Key Engineering Materials
ISSN: 1662-9795, Vol. 972, pp 89-96
doi:10.4028/p-8IMGm4

Submitted: 2023-06-07
Revised: 2023-09-25
Accepted: 2023-10-10
Online: 2023-12-22

Growth in the Worldwide Stock of E-Mobility Vehicles (by Technology and by Transport Mode) and the Worldwide Stock of Hydrogen Refueling Stations and Electric Charging Points between 2020 and 2022

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Keywords: e-mobility; FCEV; BEV; PHEV; PEV; HRS; ECP.

Abstract. This study discusses the portion of fuel cell electric vehicles (FCEVs) in the worldwide stock of vehicles on roads, particularly when compared to plug-in electric vehicles (PEVs), which comprise battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs). The study considers the overall number of these e-mobility (electric mobility) vehicles, as well as within each of 4 transport modes, namely: (1) passenger light-duty vehicles (PLDVs or simply "cars"), (2) light commercial vehicles (LCVs or simply "vans"), (3) buses, and (4) trucks. The study also investigates the progress in the number of hydrogen refueling stations (HRSs) for FCEVs, and contrasts that with electric charging points (ECPs) for PEVs; during the years 2020, 2021, and 2022.

While the number of worldwide FCEVs nearly doubled in 2022 compared to 2020, the ratio of FCEVs to PEVs declined from 0.3348% in 2020 to 0.2738% (less than 0.3%) in 2022. In 2022 also, the number of FCEVs was 0.3914% (less than 0.4%) of the number of BEVs, and 0.9113% (less than 1%) of the number of PHEVs.

The worldwide fraction of PEVs with respect to the total vehicles (both electric and non-electric) in 2022 was approximately 1.816% (split into 1.2704% for BEVs and 0.5456% for PHEVs), while the fraction of FCEVs was approximately 0.0050% (only 5 FCEVs per 100,000 vehicles).

In terms of the convenience to supply the vehicles with energy, the number of worldwide hydrogen refueling stations nearly doubled in 2022 compared to 2020. Similarly, the worldwide number of electric charging points for use with PEVs nearly doubled in 2022 compared to 2020. However, the ratio of HRSs to ECPs declined from 0.0415% in 2020 to 0.0378% in 2022. The worldwide average FCEVs per HRS in 2022 was 70.69, while the worldwide average PEVs per ECP in 2022 was 9.75. Thus, PEVs are much more attractive than FCEVs for a driver concerned about the network of hydrogen stations. Furthermore, owners of PEVs have an additional option of recharging their vehicles at home (which is not applicable for FCEVs).

Between 2020 and 2022, PEVs were dominated by BEVs, with 69.95% of PEVs being BEVs in 2022. This 2022 fraction of BEVs in PEVs reflects a consistent increase from the 2021 fraction (68.34%) and from the 2020 fraction (67.23%). Considering the worldwide increase in these e-mobility vehicles from 2020 to 2022, the number of FCEVs increased by a factor of 2.072, PHEVs increased by a factor of 2.322, and BEVs increased by a factor of 2.636, PEVs increased by a factor of 2.533. Thus, out of the 3 e-mobility vehicle technologies (FCEVs, PHEVs, and BEVs), BEVs had the strongest presence as well as the fastest growth.

Introduction

Burning fossil fuels in the internal combustion engines (ICEs) of motor vehicles is an example of anthropogenic (human-caused) activities [1] that lead to emitting not only carbon dioxide (the principal greenhouse gas) that has a harmful impact on the environment [2] and causes global warming [3], but also can emit other substances such as polycyclic aromatic hydrocarbons (PAHs) and inorganic (metals or metal oxides) particulate matter (PM), that pose health risks and local air pollution [4].

Eliminating such harmful emissions from conventional vehicles is possible with zero-emission vehicles (ZEVs), which do not have any internal combustion engines but instead use electric motors.

There are two types of ZEVs, based on the source of electric energy for the onboard motor. One type is battery electric vehicles (BEVs) and the other is fuel cell electric vehicles (FCEVs). In BEVs, the source of electricity for the electric motor (or “motors”, in the case where the electric vehicle has more than one electric motor) is a large rechargeable battery pack. Lithium-ion (Li-ion) battery packs, which have high power-to-weight ratio and a small self-discharge rate, are the most common type for BEVs [5]. In FCEVs, the source of motor electricity is a fuel cell stack that uses the polymer electrolyte membrane (or proton exchange membrane, PEM) technology to generate electricity from stored hydrogen. There are two common standards for the delivery pressure of hydrogen to FCEVs, which are 350 bar (35 MPa) and 700 bar (70 MPa) [6].

Hydrogen fuel cells (with polymer electrolyte membranes) proved to be technically successful as an alternative powering source in e-mobility (electromobility or electric mobility) vehicles, thereby facilitating the electrification of ground transportation, eliminating direct carbon dioxide emissions by replacing internal combustion engines with electric motors [7]. However, the worldwide spread of hydrogen-powered vehicles remains limited, with only two models of passenger vehicles (Toyota Mirai sedan and Hyundai Nexo sport utility vehicle) available for public sales in the market as of September 2023, which indicates restricted variety compared to hundreds of plug-in electric models and more than one thousand conventional gasoline-powered models.

Plug-in hybrid electric vehicles (PHEVs) are dual-propulsion vehicles, where they have both an internal combustion engine and one or more electric motors. Like BEVs, PHEVs mostly use a Li-ion battery pack, but with a smaller energy storage capacity, such as 20% only of the energy storage capacity for BEVs of the same vehicle size [8]. PHEVs can be powered as a conventional gasoline (petrol) vehicle when the battery pack is low. PHEVs are not strictly ZEVs, since they still emit direct fossil-based carbon dioxide when using their internal combustion engines and thus when consuming gasoline (petrol). However, PHEVs are less polluting than conventional gasoline-only vehicles due to partially replacing gasoline with electricity as an energy source. Both PHEVs and BEVs need battery recharging using a dedicated socket where a recharging cable is plugged. In this study, BEVs and PHEVs together are referred to as plug-in electric vehicles (PEVs).

The public charger outlet dedicated for use with PEVs is called an electric charging point (ECP). A public charging station may have multiple ECPs. These ECPs exclude residential recharging, where the PEV owner can recharge it using a domestic electric outlet (but typically at a much slower rate). For FCEVs, a public stationary hydrogen refueling station (HRS) is used for adding hydrogen to the vehicle tank. These do not include mobile hydrogen refueling stations (mobile hydrogen refuelers). FCEVs use the hydrogen PEM type of fuel cells, which is the most suitable for mobile applications due to low operating temperatures (thus promote safety), high power density, and quick start-up [9].

Franzò et al. [10] acknowledged the significant spread of e-mobility vehicles in the past years, but they also considered their worldwide share as still small within passenger cars. They attributed this minor portion of e-mobility vehicles to economic factors, particularly the higher purchase price of these vehicles compared to internal combustion engine vehicles (ICEVs), and the lack of buyers understanding of the long-term savings due to lower operating costs associated with e-mobility vehicles compared to conventional combustion engine vehicles. These savings are related to the higher energy conversion efficiency of e-mobility vehicles [11], thus to the avoided fuel. They also emphasized the role of existing purchasing incentives in increasing the willingness of consumers to purchase e-mobility vehicles, especially BEVs.

Mohammadi and Saif [12] correlated the growth in e-mobility vehicles with the success of the global battery market, whose size for all vehicles (electric and non-electric) was estimated as 62 billion US dollars in 2014. The common battery technologies for electric-drive vehicles (EDVs), are lithium-ion (Li-ion), nickel metal hydride (NiMH), and lead-acid. These electric-drive vehicles (EDVs) include BEVs, hybrid electric vehicles (HEVs), and PHEVs. In addition to the reduced or eliminated tailpipe CO2 emissions, another important advantage of PEVs over internal combustion engine vehicles was highlighted in their study, which is the better energy efficiency and thus the reduced energy waste. They clarified this by indicating that PEVs can convert about 60% of the electrical energy received from the power source to useful mechanical energy at the wheels. Thus, about 40% of the energy is wasted. On the other hand, conventional gasoline vehicles convert about 20% only of the energy stored in gasoline to useful mechanical energy at the wheels, was. Thus, most of the fuel energy supplied is wasted.

Yang et al. [13] advocated transport electrification as an effective solution to reduce oil dependency, and to mitigate environmental impacts through reducing greenhouse gas emissions from the road transportation sector. Considering the case of Norway, the share of BEVs in the Norwegian auto market reached 64.5% in 2021. Their study findings suggest that Norwegians in urban areas (where more ECPs are available) having higher income levels and also a higher demand for travel are more likely to adopt BEVs. In their study, they brought attention to the dependence of BEVs performance on the weather, where extremely hot or extremely cold conditions cause the BEVs performance to become degraded, which impedes adoption of BEVs in such exceptional climates. Problems faced by BEVs due to very low or very high outdoor temperatures include shorter driving distances and slower charging [14].

The current study provides data-driven assessment of the share of e-mobility (electromobility) vehicles in the worldwide vehicles stock, with some emphasis on FCEVs, and how they compare with PEVs. This assessment can be useful in answering certain questions such as: What is the significance of hydrogen fuel cells in e-mobility? Has the number of FCEVs increased or decreased recently? How does the change in the number of FCEVs compare with BEVs or PHEVs? Are FCEVs more common in one transport mode (such as trucks or buses or passenger light-duty vehicles) than others? Are PHEVs equally utilized as BEVs (overall, and in a specific transport mode)? What is the share of BEVs in all (electric and non-electric) vehicles?

Research Method

The results presented here are based on data for 3 consecutive years (2020, 2021, and 2022). The main source of the raw data is the International Energy Agency (IEA), which publishes an annual comprehensive report (Global EV Outlook) about electric vehicles (EVs) [15], and also provides various types of information through its online tool (Global EV Data Explorer) [16]. The latest released Global EV Outlook (as of September 2023) is the 2023 edition, which has data up to 2022. It is worth mentioning that IEA generally uses the term electric vehicles (EVs) to refer to PEVs only (both BEVs and PHEVs), while excluding FCEVs. Although FCEVs are electrified in the sense that they use electric motors, they are not recharged from an external electric supply, but they consume a chemical fuel (hydrogen).

When processing the raw data, care was taken to present them as relative ratios or percentages (in addition to the straightforward counts), which makes them easier to interpret.

The trend in some quantities is represented by the ratio between the 2022 value and the 2020 value. If this trend ratio is between 0.901 and 1.099, the change is considered insignificant. Thus, no trend or robust behavior of either increasing or decreasing is identified in that case. This is marked by a horizontal arrow (→) next to the trend ratio. On the other hand, if the trend ratio is 1.100 or above, a trend of increase is identified, and this is visually emphasized by an upward arrow (↑) next to the trend ratio. A trend of decrease is identified when the trend ratio is 0.900 or below. Such decline is designated by a downward arrow (↓) next to the trend ratio.

Results

Before presenting the results of the study, it should be noted that IEA commonly classifies vehicles having four or more wheels based on the transport mode (the main purpose of the vehicles) into 4 modes. These transport modes include buses as one mode and trucks as another mode. For the two other modes, the transport mode PLDVs (passenger light-duty vehicles) appears in some data of IEA [17], while the transport mode cars appear in the Global EV Data Explorer of IEA. Both mode names appear in the 2023 edition of the Global EV Outlook of IEA. In the current study, it is assumed that these are the same mode. This assumption is reasonable based on examined parts of the Global EV Outlook (editions 2021 and 2023), where an additional transport mode LDVs (light-duty vehicles) appears, and it is defined as (cars and vans), a combination of two individual modes. Similarly, the transport mode LCVs (light-commercial vehicles) is assumed to be equivalent to the mode vans. Based on the fact sheet document of the EV30@30 Campaign [18]; which is a campaign to reach a 30% sales share for (BEVs, PHEVs, and FCEVs) collectively, launched under the Electric Vehicle Initiative (EVI) owned by the Clean Energy Ministerial (CEM) and coordinated by IEA; it is also reasonable to use the transport mode passenger cars as equivalent to the transport mode PLDVs.

It is clarified here that the number of vehicles or hydrogen refueling stations (HRSs) for FCEVs or electric charging points (ECPs) for PEVs are stock counts, representing the average worldwide number of units on roads during a given year. These numbers are not sales quantities.

Table 1 provides the numbers of FCEVs in each of the 4 transport modes, as well as the overall sum of these modes. LCVs have a very small portion. PLDVs represent the dominant mode for FCEVs (about 80%), while buses and truck have about 10% share each.

Table 1. Worldwide Numbers of FCEVs (overall and by transport mode)

Year	Sum (all 4 modes)	PLDVs		LCVs		Buses		Trucks	
		Count	Share in sum	Count	Share in sum	Count	Share in sum	Count	Share in sum
2020	34,798*	25,926	74.50%	49	0.14%	5,648	16.23%	3,175	9.12%
2021	51,600	42,400	82.17%	0‴	0.00%	4,800	9.30%	4,400	8.53%
2022	72,100	57,580□	79.86%	901□	1.25%	6,509□	9.03%	7,110□	9.86%
2022/ 2020	2.072↑	2.221↑		18.388↑		1.152↑		2.239↑	

* The original value given independently was 34,800. It is replaced here by the sum of the FCEVs numbers in the 4 transport modes, which is 34,798.
‴ It is possible that the actual value is not zero, but was subject to rounding to the nearest hundred.
□ The original values were slightly adjusted here to force the sum of the 4 numbers (for 4 modes) to be 72,100, which is the number given independently as a separate value (original sum was 72,000).

Table 2 is useful for comparing the number of PEVs, BEVs, PHEVs, and FCEVs relative to the overall number of vehicles (both electric and non-electric), for 2022. BEVs and PHEVs are almost passenger cars (PLDVs).

Table 2. Worldwide Shares of PEVs, BEVs, PHEVs, and FCEVs in the Total Vehicles

Transport mode	All vehicles (approximate)	Count (and % of all vehicles)			
		PEVs	BEVs	PHEVs	FCEVs
All modes	1,450,000,000 [19]	26,332,800 (1.816%)	18,421,000 (1.2704%)	7,911,800 (0.5456%)	72,100 (0.0050%)
Passenger cars (or PLDVs)	1,100,000,000 [20]	25,900,000 (2.355%)	18,000,000 (1.6364%)	7,900,000 (0.7182%)	57,580 (0.0052%)
% Passenger cars or PLDVs	75.86%	98.36%	97.71%	99.85%	79.86%

Table 3 provides details about the numbers of PEVs, BEVs, PHEVs; with a comparison between the number of FCEVs and the number of PEVs, for the PLDVs (or cars) transport mode. Tables 4, 5, and 6 have a similar structure, but are for LCVs (or vans), buses, and trucks; respectively. PHEVs are an important part of PEVs for PLDVs only. For the other 3 transport modes, PEVs are nearly BEVs. Buses are the only transport mode (among the four transport modes analyzed) where the number of either PEVs, BEVs, or PHEVs dropped in 2022 compared to 2020.

Table 3. Worldwide Numbers of PEV Cars, and Comparison with FCEV PLDVs

Year	PEVs	Ratio (FCEV PLDVs) to (PEV Cars)	BEVs		PHEVs	
			Count	Share in PEVs	Count	Share in BEVs
2020	10,200,000	0.2542%	6,800,000	66.67%	3,400,000	50.00%
2021	16,200,000	0.2617%	11,000,000	67.90%	5,200,000	47.27%
2022	25,900,000	0.2220%	18,000,000	69.50%	7,900,000	43.89%
Ratio 2022/2020	2.539↑	0.873↓	2.647↑	1.042→	2.324↑	0.878↓

Table 4. Worldwide Numbers of PEV Vans, and Comparison with FCEV LCVs

Year	PEVs	Ratio (FCEV LCVs) to (PEV Vans)	BEVs		PHEVs	
			Count	Share in PEVs	Count	Share in BEVs
2020	86,500	0.0566%	84,000	97.11%	2,500	2.98%
2021	156,300	0.0000%	150,000	95.97%	6,300	4.20%
2022	307,900	0.2923%	300,000	97.43%	7,900	2.63%
Ratio 2022/2020	3.560↑	5.160↑	3.571↑	1.003→	3.160↑	0.885↓

Table 5. Worldwide Numbers of PEV Buses, and Comparison with FCEV Buses

Year	PEVs	Ratio (FCEV Buses) to (PEV Buses)	BEVs		PHEVs	
			Count	Share in PEVs	Count	Share in BEVs
2020	73,700	7.6635%	70,000	94.98%	3,700	5.29%
2021	56,900	8.4359%	55,000	96.66%	1,900	3.45%
2022	65,400	9.9388%	63,000	96.33%	2,400	3.81%
Ratio 2022/2020	0.887↓	1.297↑	0.900↓	1.014→	0.649↓	0.721↓

Table 6. Worldwide Numbers of PEV Trucks, and Comparison with FCEV Trucks

Year	PEVs	Ratio (FCEV Trucks) to (PEV Trucks)	BEVs		PHEVs	
			Count	Share in PEVs	Count	Share in BEVs
2020	34,420	9.2243%	34,000	98.78%	420	1.24%
2021	41,000	10.7317%	40,000	97.56%	1,000	2.50%
2022	59,500	11.9328%	58,000	97.48%	1,500	2.59%
Ratio 2022/2020	1.729↑	1.294↑	1.706↑	0.987→	3.571↑	2.094↑

Considering the stationary public stations for replenishing the vehicles, Fig. 1 illustrates the increase in the worldwide number of HRSs from 2020 to 2022. It also illustrates a similar increase in the number of FCEVs. The global ratio of FCEVs per HRS in the 3 years was nearly fixed near 70.

Fig. 2 illustrates similar data but for ECPs and PEVs. The number of each of them increased in 2021 and in 2022. In addition, the figure shows the ratio of the number of HRSs to the number ECPs, which decreased in 2021 and in 2022, due to the faster expansion of ECPs compared to HRSs.

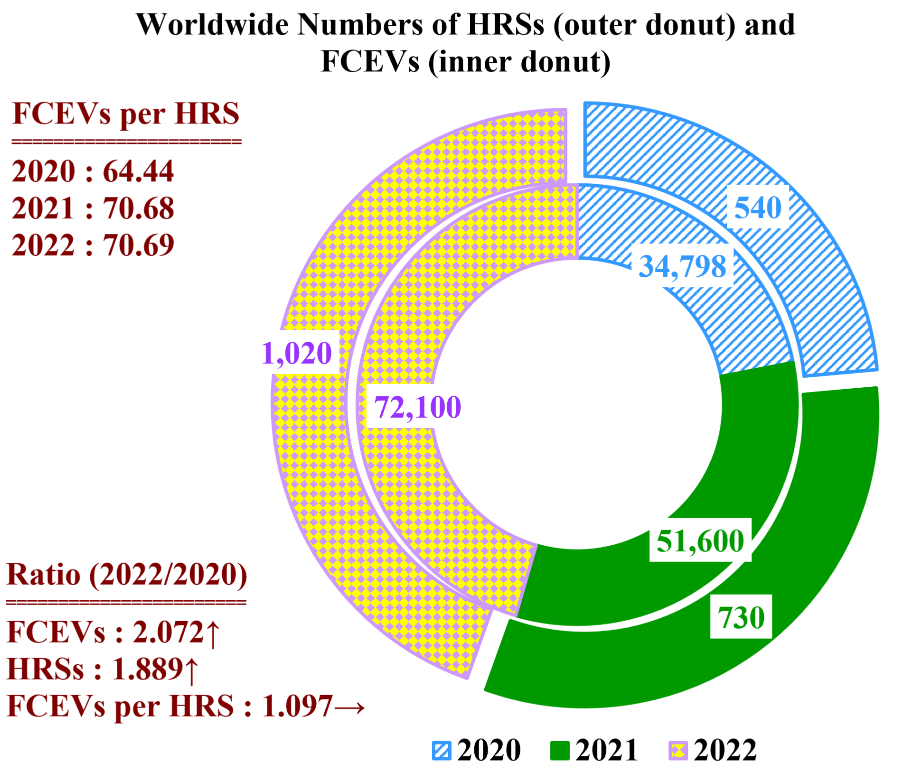

Fig. 1. Worldwide Numbers of FCEVs and HRSs in 2020, 2021, and 2022

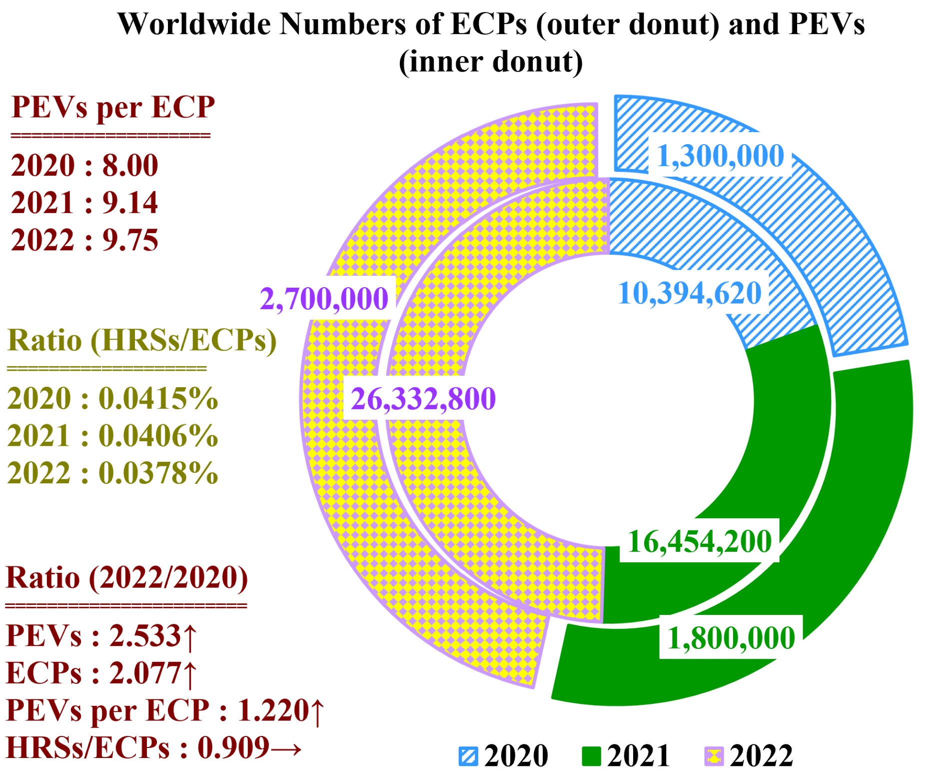

Fig. 2. Worldwide Numbers of PEVs and ECPs in 2020, 2021, and 2022; and Comparison between the Numbers of ECPs and the Numbers of HRSs

Conclusions

The worldwide stock size of the 3 types of e-mobility vehicles were discussed as well as the number of public stations for supplying hydrogen or electricity to these vehicles. The 3 types are hydrogen fuel cell electric vehicles (FCEVs), battery electric vehicles (BEVs), and plug-in hybrid electric vehicles (PHEVs).

Worldwide data for 2022 showed that the number of FCEVs was 0.3914% (72,100/18,421,000) of the number of BEVs, 0.9113% (72,100/7,911,800) of the number of PHEVs, and 0.2738% (72,100/26,332,800) of the number of PEVs (both BEVs and PHEVs combined).

The 2022 global share of FCEVs in all vehicles (either electric or not) was 0.0050%. This 2022 global share was 1.2704% for BEVs, 0.5456% for PHEVs, and 1.816% for PEVs.

For FCEVs, the number of vehicles increased in 2022 compared to 2020 for all 4 transport modes considered here: passenger light-duty vehicles (PLDVs or cars), light commercial vehicles (LCVs or vans), buses, and trucks.

For BEVs and PHEVs, the number of vehicles in 2022 increased compared to 2020 in 3 transport modes, while it decreased in the transport mode of buses for both vehicle technologies. But overall (combining the 4 transport modes), the number of BEVs increased by a factor of 2.636, and the number of PHVEs increased by a factor of 2.322. These factors are larger than the one for FCEVs, which was 2.072.

References

[1] O.A. Marzouk, Assessment of global warming in Al Buraimi, sultanate of Oman based on statistical analysis of NASA POWER data over 39 years, and testing the reliability of NASA POWER against meteorological measurements, Heliyon 7:3 (2021) E06625. https://doi.org/10.1016/j.heliyon.2021.e06625

[2] O.A. Marzouk, Compilation of Smart Cities Attributes and Quantitative Identification of Mismatch in Rankings, J. Eng. 2022 (2020) 5981551. https://doi.org/10.1155/2022/5981551

[3] O.A. Marzouk, Chronologically-Ordered Quantitative Global Targets for the Energy-Emissions-Climate Nexus, from 2021 to 2050, in: Proceedings of the 2022 International Conference on Environmental Science and Green Energy (ICESGE), 2022, pp. 1–6. https://doi.org/10.1109/ICESGE56040.2022.10180322

[4] I. Cattani-Cavalieri, S.S. Valença, M. Schmidt, Nanodomains in cardiopulmonary disorders and the impact of air pollution, Biochem. Soc. Trans. 48:3 (2020) 799–811. https://doi.org/10.1042%2FBST20190250

[5] V. Arun, R. Kannan, S. Ramesh, M. Vijayakumar, P.S. Raghavendran, M.S. Ramkumar, P. Anbarasu, V.P. Sundramurthy, Review on Li-Ion Battery vs Nickel Metal Hydride Battery in EV, Adv. Mater. Sci. Eng. 2022 (2018), 7910072. https://doi.org/10.1155/2022/7910072

[6] Z. Lin, S. Ou, A. Elgowainy, K. Reddi, M. Veenstra, L. Verduzco, A method for determining the optimal delivered hydrogen pressure for fuel cell electric vehicles, Appl. Energy 216 (2018) 183–194. https://doi.org/10.1016/j.apenergy.2018.02.041

[7] O.A. Marzouk, Urban air mobility and flying cars: Overview, examples, prospects, drawbacks, and solutions, Open Eng. 12 (2022) 662–679. https://doi.org/10.1515/eng-2022-0379

[8] I. Hsieh, W. Green, Transition to Electric Vehicles in China: Implications for Total Cost of Ownership and Cost to Society, SAE Int. J. Sustain. Transp. Energy Environ. Policy 1:2 (2020) 87–101. https://doi.org/10.4271/13-01-02-0005

[9] S. Park, D. Jung, Effect of operating parameters on dynamic response of water-to-gas membrane humidifier for proton exchange membrane fuel cell vehicle, Int. J. Hydrog. Energy 38:17 (2013) 7114–7125. https://doi.org/10.1016/j.ijhydene.2013.03.170

[10] S. Franzò, A. Nasca, V. Chiesa, Factors affecting cost competitiveness of electric vehicles against alternative powertrains: A total cost of ownership-based assessment in the Italian market, J. Clean. Prod. 363 (2022) 132559. https://doi.org/10.1016/j.jclepro.2022.132559

[11] S. Verma, G. Dwivedi, P. Verma, Life cycle assessment of electric vehicles in comparison to combustion engine vehicles: A review, Mater. Today Proc. 49:2 (2022) 217–222. https://doi.org/10.1016/j.matpr.2021.01.666

[12] F. Mohammadi, M. Saif, A comprehensive overview of electric vehicle batteries market, e-Prime Adv. Electr. Eng. Electron. Eng. Energy 3 (2023) 100127. https://doi.org/10.1016/j.prime.2023.100127

[13] A. Yang, C. Liu, D. Yang, C. Lu, Electric vehicle adoption in a mature market: A case study of Norway, Transp. Geogr. 106 (2023) 103489. https://doi.org/10.1016/j.jtrangeo.2022.103489

[14] X. Li, X. Zhao, D. Xue, Q. Tian, Impact of regional temperature on the adoption of electric vehicles: an empirical study based on 20 provinces in China, Environ. Sci. Pollut. Res. 30 (2023) 11443–11457. https://doi.org/10.1007/s11356-022-22797-0

[15] IEA [International Energy Agency], Global EV Outlook 2023, IEA, Paris, 2023.

[16] IEA [International Energy Agency], Global EV Data Explorer, https://www.iea.org/data-and-statistics/data-tools/global-ev-data-explorer.

[17] IEA [International Energy Agency], Fuel cell electric vehicle (FCEV) stock by region and by mode, 2022, https://www.iea.org/data-and-statistics/charts/fuel-cell-electric-vehicle-fcev-stock-by-region-and-by-mode-2022.

[18] CEM [Clean Energy Ministerial], EV30@30 Campaign Fact Sheet, 2019.

[19] Wheels Media, How many cars in the world, https://www.whichcar.com.au/news/how-many-cars-are-there-in-the-world.

[20] EIA [U.S. Energy Information Administration], EIA projects global conventional vehicle fleet will peak in 2038, https://www.eia.gov/todayinenergy/detail.php?id=50096.