 k	$50 k
GHG emission	62 g CO2 MJ-1	41 g CO2 MJ-1
Performance (0–60 mph)	5.1 s	8.5 s
Efficiency	4.375 km/kWh	3.33 km/kWh

III.ECONOMIC FACTORS

A. *Government Incentives*
1) *Current and Proposed EV Incentive Programs:* The Indian government has introduced various subsidies for EV purchases and tax breaks for manufacturers to promote EV adoption. These incentives are crucial in making EVs more affordable for consumers and encouraging manufacturers to invest in EV technology. For instance, under the Faster Adoption and Manufacturing of Electric Vehicles FAME scheme, the government provides financial assistance for purchasing electric vehicles and setting up charging infrastructure[11].
2) *Effectiveness and Economic Impact:* Industry reports suggest that while existing incentives have stimulated initial market growth, their long-term economic impacts need further analysis. Studies indicate that sustained incentives can significantly boost the EV market and associated industries. For example, ongoing subsidies and tax breaks can lower the total cost of ownership for EVs, making them more competitive with traditional internal combustion engine vehicles[12].

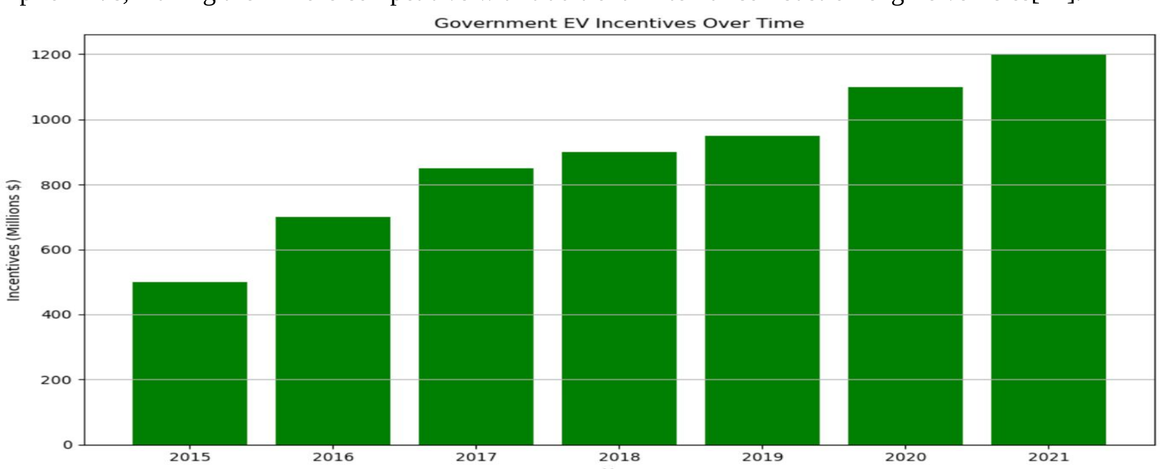

Fig. 2 Government EV Incentives Over Time.

B. Battery Costs

1) *Trends and Projections:* Research from institutions like McKinsey and Bloomberg New Energy Finance indicates a downward trend in battery costs, driven by technological advancements and economies of scale. As battery costs decrease, the overall cost of electric vehicles is expected to fall, making them more accessible to a broader range of consumers[13].
2) *Factors Influencing Costs:* Key factors affecting battery costs include raw material prices, technological innovations, and the development of efficient manufacturing processes. Additionally, advances in battery technology, such as improvements in battery life and reductions in charging times, are crucial for the economic viability of EVs. For example, innovations in solid-state batteries could potentially offer higher energy densities and faster charging times at a lower cost[14].

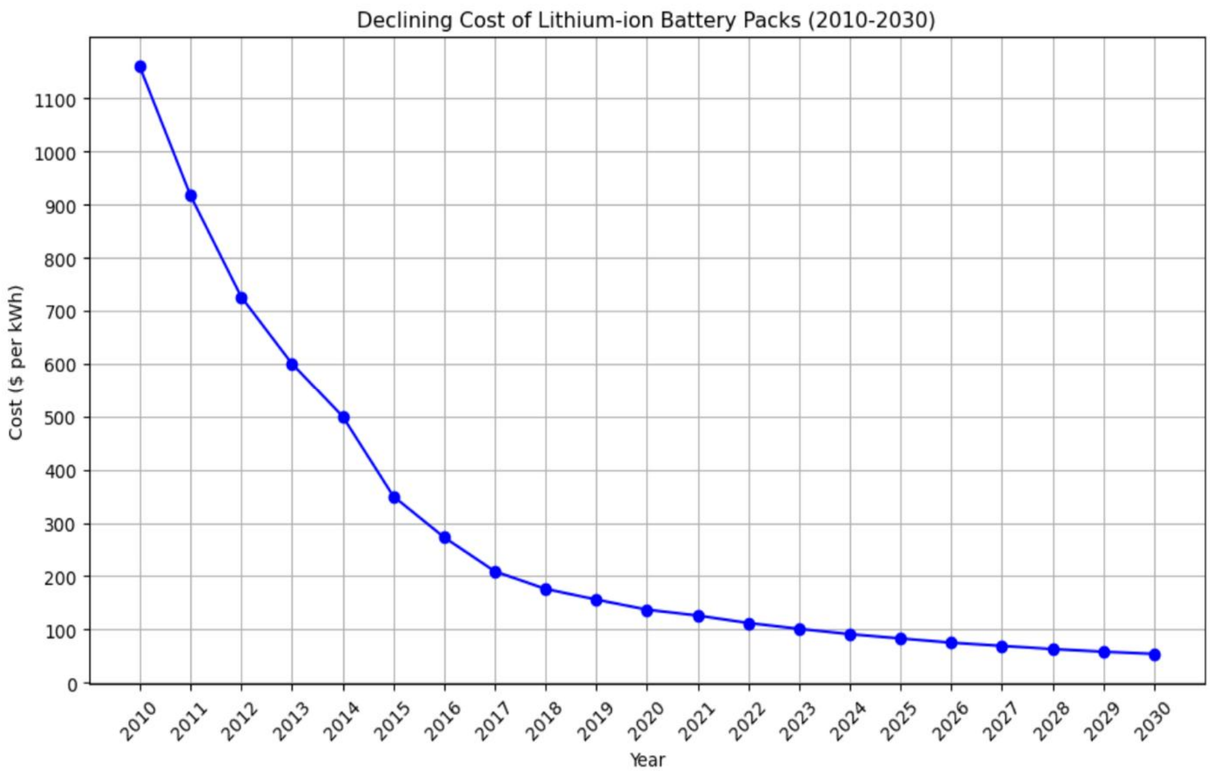

Fig. 3 Declining Cost of Lithium-ion Battery Packs (2010-2030)

C. Charging Infrastructure

1) *Government Plans and Reports:* The Indian government has outlined comprehensive plans to develop a widespread charging infrastructure, essential for supporting EV adoption. This includes setting up charging stations along highways and in urban areas. Government initiatives like the National Electric Mobility Mission Plan NEMMP aim to establish a robust network of charging stations to alleviate range anxiety among EV users[15].
2) *Industry Estimates:* Industry estimates highlight the need for a dense charging network to meet future EV demand. The development of this infrastructure is expected to generate significant economic benefits, including job creation and enhanced grid stability. For instance, building and maintaining charging stations can create employment opportunities in various sectors, from construction to IT services[16].

D. Oil Price Fluctuations

1) *Historical Data and Trends:* Historical oil price data and forecasts from energy agencies like the International Energy Agency IEA provide insights into the volatile nature of oil prices and their impact on consumer preferences towards EVs. Periods of high oil prices often correlate with increased interest in electric vehicles as a more cost-effective alternative[17].
2) *Economic Models:* Economic models suggest that rising oil prices tend to increase the attractiveness of EVs, as they offer a more stable and potentially cheaper alternative to fossil fuel-powered vehicles. For example, during times of high fuel prices, the lower operating costs of EVs become more apparent, driving consumer demand[18].

E. Environmental Regulations

1) *Impact on Production Costs:* Strict environmental regulations in India impact the production costs of EVs and related components, as manufacturers need to comply with these standards, which can lead to higher operational costs but also promote sustainability. Compliance with regulations such as Bharat Stage VI emission norms ensures that EV manufacturers produce environmentally friendly vehicles.
2) *Sustainable Practices:* Adopting environmentally friendly practices can give companies a competitive edge, as global markets increasingly Favor sustainable products. This aligns with India’s push for greener technology and reduced carbon footprints. For example, companies that invest in sustainable manufacturing processes and supply chains may benefit from increased consumer preference and potential government support.

F. Technological Advancements

1) *Battery and Infrastructure Technology:* Advances in battery technology, including improvements in battery life and reduction in charging times, are crucial for the economic viability of EVs. Additionally, advancements in charging infrastructure technology enhance the efficiency and accessibility of EV charging networks. For instance, faster charging technologies can significantly reduce downtime for EV users, making electric vehicles more convenient.
2) *Graphite and Battery Materials:* The evolution of graphite processing technologies can significantly reduce production costs and improve the quality of battery anodes, which are essential for EV performance. Innovations in material science can lead to more efficient and longer-lasting batteries, further driving down the cost of EVs.

G. Investment in Domestic Production

1) *Boosting Local Manufacturing:* Increasing investments in domestic EV manufacturing facilities can enhance India’s market position by reducing dependence on imports and fostering local job creation. This also includes investments in the mining and processing of essential materials like graphite. For example, establishing local supply chains for battery materials can reduce costs and improve supply security.
2) *Trade Policies and Tariffs:* Trade policies and tariffs on imported EV components can affect the overall cost structure and competitiveness of locally manufactured EVs. Favourable trade policies could boost domestic production and market growth. For instance, reducing import duties on key components could lower production costs, making locally produced EVs more competitive.

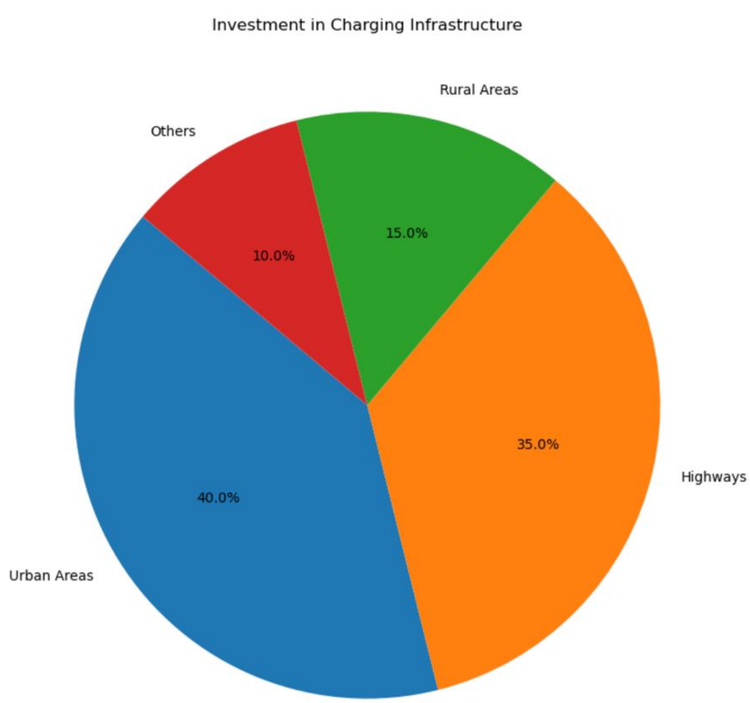

Fig. 4 Investment in Charging Infrastructure

Economic factors play a crucial role in the development and adoption of electric vehicles in India. Government incentives, battery cost trends, charging infrastructure, oil price fluctuations, environmental regulations, technological advancements, and investment in domestic production collectively influence the economic landscape of the EV market. By addressing these factors through strategic policies and investments, India can accelerate the transition to electric mobility, ensuring sustainable growth and energy security for the future.

IV. GEOPOLITICAL FACTORS

A. *Fossil Fuel Dependence*

1) *Utilize government reports or research papers analysing India's dependence on fossil fuel imports (types of fuel, major source countries):* India heavily relies on imports for its fossil fuel needs, including crude oil, natural gas, and coal. The major source countries include Saudi Arabia, Iraq, and the UAE for crude oil; Qatar and the US for natural gas; and Indonesia, Australia, and South Africa for coal.
2) *Consider news articles or industry reports discussing geopolitical risks associated with this dependence:* The reliance on these imports exposes India to geopolitical risks such as supply disruptions due to political instability in supplier countries, fluctuating global oil prices, and strategic manoeuvres by oil-exporting countries 3†source .

B. *Trade Agreements*

1) *Research recent trade agreements India has signed with other countries regarding electric vehicles or related technologies:* India has signed several trade agreements focused on enhancing cooperation in EV technology. Notable agreements include partnerships with Japan and South Korea, which aim to facilitate technology transfer and reduce import duties on key EV components.
2) *Analyse potential implications of these agreements on EV technology transfer, import duties, and overall market competitiveness:* These agreements are expected to bolster India's EV market competitiveness by ensuring a steady influx of advanced EV technologies and reducing the cost of importing essential components 3†source .

C. *Battery Material Sourcing*

1) *Investigate the origin of key battery materials (lithium, cobalt) used in EVs and the geopolitical risks associated with sourcing them:* India sources key battery materials like lithium and cobalt primarily from countries such as Australia, Chile, and the Democratic Republic of Congo. These materials are critical for the production of lithium-ion batteries used in EVs.
2) *Consider news articles or research reports discussing potential disruptions in supply chains and efforts towards diversification:* The geopolitical risks associated with sourcing these materials include potential supply chain disruptions due to political instability, trade restrictions, and monopolistic practices by major producing countries. Efforts are being made to diversify supply sources and invest in domestic mining capabilities 3†source .

D. *Government Manufacturing Policies*

1) *Analyse current and proposed government policies aimed at promoting domestic EV manufacturing in India:* The Indian government has implemented several policies to promote domestic EV manufacturing. These include the Faster Adoption and Manufacturing of Hybrid and Electric Vehicles FAME scheme, which provides financial incentives for EV production and infrastructure development.
2) *Research the potential impact of these policies on attracting foreign investment and technological advancements:* These policies aim to attract foreign investment by offering tax incentives and subsidies to EV manufacturers. Additionally, they encourage technological advancements by supporting R&D initiatives and facilitating partnerships between domestic and international companies 3†source.

E. *India's Fossil Fuel Import Dependence (2010-2022)*

1) *Crude Oil Imports:* The volume of crude oil imports has consistently increased from 159 million metric tonnes in 2010 to approximately 248 million metric tonnes in 2022. This steady rise reflects India's growing energy demands and its reliance on imported crude oil.
2) *Natural Gas Imports:* Natural gas imports have also seen a significant rise from 11 million metric tonnes in 2010 to about 31 million metric tonnes in 2022. This growth is driven by increasing industrial usage and the need for cleaner energy sources.

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3) *Coal Imports:* Coal imports have grown from 69 million metric tonnes in 2010 to approximately 165 million metric tonnes in 2022, indicating a substantial increase in demand for coal to support power generation and industrial activities.

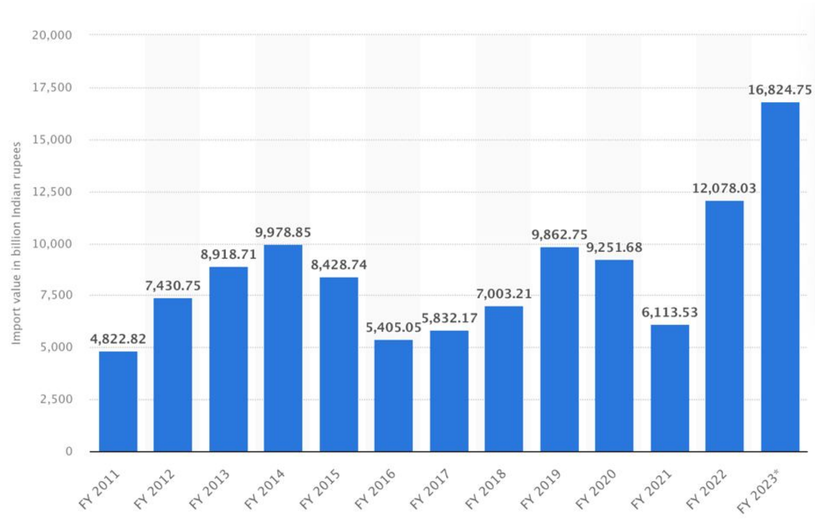


Fig. 5 Value of petroleum products imported into India from financial year 2011 to 2023

V. SOCIO-ECONOMIC FACTORS

Converting the conventional sources of energy into renewable ones is very crucial for resolving the dilemmas between energy security and environmental preservation. Among the several renewable energy technologies known today, hydrogen fuel cells and lithium-ion batteries seem to take a leading position. Although lithium-ion batteries have been dominating in many applications, hydrogen fuel cells offer significant socio-economic benefits that must be thoroughly studied.

A. *Economic Impacts*

1) *Job Creation and Economic Growth:* Hydrogen fuel cells can potentially create numerous jobs across various sectors such as manufacturing, installation, maintenance and infrastructure development. Production of hydrogen may be an opportunity for local economies to grow through using available resources and workforce hence moving from centralization in lithium-ion battery industry to more decentralized economic system.
2) *Supply Chain and Resource Utilization:* The supply chain for lithium-ion batteries is dependent on the extraction of finite minerals like cobalt, lithium, and nickel. In some cases, these resources are found in concentrated forms within a small number geographic areas thereby creating geopolitical risks and supply chain vulnerabilities. Meanwhile, hydrogen can be sourced from multiple sources including biomass, water (electrolysis) as well as natural gas hence promoting energy security through minimizing dependency on critical mineral imports.
3) *Cost Competitiveness:* Technological advancements in hydrogen production together with economies of scale have been predicted to eventually reduce costs associated with fuel cells and in turn making them cheaper compared to lithium-ion batteries. Moreover, fuel cells have a longer life span as well as lower maintenance requirements potentially leading to significant savings over time consequently making them more attractive in terms of return on investment for both end-users and businesses.

B. *Environmental and Health Benefits*

1) *Reduction of Greenhouse Gas Emissions:* Unlike lithium-ion batteries that are relatively cleaner than fossil fuels but still involve energy-intensive mining and manufacturing processes resulting in carbon dioxide emissions; hydrogen fuel cells emit nothing else other than water vapor hence offering substantial greenhouse gas reductions.
2) *Air Quality Improvement:* The adoption of hydrogen fuel cells in transportation and industrial applications could significantly improve the quality of air around us. This implies that hydrogen fuel cells are environment friendly and do not produce emissions (unlike lithium-ion batteries which may cause respiratory infections). As a result, respiratory diseases associated with air pollution that are widespread today will reduce substantially when these cells are used instead of lithium-ions batteries.

C. Social Equity and Community Benefits

1) *Energy Access and Equity:* Hydrogen fuel cells can be integrated into decentralized electricity systems, providing dependable and clean power get admission to to remote and underserved communities. This can bridge the energy divide and enhance energy equity, fostering inclusive economic improvement and improving the fine of lifestyles for marginalized populations.
2) *Community Resilience:* The implementation of hydrogen fuel cells can enhance network resilience by using diversifying strength resources and reducing vulnerability to energy supply disruptions. This is especially crucial in regions at risk of herbal disasters or geopolitical instability, in which stable and dependable electricity is crucial for restoration and stability.
3) *Empowerment Through Innovation:* The hydrogen financial system can power innovation and educational opportunities, empowering communities through skills development and information transfer. This fosters a tradition of sustainability and technological development, getting ready the personnel for destiny strength challenges and possibilities.

D. Technological Advancements and Infrastructure Development

1) *Scalability and Flexibility:* Hydrogen gasoline cells offer scalability and flexibility in various applications, from small transportable devices to big-scale energy technology. This adaptability can power technological improvements and stimulate infrastructure development, helping a numerous variety of industries and packages.
2) *Integration with Renewable Energy:* Hydrogen can serve as an powerful energy storage medium, complementing intermittent renewable energy resources such as solar and wind. This integration complements the steadiness and reliability of renewable strength structures, selling a extra sustainable and resilient power grid.
3) *Innovation in Transportation:* The transportation zone stands to benefit significantly from hydrogen gasoline cells, especially in heavy-responsibility and long-range applications wherein lithium-ion batteries face barriers. Hydrogen gas mobile motors offer longer riding stages and quicker refuelling instances, addressing key boundaries to the adoption of electric cars and contributing to the decarbonization of transportation.

E. Policy and Regulatory Support

1) *Government Incentives and Support:* Policy frameworks and authorities incentives play a important role within the adoption of hydrogen gasoline cells. Supportive guidelines which may be carried out along with subsidies, tax incentives, and studies funding those can definitely boost up the improvement and the deployment of hydrogen technology for this reason growing a good environment for investment and innovation.
2) *Standardization and Safety Regulations:* Establishing a clean fashionable and protection policies for the hydrogen manufacturing, storage, and usage is essential for gaining the general public's agree with and ensuring the safe adoption of hydrogen technology. Effective regulatory frameworks can facilitate market access and power enterprise increase, improving the socioeconomic benefits of hydrogen gas cells.

Hydrogen gasoline cells gift several socioeconomic advantages over lithium-ion batteries, from economic increase and process advent to environmental sustainability and social equity. By leveraging numerous resources, promoting cleaner air, and fostering innovation, hydrogen gasoline cells can contribute to a more resilient and equitable power destiny. Policymakers, enterprise stakeholders, and communities have to collaborate to harness the full capacity of hydrogen gas cells, ensuring a sustainable and rich transition to a low-carbon economic system.

VI. CONCLUSION

The growing transport sector in India requires a paradigm shift towards clean energy alternatives to combat air pollution and greenhouse gas emissions. Battery electric vehicles (BEVs) and fuel cell electric vehicles (FCEVs) have emerged as pioneers in this transition, each with unique advantages and disadvantages. BEVs offer superior drive efficiency, resulting in less environmental impact during operation. However, their range anxiety due to slower charging times compared to FCEVs remains a significant obstacle to greater adoption. On the other hand, FCEVs have extended range and quick fuel capacity, imitating the user experience of conventional gasoline vehicles. Furthermore, if hydrogen production is made from renewable energy sources, FCEVs can create a more sustainable resource profile. While BEVs offer promise for short-distance urban transportation because of their efficiency, FCEVs offer a convincing alternative to long-distance travel due to their extensive range and rapid fuel consumption. It is clear that BEVs and FCEVs play a role in India's clean mobility future. To achieve this future, it is necessary to overcome the limitations of each technology. For BEVs, advancing battery technology are crucial to improving range and reducing charging times. For FCEVs, the development of a robust hydrogen fuel infrastructure remains vital.

Finally, a multi-pronged approach encompassing technological progress, infrastructure development and strategic policy interventions is required to pave the way for a clean and sustainable transportation sector in India. By strategically exploiting the strengths of BEVs and FCEVs, India can navigate towards cleaner transportation futures while ensuring energy security and environmental sustainability.

REFERENCES

[1] Svante Arrhenius, On the influence of carbonic acid in the air upon the temperature of the ground, London, Edinb., Dublin Philos. Mag. J. Sci. 41 (251) (1896) 237–276.

[2] Tomiwa Sunday Adebayo, Abraham Ayobamiji Awosusi, Seun Damola Oladipupo, Ephraim Bonah Agyekum, Arunkumar Jayakumar, Nallapaneni Manoj Kumar, Dominance of fossil fuels in Japan’s national energy mix and implications for environmental sustainability, Int. J. Environ. Res. Public Health (ISSN: 1660-4601) 18 (14) (2021) http://dx.doi.org/10.3390/ijerph18147347.

[3] Mustafa İnci, Future vision of hydrogen fuel cells: A statistical review and research on applications, socio-economic impacts and forecasting prospects, Sustain. Energy Technol. Assess. (ISSN: 2213-1388) 53 (2022) 102739, http: //dx.doi.org/10.1016/J.SETA.2022.102739.

[4] Abdulfatah Abdu Yusuf, Jeffrey Dankwa Ampah, Ibham Veza, A.E. Atabani, Anh Tuan Hoang, Adolphus Nippae, Mencer T. Powoe, Sandylove Afrane, Danjuma A. Yusuf, Ibrahim Yahuza, Investigating the influence of plastic waste oils and acetone blends on diesel engine combustion, pollutants, morphological and size particles: Dehalogenation and catalytic pyrolysis of plastic waste, Energy Convers. Manage. (ISSN: 0196-8904) 291 (2023) 117312, http://dx.doi.org/10. 1016/j.enconman.2023.117312.

[5] Abdulfatah Abdu Yusuf, Jeffrey Dankwa Ampah, Manzoore Elahi M. Soudagar, Ibham Veza, Ukoba Kingsley, Sandylove Afrane, Chao Jin, Haifeng Liu, Ashraf Elfasakhany, Kasumba A. Buyondo, Effects of hybrid nanoparticle additives in n-butanol/waste plastic oil/diesel blends on combustion, particulate and gaseous emissions from diesel engine evaluated with entropy-weighted PROMETHEE II and TOPSIS: Environmental and health risks of plastic waste, Energy Convers. Manage. (ISSN: 0196-8904) 264 (2022) 115758, http://dx.doi.org/10.1016/j. enconman.2022.115758.

[6] Jeffrey Dankwa Ampah, Sandylove Afrane, Ephraim Bonah Agyekum, Humphrey Adun, Abdulfatah Abdu Yusuf, Olusola Bamisile, Electric vehicles development in Sub-Saharan Africa: Performance assessment of standalone renewable energy systems for hydrogen refuelling and electricity charging stations (HRECS), J. Clean. Prod. (ISSN: 0959-6526) 376 (2022) 134238, http://dx.doi.org/10.1016/ j.jclepro.2022.134238.

[7] Mehmet Gurz, Ertugrul Baltacioglu, Yakup Hames, Kemal Kaya, The meeting of hydrogen and automotive: A review, Int. J. Hydrogen Energy (ISSN: 0360-3199) 42 (2017) 23334–23346, http://dx.doi.org/10.1016/J.IJHYDENE.2017.02.124.

[8] Xinhai Xu, Ben Xu, Jun Dong, Xiaotong Liu, Near-term analysis of a roll- out strategy to introduce fuel cell vehicles and hydrogen stations in Shenzhen China, Appl. Energy (ISSN: 0306-2619) 196 (2017) 229–237, http://dx.doi.org/ 10.1016/J.APENERGY.2016.11.048.

[9] Simon T. Thompson, Brian D. James, Jennie M. Huya-Kouadio, Cassidy Houchins, Daniel A. DeSantis, Rajesh Ahluwalia, Adria R. Wilson, Gregory Kleen, Dimitrios Papageorgopoulos, Direct hydrogen fuel cell electric vehicle cost analysis: System and high-volume manufacturing description, validation, and outlook, J. Power Sources (ISSN: 0378-7753) 399 (2018) 304–313, http://dx.doi.org/10.1016/J. JPOWSOUR.2018.07.100.

[10] Mustafa İnci, Mehmet Büyük, Mehmet Hakan Demir, Göktürk İlbey, A review and research on fuel cell electric vehicles: Topologies, power electronic converters, energy management methods, technical challenges, marketing and future aspects, Renew. Sustain. Energy Rev. (ISSN: 1364-0321) 137 (2021) 110648, http://dx. doi.org/10.1016/J.RSER.2020.110648.

[11] Ministry of Heavy Industries, Government of India. "Faster Adoption and Manufacturing of Hybrid & Electric Vehicles (FAME) India Scheme." Retrieved from [https://fame-india.gov.in] (https://fame-india.gov.in).

[12] Press Information Bureau, Government of India. "State-wise Electric Vehicle Policies and Incentives." Retrieved from [https://pib.gov.in] (https://pib.gov.in).

[13] Bloomberg New Energy Finance. "Battery Price Survey." Retrieved from https://about.bnef.com.

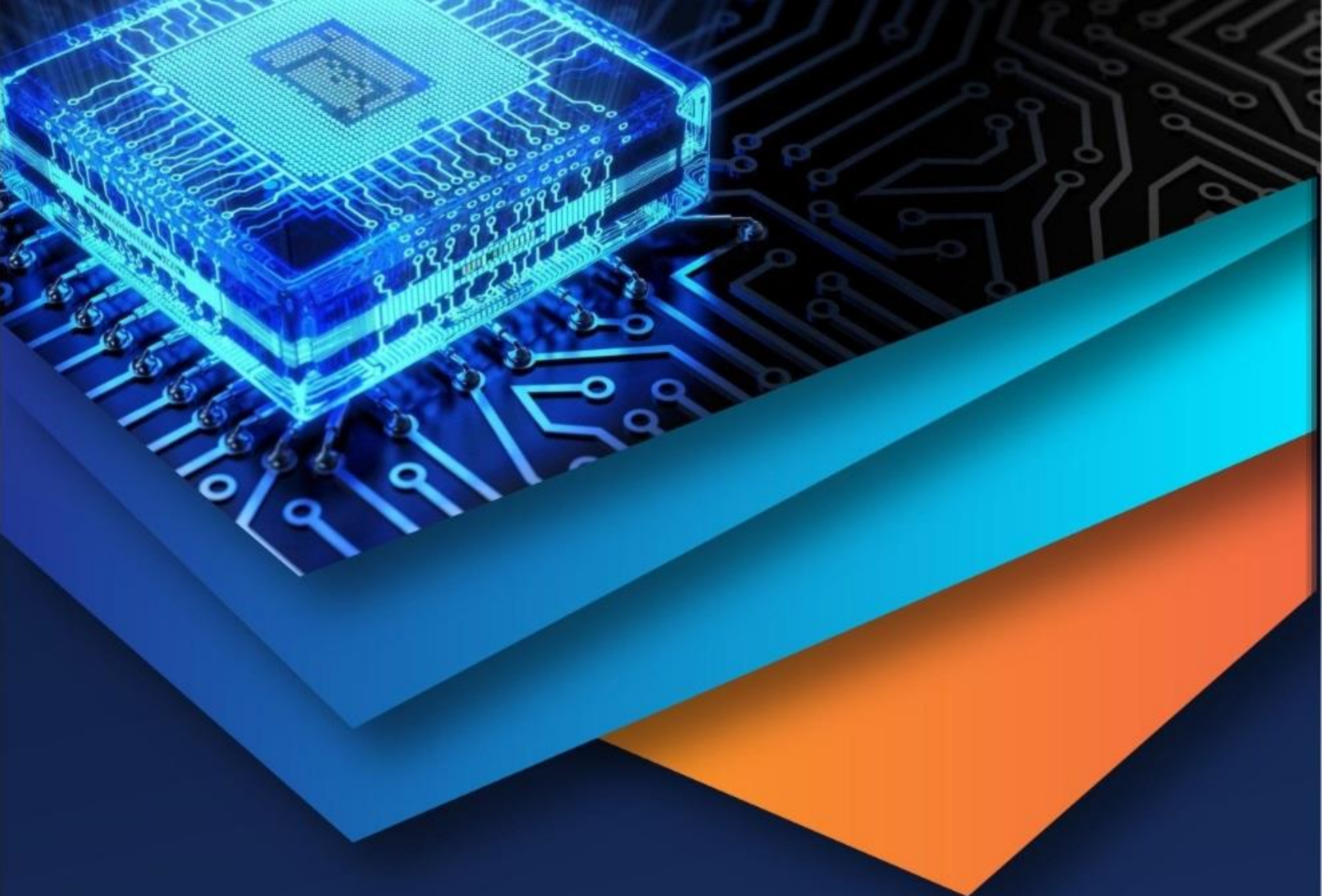
[14] Ministry of Power, Government of India. "National Electric Mobility Mission Plan (NEMMP) 2020." Retrieved from https://powermin.gov.in.

[15] International Energy Agency (IEA). "Global EV Outlook 2020: Charging Infrastructure Development." Retrieved from https://www.iea.org.

[16] International Energy Agency (IEA). "World Energy Outlook 2021." Retrieved from https://www.iea.org.

[17] Journal of Cleaner Production. "The Impact of Oil Price Fluctuations on Electric Vehicle Adoption: An Econometric Analysis." Retrieved from https://www.journals.elsevier.com/journal-of-cleaner-production.

[18] McKinsey & Company. "The Future of Battery Technologies." Retrieved from https://www.mckinsey.com



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