Research on application of electric vehicles in urban transportation systems for greenhouse gas reduction

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Abstract. While still in their fancy, electric vehicles have become a global sensation over the past decade. With the backing and high ambitions of many nations and private businesses, the number of electric vehicles sold worldwide boosted from only 0.1million in 2012 to 14 million in 2023, and still keeps an upward trend. The term "green" is frequently applied to electric vehicles, as they are believed to dramatically reduce greenhouse gas emissions and lead the way to sustainable development. This article evaluates the potential of electric vehicles to reduce greenhouse gas emissions under different scenarios for battery electric vehicles and plug-in hybrid electric vehicles. In the most ideal scenario, battery electric vehicles would replace tiny electric vehicles and plug-in hybrid electric vehicles would replace all other light-duty vehicles, including cars and trucks, with an approximate 24.8% reduction in greenhouse gas emissions. The study also points out the lack of electric vehicles needed to be improved in the future, including costs, limited driving range, battery performance, accessibility of charging infrastructure and so on. Besides, the future tendency is proposed in relation to the technological advancement of electric vehicles.

Keywords: electric vehicles, urban transportation, greenhouse gas.

1. Introduction

In twenty-first century, achieving sustainable development is no longer an option, but an inevitable path in the history of human development. Transportation is the only sector where carbon dioxide emissions are growing because of the increasing use of private vehicles [1]. The transport-related emissions not only drive climate change but are also associated with negative health impacts. As a result, it has proven to be one of the most difficult challenges facing sustainable development.

However, the significant reliance on fossil fuels remains a major obstacle to the global transformation of transportation systems, with almost 91% of the ultimate energy used in transportation still originating from oil products [2].

An extensive application mid-term solution is the introduction of Electric Vehicles (EVs) which have the potential to drastically reduce the emission of greenhouse gas, and their low noise and flexibility make them a promising replacement for traditional diesel or gasoline-powered vehicles [3]. As a result, EVs have drawn lots of attention and offer a big potential in the transportation industry. Thus, making direct and intelligent use of electricity generated from renewable sources would seem to be a sensible way to rationalize and reorganize the transportation system.

Though EVs have a number of advantages for environment and society, there are still a number of technological and financial barriers that need to be solved before the EVs can be successfully commercial used. The challenges associated with electric vehicles include its limited battery range, longer charging time, lower top speed and more expensive to purchase compared with the fossil fuel-powered vehicles. Moreover, the temperature rising at high loading and frequent changes in driving pattern cause degradation difficulties for EVs. Along with these regional concerns, other factors that affect the lifespan and efficiency of electric vehicles include the weather and fine dust particles, especially those coming from iron ore [4, 5]. This could make applying such technology in various locations less effective.

The integration of electric vehicles technologies into urban transportation systems is further complicated by the high upfront costs, complex energy management requirements, and the need for extensive infrastructure development. Additionally, achieving a 100% EV transportation system

requires addressing significant material and energy limitations, as well as optimizing the mix of different clean energy sources within vehicle batteries to balance cost and environmental impact. Hence, the scientific community is quiet interested in studying EVs in order to improve its efficiency and system longevity.

This article offers an analysis of the state of current global transportation, along with an analysis of the electric vehicle approach, present electric car models and prospects for advancement.

2. Status

2.1. Current Circumstance for GHG emission

According to the report of United Nations estimate, about 25% of the world's emissions of CO_2, which is a type of greenhouse gas, are attributed to the transportation sector, and 95% of the energy used for transportation worldwide still comes from fossil fuels [6]. Meanwhile, the transportation sector was responsible for 57% of global oil demand and 28% of world's energy consumption [6]. In order to achieve the goal of sustainable development, it's necessary to lower the transportation emissions by more than 80% from 2009 levels [7]. Since the current technologies may make it difficult for sectors like rail, aviation, and marine to accomplish their equitable reductions in share through direct electrification [8], the light duty vehicle (LDV) industry may need to make greater progress in order to meet the overall target, especially considering that road transportation accounted for 75% of CO_2 emissions from the transportation sector worldwide [9], shown as Fig 1.

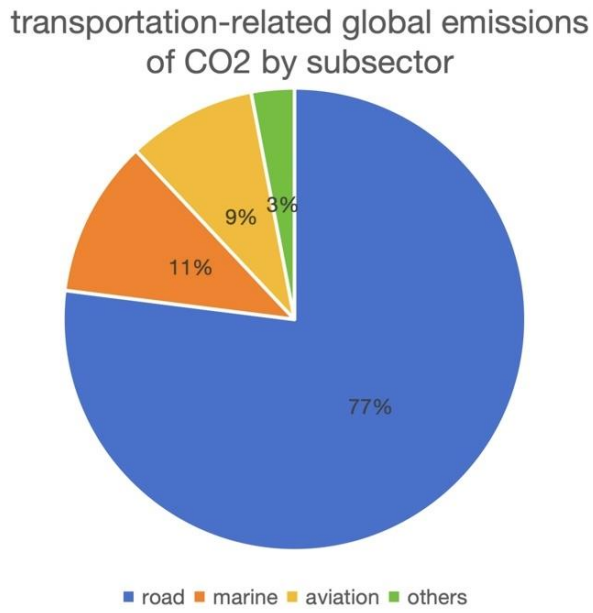


Figure 1. Transportation-related global emissions of CO_2 by sector [9]

2.2. Types of Electric Vehicles

Among various reports presented, there are mainly four types of electric vehicles: battery electric vehicle (BEV), fuel cell electric vehicle (FCEV), hybrid electric vehicle (HEV) and plug-in hybrid electric vehicle (PHEV), shown as Fig 2.

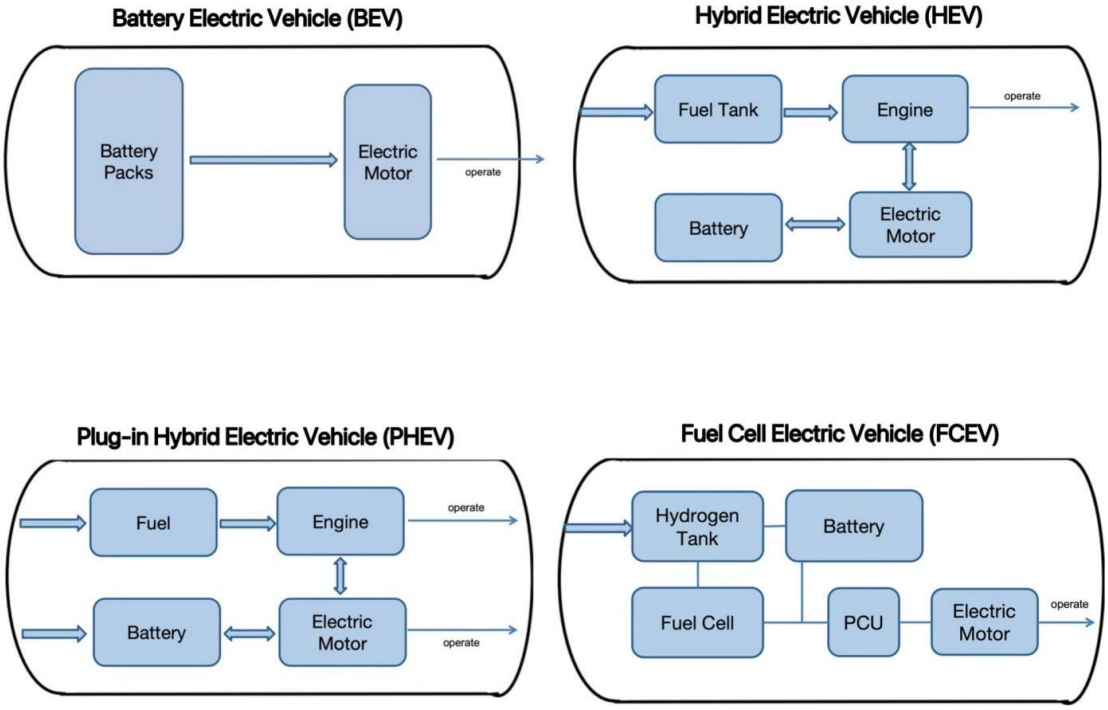


Figure 2. Types of Electric Vehicles [10]

2.2.1. Battery Electric Vehicle (BEV)

A BEV is powered entirely by electricity stored in a sizeable battery, which can be charged by connecting to the electrical grid, and then the charged battery powers the electric motors to operate the vehicle.

2.2.2. Hybrid Electric Vehicle (HEV)

A HEV is a low-emission vehicle that combines an electric motor with a gasoline engine. The electric motor is powered by batteries, while fuel drives the engine, and together, they work in unison to rotate the transmission. The wheels are subsequently driven by this.

2.2.3. Plug-in Hybrid Electric Vehicle (PHEV)

A PHEV is similar to a hybrid, but with a larger battery and electric motor. There is a choice between traditional fuels like gasoline and alternative fuels like bio-diesel. Additionally, a rechargeable battery pack power it and external charging of the battery is possible.

2.2.4. Fuel Cell Electric Vehicle (FCEV)

The FCEV, also referred to as Zero-Emission Vehicles, uses fuel cell technology to produce the electricity needed to operate. This process involves converting the chemical energy of the fuel directly into electrical energy.

In many parts of the world, like the US, governments are now supporting and subsidizing the use of plug-in hybrid electric cars (PHEVs) and battery electric vehicles (BEVs) as alternative automobiles to cut down on oil use and greenhouse gas emission [7]. It is predicted that more than 60 billion tons of CO2 could be avoided if BEVs and PHEVs made up 60% of the total number of vehicles on the road from now to 2050 [6].

3. The reduction of GHG emission achievable

The amount of GHG emission that can be reduced by using EVs is dependent on both the GHG emission generated by the power plants that charge the batteries and the market penetration potential of EVs.

Electric cars were niche items prior to 2012.However, starting in 2016, their sales surged, and by 2023, they had become mainstream, with approximately 14 million units sold, making up of nearly 16% global light vehicles sales [10], shown as Fig.3.

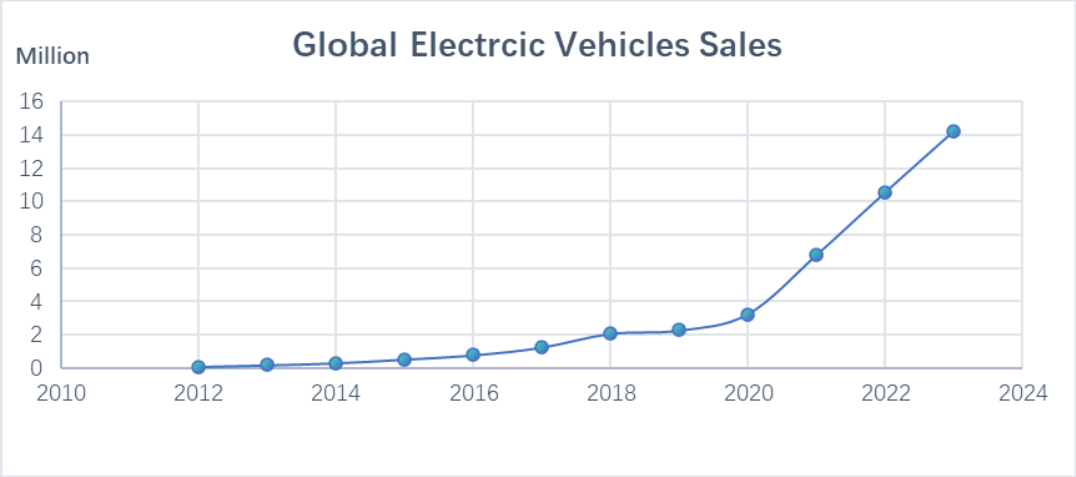


Figure 3. Global Electric Vehicles Sales between 2012 and 2023 [10]

It's worth noting that not all vehicles on the road is appropriate for a BEV, as the lithium-ion batteries currently employed in BEVs are too bulky to be utilized in long-distance cars. These batteries' mass and volume increase nonlinearly with increasing range because of a phenomenon known as "mass compounding." Based on available data, it is conservatively estimated that approximately 39.6% of all vehicles on the road can be substituted by BEVs [7,11]. While for PHEVs, the replacement rate is 100%.

Research found that up to 40% of the electricity used to charge BEV and PHEV batteries would be generated by natural gas-fired combustion turbines, with the impact on greenhouse gas emissions shown in Fig. 4 [12].

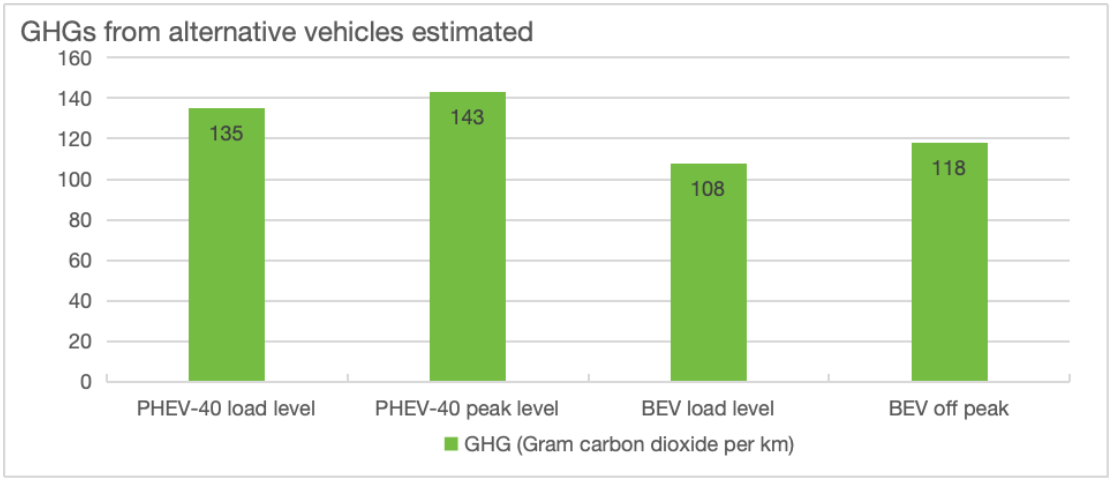


Figure 4. GHG emission from alternative vehicles estimated [12]

Combine theses data with the Ratio of PHEV and BEV for EVs (Fig. 5), we could estimate the reductions in GHG emission in 2035 across three different scenarios: (i). BEVs only; (ii). PHEVs only; (iii). BEVs for small vehicles and PHEVs for all other LDVs. The results in Fig. 6 indicate that scenario (iii) has the greatest impact on reducing greenhouse gas emissions (24.8%), followed by scenario (ii) with a reduction of 23.4% [7].

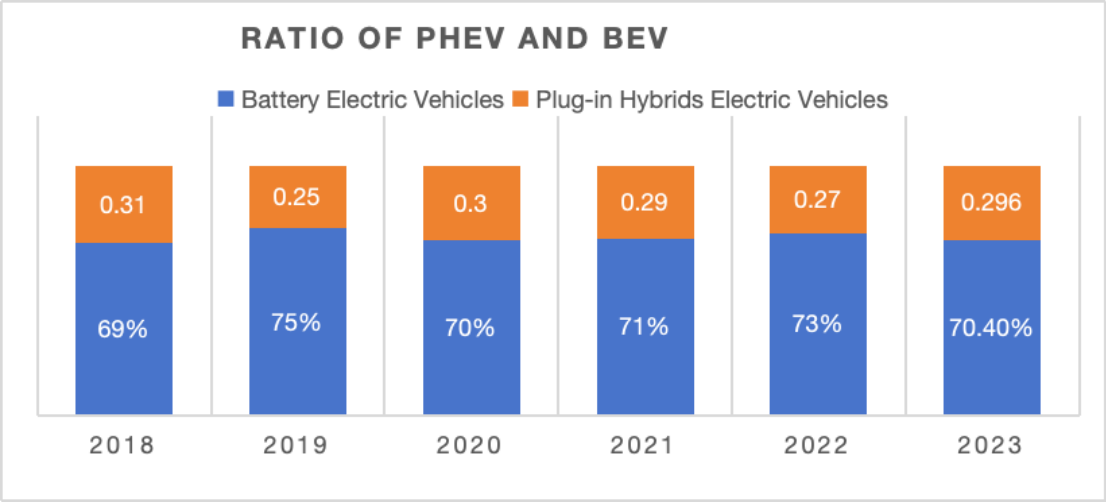


Figure 5. Ratio of PHEV and BEV from 2018 to 2023 [10]

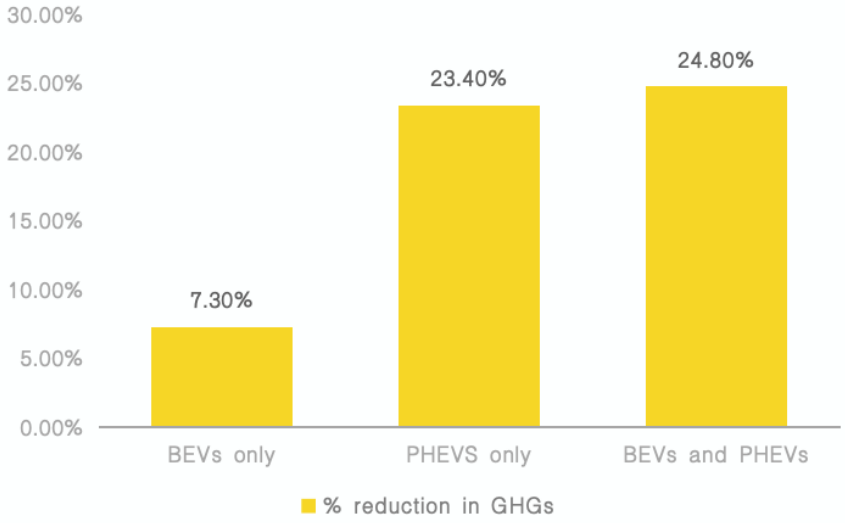


Figure 6. Predicted percentage reduction in GHG emission for 3 vehicle scenarios in 2035 [7]

4. Challenges and Future Outlook

4.1. Main Challenges

Despite the fact that the evolution and development of electric vehicles have advanced significantly, particularly in recent years, we discuss in this section the areas that remain unresolved or that merit more investigation in order to offer improved and novel solutions.

4.1.1. BEVs

For BEVs, there are several challenges to consider. First, driving ranges are typically limited, with a full charge usually allowing between 200 and 350 kilometers [13]. Second, charging times can be quite lengthy, often requiring 4 to 8 hours to fully recharge the battery pack and the poor performance of batteries in cold weather conditions (lower actual all-electric range) needs to be improved. [14]. Lastly, BEVs tend to be heavier and bulkier compared to hydrogen systems, as the battery packs are significantly larger and take up more space in the vehicle, as shown in Table 1. (Useful Specific Energy: measure the density of batteries' energy; Useful Energy Density: the amount of space a car needs to have in order to have the necessary range.)

Table 1. Batteries' useful specific energy and useful energy density in comparison to hydrogen energy storage system [7]

Energy System and Species		Useful Specific Energy (Wh/kg)	Useful Energy Density (Wh/Liter)
Batteries	Pb-A	35	95
	NiMH	75	135
	Nissan Leaf	80	200
	USABC Goal	150	230
Hydrogen energy storage System	35MPa	555	234
	70MPa	482	301

4.1.2. PHEVs

PHEVs also face several notable challenges. One issue is the limited economic efficiency, as the cost of electricity generated by PHEVs remains high [15]. Another major obstacle is the insufficient hydrogen infrastructure, which hinders market growth by limiting production, storage, and transportation capacities [16]. Furthermore, the lack of advanced technology for safely storing and distributing hydrogen complicates matters, with significant storage space requirements, non-standardized infrastructure, and high costs. Improvements in supply chain visibility and data tracking may also be needed [17].

What's more, the manufacturing of EVs and lithium-ion batteries could bring health hazards to society, this must draw governments' attention and ss a still-developing technology, the health risks of lithium-ion batteries have only recently begun to be assessed [18,19].

4.2. Looking ahead to Future

Sales of electric cars continued to rise in the first quarter of 2024, topping those of the corresponding time in 2023 by about 25% to exceed 3 million units [20]. It is predicted that the expansion will not be fairly spread across the nations of the world. Naturally, the America, China, European Union and Japan-countries with robust state backing for EVs and localized production-will contribute the most to the increase [21]. Moreover, this expansion tendency of EV market is spreading from leading cities to all cities.

In the future, GHG emission can be further decreased by producing power and hydrogen from sources with lower carbon. Renewable energy sources have great potential to produce zero-carbon hydrogen profitably. Additionally, more pathways for renewable hydrogen can be explored. (One current pathway is to convert methane from landfill gas into hydrogen. According to research conducted in America, switching to FCEVs powered by hydrogen derived from landfills or wastewater could cut transportation-related greenhouse gas emissions by 109% [7, 22].)

Researchers from multiple disciplinary may collaborate to develop a theoretically advance model by incorporating inputs from various mobility innovations like autonomous driving, connected mobility and shared mobility [23].

5. Conclusion

This study offers a comprehensive review of how electric vehicle could potentially help in reducing greenhouse gas emissions, along with its current obstacles and future perspectives. Based on the detailed analysis with the help of available research data, findings include the following. The use of gasoline and diesel in traditional vehicle operations must be restricted if governments aim to significantly reduce GHG emissions. To achieve GHG emission reductions in transportation, a diverse portfolio of alternative vehicles will be required. Currently, the most common alternatives on the market are BEVs and PHEVs. Considering, their individual benefits and drawbacks, BEVs are the more cost-effective choice, whilst PHEVs are more appropriate for drivers with high daily average

mileage or significant variation in trip distances. The scenarios of a combination of BEVs for small vehicles and PHEVs for all other LDVs and PHEVs only could achieve maximum GHG emission reductions of 24.7% and 24.2% respectively, while the BEVs only scenario results in a reduction of just 7.3%. So far, electric cars are still not entirely competitive with conventional cars since they lack a number of utilitarian and cost-effective features. With respect to the research scope, full competitiveness of EVs will be attained in the near future if technology advancement reaches its natural conclusion and policies is supported from the government. Undoubtedly, expansion of electric transport is an inevitable way toward the sustainable development of humankind, provided that it needs to be a part of a harmonized system.

References

[1] F.R. Ashik, M.H. Rahman, M. Kamruzzaman. Investigating the impacts of transit-oriented development on transport-related CO2 emissions. Transportation Research Part D: Transport and Environment, 2022, 105: 103227.

[2] OECD. Global EV Outlook 2023: Catching up with Climate Ambitions. OECD ILibrary, Paris, Organisation for Economic Co-operation and Development, 26th April, 2023. Retrieved on September 15, 2024, retrieved from www.oecd-ilibrary.org/energy/global-ev-outlook-2023_cbe724e8 - en.

[3] Pobitra Halder, Meisam Babaie, Farhad Salek, et al. Performance, emissions and economic analyses of hydrogen fuel cell vehicles. Renewable and Sustainable Energy Reviews, 2024, 199: 114543.

[4] Zhen Song, Yue Pan, Huicui Chen, et al. Effects of temperature on the performance of fuel cell hybrid electric vehicles: A review. Applied Energy, 2021, 302: 117572.

[5] Gwangryeol Lee, Jingeun Song, Yunsung Lim, et al. Energy consumption evaluation of passenger electric vehicle based on ambient temperature under Real-World driving conditions. Energy Conversion and Management, 2024, 306: 118289.

[6] Nations, United. Climate Fast Facts. United Nations. Retrieved on September 15, 2024, retrieved from www.un.org/en/climatechange/climate-fast-facts.

[7] C.E. Sandy Thomas. How green are electric vehicles? International Journal of Hydrogen Energy, 2011, 37: 6053 - 6062.

[8] D.F. Dominković, I. Bačeković, A.S. Pedersen, G. Krajačić. The future of transportation in sustainable energy systems: Opportunities and barriers in a clean energy transition. Renewable and Sustainable Energy Reviews, 2018, 82: 1823 - 1838.

[9] International Energy Agency. Greenhouse Gas Emissions from Energy Data Explorer – Data Tools. IEA, 2nd August, 2023. Retrieved on September 15, 2024, retrieved from www.iea.org/data-and-statistics/data-tools/greenhouse-gas-emissions-from-energy-data-explorer.

[10] IEA. Electric car sales, 2012-2024. IEA, Paris, 22nd April, 2024. Retrieved on September 15, 2024, retrieved from https: //www.iea.org/data-and-statistics/charts/electric-car-sales - 2012 - 2024.

[11] Davis SC, Diegel SW, Boundy RG. Transportation energy data Book: Edition 40. Retrieved on September 15, 2024, retrieved from https: //tedb.ornl.gov/data/.

[12] Ryan McCarthy, Christopher Yang. Determining marginal electricity for near-term plug-in and fuel cell vehicle demands in California: Impacts on vehicle greenhouse gas emissions. Journal of Power Sources, 2010, 195: 2099 - 2109.

[13] Xu Hao, Zhenhong Lin, Hewu Wang, et al. Range cost-effectiveness of plug-in electric vehicle for heterogeneous consumers: An expanded total ownership cost approach. Applied Energy, 2020, 275: 115394.

[14] Electric Car (EV) Charging Points UK - A Complete Guide | EDF. Retrieved on September 16, 2024, retrieved from https: //www.edfenergy.com/electric-cars/charging-points.

[15] Kotz, Andrew, Le Dong-Yeon, Elgowainy, et al. Life-Cycle Implications of Hydrogen Fuel Cell Electric Vehicle Technology for Medium- and Heavy-Duty Trucks. Journal of Power Sources, 2018, 393: 217 - 229.

[16] Peng Ren, Pucheng Pei, Yuehua Li, et al. Degradation mechanisms of proton exchange membrane fuel cell under typical automotive operating conditions, Progress in Energy and Combustion Science, 2020, 80: 100859.

[17] S. Gupta, A. Maulik, D. Das, et al. Coordinated stochastic optimal energy management of grid-connected microgrids considering demand response, plug-in hybrid electric vehicles, and smart transformers. Renewable and Sustainable Energy Reviews, 2022, 155: 111861.

[18] Nuri Cihat Onat, Murat Kucukvar, Omer Tatari. Conventional, hybrid, plug-in hybrid or electric vehicles? State-based comparative carbon and energy footprint analysis in the United States. Applied Energy, 2015, 150: 36 - 49.

[19] Alaize Dall-Orsoletta, Paula Ferreira, Géremi Gilson Dranka. Low-carbon technologies and just energy transition: Prospects for electric vehicles. Energy Conversion and Management: X, 2022, 16: 100271.

[20] IEA (2024), Global EV Outlook 2024, IEA, Paris, Licence: CC BY 4.0. Retrieved on September 17, 2024, retrieved from https: //www.iea.org/reports/global-ev-outlook-2024.

[21] Kapustin Dmitry A., Nikita O., Grushevenko. Long-term electric vehicles outlook and their potential impact on electric grid. Energy Policy, 2020, 137: 111103.

[22] Bieker, Georg. A Global Comparison of the Life-Cycle Greenhouse Gas Emissions of Combustion Engine and Electric Passenger Cars. International Council on Clean Transportation. Retrieved on September 17, 2024, retrieved from https: //theicct.org/publication/a-global-comparison-of-the-life-cycle-greenhouse-gas-emissions-of-combustion-engine-and-electric-passenger-cars/.

[23] Rajeev Ranjan Kumar, Kumar Alok. Adoption of electric vehicle: A literature review and prospects for sustainability. Journal of Cleaner Production, 2020, 253: 119911.