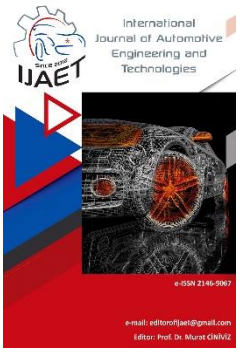
e-ISSN: 2146 - 9067

International Journal of Automotive Engineering and Technologies

journal homepage:
https://dergipark.org.tr/en/pub/ijaet



Original Research Article

A benchmarking analysis on electric vehicle emissions of leading countries in electricity generation by energy sources

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ARTICLE INFO

Orcid Numbers
1. 0000-0002-9531-3944

Doi: 10.18245/ijaet.1285587

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Received: Apr 19, 2023
Accepted: Dec 15, 2023

Published: 31 Dec 2023

Published by Editorial Board Members of IJAET

ABSTRACT

A benchmarking analysis on vehicle emissions has been performed in this study. Sport Utility Vehicle (SUV) powered by electricity is taken into consideration in emission analysis. Calculations have been conducted for leading G20 countries in certain energy sources in electricity generation. According to the analysis, most optimal results are obtained in Volatile Organic Compounds (VOC), Carbon Monoxide (CO), Particulate Matters (PM10 & PM2.5), Sulfur Oxides (SOx), and Carbon Dioxide (CO2) emissions, if the vehicle is charged in France. Only Nitrogen Oxides (NOx) emissions are calculated as to be the lowest values in Canada, compared to other countries. Emissions of an average SUV Internal Combustion Engine Vehicle (ICEV) powered by gasoline are also added to the comparison.

Keywords: Benchmarking; Electric vehicles; Electricity generation; Vehicle emissions.

1. Introduction

Although electric vehicles (EV) do not emit exhaust emissions, they have different amounts of background emissions depending on the energy sources from which the electricity of the vehicle is generated. Therefore, EVs bring about VOC, CO, NO_x, PM_{10}, $PM_{2.5}$, SO_x, and CO_2 emissions, even though there is no exhaust pipe in them at all. There are many studies on why these emissions occur and what kind of damage they cause in the literature. Kim et al. [1] and Schürmann et al. [2] found out that VOC is one of the most deteriorating emissions to the ambient air quality. Derwent et al. [3], Palli et al. [4], and Toro et al. [5] showed that it is an important ozone precursor that increases aerosol formation. In addition, its smoke is dangerous to human life. Above all, VOC smoke irritates human organs such as eyes and lungs [6, 7] and damages some crops, reducing useful agricultural products [8]. CO emissions, mainly resulting from incomplete combustion of hydrocarbon energy sources, is a highly toxic gas that causes death when exposed to high amounts [9]. NO_x emissions, which is a combination of nitric oxide and nitrogen dioxide are emitted to the atmosphere due to very high temperatures in combustion chambers of vehicle engines. Human health and the environment are significantly affected by NO_x emissions [10]. PM pollution is a common vehicle emission in the atmosphere [11] that impairs human health [12] and

disrupts the climate [13]. PM pollution affects the health of living things not only in the short term [14] but also in the long term [15], and exposure to this pollution is the sixth leading risk factor worldwide [12]. PM emissions are largely vehicle-related emissions. Many studies show the negative effects of PM_{10} emissions on human health. Some of these studies focus on children [16], some on pedestrians [17], and some on lung cancer and tuberculosis patients living in urban areas [18, 19]. $PM_{2.5}$ emissions have a great potential to increase cardiovascular and respiratory diseases worldwide [20]. SO_x, another one of the main emissions from vehicles, is also included in the literature. Its negative effects locally and globally deteriorate not only air quality and human health, but also climate change [21, 22]. Finally, carbon dioxide emissions, that is, greenhouse gas emissions, which are mentioned more in the literature than other emissions, are not actually toxic emissions, but their effects are perhaps the worst for life on Earth. Since, one of the most important problems faced by the environment in the last century is climate change, and the main reason for climate change is the increase in greenhouse gases, this problem should be addressed seriously [23, 24]. In brief, these emissions occur due to the characteristics of combustion, characteristics of the energy sources, incomplete combustion, high combustion temperatures, and oxygen deficiencies during combustion; and spread to the environment, causing damages such as various diseases, pollution, and global warming. Therefore, it is very important to reduce the mentioned emissions.

Some energy sources are frequently preferred in electricity production in the world. These are coal, nuclear, oil, natural gas, renewable wastes, hydro, geothermal, wind, and solar. While some of these energy sources cause low emissions in electricity production, some increase harmful emissions. Especially for countries with high energy consumption, which are at the top of the world economy, it is important from which source the electricity is obtained. Hence, the same vehicle causes different emissions in different countries depending on the source from which electricity is produced. In literature, several studies show that this is the case. For example, Wu and Zhang [25] report that in terms of WTW emissions in countries whose electricity grids rely heavily on thermal energy production, EVs may cause higher PM_{10}, SO_2 and NO_X emissions, although they give lower CO_2 emissions compared to internal combustion engines. Doucette and McCulloch [26] suggested that in countries such as India that produce their electricity with carbon-based fuels, EVs may lead to more CO_2 emissions than conventional vehicles. The findings in another study [27] demonstrate the advantages of using decarbonized energy sources in electricity generation to reduce emissions. According to their studies, vehicles charged in the Scandinavian countries, which produce their electricity from renewable energy sources at a higher rate, give lower emissions than those charged in the Balkan countries, which produce their electricity with more traditional methods. Sheng et al. [28] conducted an empirical study and it appeared that EVs offer the most promising results in terms of minimizing energy consumption and emissions as they clearly provide the best values among other fuel type vehicles. Garcia et al [29] found out that the emission advantages of EVs would be decreased if nuclear power plants are closed. Another study [30] that shows EVs as having lower emissions when compared to ICEVs. On the other hand, they concluded that in a country predominantly using coal-fired power plants to generate electricity, it should be focused on to decarbonize the electricity production sector. Garcia and Freire [31] showed in their review study that the electrified vehicle fleet emissions have been directly related to the electricity generation source. Wang and Tang [32] found out in their comparison study that EVs have higher carbon emissions in the production phase, but throughout the life cycle of their carbon emissions are lower than gasoline powered ICEVs.

In this study, VOC, CO, NO_x, PM_{10}, $PM_{2.5}$, SO_x, and CO_2 emissions for the cases that the EV is charged in countries that generate their electricity from different energy sources at different rates are given in the analysis. Countries that are selected from G20 with the best and worst results are presented for each

emission, also comparing to the emissions from an average gasoline powered SUV ICEV.

2. Methodology

The countries compared in this benchmarking analysis have been selected from the G20 countries, so that a small country that obtains all of its electricity from any source does not come to the fore. Since developed countries produce and consume large amounts of electricity, the improvements they will make will contribute greatly to air pollution.

In the emission analysis of the vehicle, processes of the production, transportation, storage, and filling are included with the vehicle operation by that energy source. Electricity generation shares of energy sources, which are given in Table1, are adapted exactly to the declared shares for the related year 2021 [33]. Even some reports show disorders in shares, they are utilized exactly as given by the reference. In G20 countries, South Africa is the leader coal user with 85.78% in electricity production. With 61.22%, Argentina has the highest share in natural gas, with 59.61% Canada in hydro energy, with 11.66% Australia in solar energy, with 20.80% United Kingdom in wind energy, with 30.22% Saudi Arabia in oil, and with as high as 69.33% France in nuclear energy in their electricity generations. World, G20, and OECD average shares of energy sources in electricity production are also given in the figure. The deficiencies in the shares due to some wrong data encountered in the related references are completed to 100% in the analysis using correction values, which demonstrated in the last line of the table.

Emission analysis is performed using GREET software, which determines VOC, CO, NO_x, PM_{10}, $PM_{2.5}$, SO_x, and CO_2 emission values in the study.

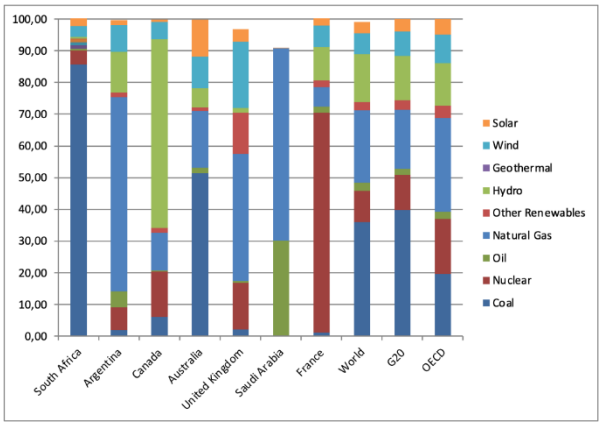

Figure 1: Percentage of the energy sources in electricity generation of the countries.

Electricity powered SUV is selected as a target vehicle to be investigated on emission basis in the analysis. SUVs are getting more attention by years in the world market. Calculation of the emissions is conducted according to the equation as follows, which is detailed by Wang [34]:

$$(TE)_i = \sum_j \left[(CE)_{i,j} + (UE)_{i,j}\right] \times (EC)_j \quad (1)$$

where, , , , and are the total emissions of pollutant i of the energy source throughput for the given process, the combustion emissions of the pollutant i of the energy source j burned, the upstream emissions of the pollutant i of the energy source j utilized to produce and distribute the energy source to the related process, and the energy consumption of the energy source j during the process, respectively. Total emissions are calculated in kg/hkm for every process of all the energy sources depleted through all the combustion and upstream emissions in kg/kJ of consumed energy in kJ/hkm according to the formula.

Table 1: Energy sources in electricity generation of the countries.

%	South Africa	Argentina	Canada	Australia	United Kingdom	Saudi Arabia	France	World	G20	OECD
Coal	85.78	1.91	6.03	51.37	2.10	0.00	1.11	35.99	39.77	19.58
Nuclear	4.27	7.10	14.35	0.00	14.80	0.00	69.33	9.84	11.07	17.33
Oil	0.64	5.20	0.45	1.76	0.50	30.22	1.94	2.53	1.87	2.36
Natural Gas	0.00	61.22	11.85	17.81	40.07	60.55	6.20	22.90	18.78	29.57
Other Renewables	0.18	1.38	1.51	1.25	12.91	0.00	2.05	2.68	2.85	3.85
Hydro	0.57	12.85	59.41	5.98	1.62	0.00	10.59	15.01	14.04	13.37
Wind	3.35	8.49	5.48	10.02	20.80	0.00	6.76	6.54	7.62	9.06
Solar	3.23	1.44	0.81	11.66	4.00	0.23	2.67	3.63	4.00	4.89
Correction	1.98	0.41	0.11	0.15	3.20	9.00	-0.65	0.88	0.00	-0.01

3. Results and Discussion

Table 2 shows VOC, CO, NO_x, PM_{10}, $PM_{2.5}$, SO_x, and CO_2 emissions of an SUV-EV in South Africa, Argentina, Canada, Australia, United Kingdom, Saudi Arabia, and France, with World, G20, and OECD averages. Emissions are given in kg/hkm in the table and the figure that shows how much emission in kg a vehicle emits in 100 km distance cruising of the vehicle. Green color demonstrates the lowest emission values, while red color shows the highest values in the table. Emissions of a reference SUV Spark Ignition (SI) ICEV are also added to the table, which can be compared to SUV EV emissions. SUV SI ICEVs have the highest emissions except NO_x, PMs, and SO_x. As South Africa generates nearly all its electricity from coal (85.78%), it has three highest emissions: PM_{10}, SO_x, and CO_2. Other emissions are also very high compared to the other countries. Argentina generates 61.22% of its electricity from natural gas. Hydro (12.85%), wind (8.49%), and nuclear (7.1%) energy sources find a comparable share in electricity mix in Argentina also. Therefore, Argentina has lower values in all emissions when compared to the other countries. Canada, where its electricity depends highly on hydro (59.41%), nuclear (14.35%), and natural gas (11.85%), has the lowest value in NO_x emissions among all the countries. It can be seen that Canada is the second environmentally friendly country in the list also. Although Australia has a big share (51.37%) of coal consumption in electricity generation, it is the leading country in solar energy to a considerable extent (11.66%) in the list, and that is because the emissions are seemed to be balanced in some degree, still close to the highest values in all emissions with no exception. United Kingdom, wind energy leader (20.80%) in the list, generates its electricity using natural gas as high as 40.07% share with comparable emissions near to the lowest values more than the highest values in all kinds of emissions except CO and CO_2. Saudi Arabia, which is famous for its worldwide oil and natural gas production, naturally also benefits from these energy sources in electricity production, thus becoming the country with the highest emissions, especially in VOC, CO, NO_x, and $PM_{2.5}$. Saudi Arabia is the leader country in oil consumption in electricity generation with a share of 30.22% compared to the countries in the list. It has also a very big share for natural gas, which is as high as 60.55%. France, on the other hand, appears to be the greenest country in the list by means of nuclear energy with the highest share (69.33%) giving the lowest emissions in VOC, CO, PM_{10}, $PM_{2.5}$, SO_x, and CO_2, leaving nuclear energy waste problems to another study. NO_x emissions are also very low in France, near to the lowest value. Finally, the list also gives information about the emissions of World, G20, and OECD averages. Although all three have similar values in emissions, OECD differs slightly from the others in a positive way. The reason for that is the average mix of the energy sources in electricity generation in OECD countries is shifting from coal to nuclear and renewable energy sources compared to the averages of world and G20 countries.

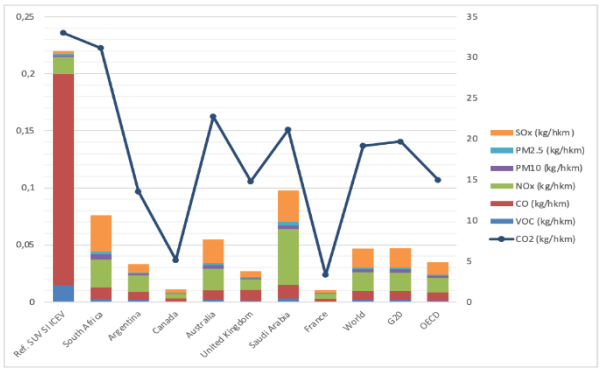

Figure 2: Emissions by countries.

Fig. 2 demonstrates VOC, CO, NO_x, PM_{10}, $PM_{2.5}$, SO_x, and CO_2 emissions of the SUV-EV in South Africa, Argentina, Canada, Australia, United Kingdom, Saudi Arabia, and France, with World, G20, and OECD averages. As clearly seen from the figure, France and Canada have the lower emissions compared to the other countries, thanks to their higher renewable energy shares in electricity production. Saudi Arabia and South Africa on the other hand, have higher emissions due to carbon-based energy source utilization in their electricity generation. CO_2 emissions draw a parallel image compared to the total emissions with slight differences in all countries. Coal in particular is responsible for high CO_2 emissions. It can be understood from the figure that Nuclear (France) and hydro

(Canada) energy sources produce lower CO_2 emissions.

Table 2: SUV emissions in the analyzed countries.

(kg/hkm)	Ref. SUV SI ICEV	South Africa	Argentina	Canada	Australia	United Kingdom	Saudi Arabia	France	World	G20	OECD
VOC	0.0148	0.0027	0.0019	0.0005	0.0021	0.0013	0.0032	0.0004	0.0019	0.0018	0.0015
CO	0.1846	0.0099	0.0070	0.0025	0.0082	0.0094	0.0117	0.0022	0.0077	0.0077	0.0069
NO_x	0.0153	0.0244	0.0147	0.0040	0.0187	0.0091	0.0490	0.0045	0.0166	0.0163	0.0129
PM_{10}	0.0014	0.0050	0.0011	0.0005	0.0033	0.0009	0.0033	0.0004	0.0026	0.0027	0.0017
$PM_{2.5}$	0.0010	0.0023	0.0010	0.0003	0.0016	0.0008	0.0030	0.0003	0.0014	0.0014	0.0010
SO_x	0.0029	0.0316	0.0073	0.0033	0.0209	0.0055	0.0275	0.0027	0.0165	0.0172	0.0109
CO_2	33.0	31.2	13.5	5.1	22.7	14.8	21.1	3.3	19.2	19.7	15.0

While CO_2 emissions vary between 31.2 and 3.3 kgs/hkm, other emissions fluctuate between the approximate values of 0.10 and 0.01 kgs/hkm. On the other hand, the reference SUV SI ICEVs appears to be ranked as the worst vehicle in terms of CO_2 and total emissions.

4. Conclusion

An emission analysis has been conducted benchmarking the leading countries in electricity generation in this study.

The leading countries have been selected from the G20 countries, so that every energy source has the highest share in electricity generation mix. Other energy resource ratios of selected countries are also included in the calculation. Electric SUVs, sales rates of which have been increasing in recent years in the world, have been chosen as the sample vehicles. Gasoline powered SUVs are also presented for comparison. The calculations have been performed using GREET software. VOC, CO, NO_x, PM_{10}, $PM_{2.5}$, SO_x, and CO_2 emissions have been taken into consideration. It can be concluded that France and Canada have been appeared to be the most environmental countries thanks to their low emission energy sources in electricity generation such as nuclear and hydro energy. Saudi Arabia and South Africa, on the other hand, have been seen as the countries that have the highest emissions due to their especially oil and coal utilization in electricity generation. It has also been revealed that SUVs with SI ICEVs have the highest CO_2 and total emissions when compared to EVs in all country selections.

EVs have no emissions when running on road, but they indirectly emit emissions according to how the electricity they are charged with is generated. Therefore, the same vehicle can have different emissions in different countries. This study has revealed that these emissions are high in countries that produce their electricity with carbon-based fuels such as coal, oil, and natural gas; while the emissions are reduced in countries that obtain their electricity from renewable energy sources such as hydro, solar, and wind. Nuclear energy also decreases VOC, CO, NO_x, PM_{10}, $PM_{2.5}$, SO_x, and CO_2 emissions, if nuclear wastes are not taken into consideration, as in this study. While electric vehicles travel on the roads without emitting harmful emissions ensures that the traffic flows in a clean air, generating the necessary electricity with clean energy sources is very important in terms of keeping the whole atmosphere clean. Here, it is important to benchmark with countries that produce their electricity with clean sources and to try to reduce emissions accordingly.

Nomenclature

CO	carbon monoxide
CO_2	carbon dioxide
EC	energy consumption
NO_x	nitrogen oxides
PM_x	particulate matters
NO_x	nitrogen oxides
SO_x	sulfur oxides
TE	total emissions
UE	upstream emissions

Greeks

$\sum$	summation

Subscripts

i pollutant of the energy source throughput for the given process

j energy source utilized to produce and distribute to the related process

5. References

1. Kim K.H., Shon Z.H., Kim M.Y., Sunwoo Y., Jeon E.C., Hong J.H., “Major aromatic VOC in the ambient air in the proximity of an urban landfill facility”, J.

Hazard Mater., 150, Pages 754-764, 2008.
2. Schürmann G., Schäfer K., Jahn C., Hoffmann H., Bauerfeind M., Fleuti E., Rappenglück B., "The impact of NOx, CO and VOC emissions on the air quality of Zurich airport", Atmos. Environ., 41, Pages 103-118, 2007.
3. Derwent R.G., Jenkin M.E., Utembe S.R., Shallcross D.E., Murrells T.P., Passant N.R., "Organic aerosol formation from a large number of reactive man-made organic compounds", Sci. Total. Environ., 408, Pages 3374-3381, 2010.
4. Palli D., Sera F., Giovannelli L., Masala G., Grechi D., Bendinelli B., Caini S., Dolara P., Saieva C., "Environmental ozone exposure and oxidative DNA damage in adult residents of Florence, Italy", Environ. Pollut., 157, Pages 1521-1525, 2009.
5. Toro M.V., Cremades L.V., Calbó J., "Relationship between VOC and NOx emissions and chemical production of tropospheric ozone in the Aburrá Valley (Colombia)", Chemosphere, 65, Pages 881-888, 2006.
6. Durmusoglu E., Taspinar F., Karademir A., "Health risk assessment of BTEX emissions in the landfill environment", J. Hazard Mater., 176, Pages 870-877, 2010.
7. WHO, "Air quality guidelines for Europe", European Series, 91, WHO Regional Publications, Copenhagen, Denmark, 87-91, 2000.
8. Bortolin R.C., Caregnato F.F., Divan Junior A.M., Reginatto F.H., Gelain D.P., Moreira J.C.F., "Effects of chronic elevated ozone concentration on the red oxstate and fruit yield of red pepper plant Capsicum baccatum", Ecotoxicol Environ. Saf., 100, Pages 114-121, 2014.
9. Aldossary M., Almadni O., Kharoshah M., Alsaif D., Alsowayigh K., Alfaraidy M., "Carbon monoxide toxicity in Dammam, KSA: Retrospective study", Egyptian Journal of Forensic Sciences, 5, Pages 36-38, 2015.
10. Alcantara V., Padilla E., Piaggio M., "Nitrogen oxide emissions and productive structure in Spain: an input-output perspective", J. Clean. Prod., 141, Pages 447-461, 2017.
11. Sharma M., Dikshit O., "Comprehensive study on air pollution and green house gases (GHGs) in Delhi", A report submitted to Government of NCT Delhi and DPCC Delhi, 1-334, 2016.
12. GBD 2015 Risk Factors Collaborators, "Global, regional, and national comparative risk assessment of 79 behavioral, environmental and occupational, and metabolic risks or clusters of risks, 1990-2015: a systematic analysis for the Global Burden of Disease study", 2015 Lancet., 388, Pages 1659-1724, 2016.
13. Von Schneidemesser E., Monks P.S., Allan J.D., Bruhwiler L., Forster P., Fowler D., Lauer A., Morgan W.T., Paasonen P., Righi M., Sindelarova K., Sutton M.A., "Chemistry and the linkages between air quality and climate change", Chem. Rev., 115, Pages 3856-3897, 2015.
14. Díaz-Robles L., Cortés S., Vergara-Fernández A., Ortega J.C., "Short term health effects of particulate matter: a comparison between wood smoke and multi-source polluted urban areas in Chile", Aerosol Air Qual Res., 15, Pages 306-318, 2015.
15. Hampel R., Peters A., Beelen R., Brunekreef B., Cyrys J., de Faire U., "Long-term effects of elemental composition of particulate matter on inflammatory blood markers in European cohorts", Environ. Int., 82, Pages 76-84, 2015.
16. Chen Z., Cui L., Cui X., Li X., Yu K., Yue K., Zhang J., "The association between high ambient air pollution exposure and respiratory health of young children: a cross sectional study in Jinan, China", Sci. Total. Environ., 656, Pages 740-749, 2019.
17. Qiu Z., Song J., Hao C., Li X., Gao H.O., "Investigating traffic-related PM exposure on and under pedestrian bridges: a case study in Xi'an, China", Atmos. Pollut. Res., 9, 5, Pages 877-886, 2018.
18. Popovic I., Magalhaes R.J.S., Ge E., Marks G.B., Dong G., Wei X., Knibbs L.D., "A systematic literature review and critical appraisal of epidemiological studies on outdoor air pollution and tuberculosis outcomes", Environ. Res., 170, Pages 33-45, 2019.
19. Stabile L., Massimo A., Rizza V., D'Apuzzo M., Evangelisti A., Scungio M., Buonanno G., "A novel approach to evaluate the lung cancer risk of airborne particles

emitted in a city", Sci. Total. Environ., 656, Pages 1032-1042, 2019.
20. Anderson J.O., Thundiyil J.G., Stolbach A., "Clearing the air: a review of the effects of particulate matter air pollution on human health", J. Med. Toxicol., 8, Pages 166-175, 2012.
21. Aksoyoglu S., Baltensperger U., Prévôt A., "Contribution of ship emissions to the concentration and deposition of air pollutants in Europe", Atmos. Chem. Phys., 16, Pages 1895-1906, 2016.
22. Costa S., Ferreira J., Silveira C., Costa C., Lopes D., Relvas H., Borrego C., Roebeling P., Miranda A.I., Teixeira J.P., "Integrating health on air quality assessment - review report on health risks of two major European outdoor air pollutants: PM and NO_2", J. Toxicol. Environ. Health B., 17, Pages 307-340, 2014.
23. Friedrich T., Timmerman A., Tigchelaar M., Elison Timm O., Ganopolski A., "Nonlinear climate sensitivity and its implications for future greenhouse warming", Sci. Adv., 2, e1501923, Nov 9, Pages 1–11, 2016.
24. Valadkhani A., Smyth R., Nguyen R., "Effects of primary energy consumption on CO_2 emissions under optimal thresholds: Evidence from sixty countries over the last half century", Energy Economics, 80, Pages 680-690, 2019.
25. Wu Y., Zhang L., "Can the development of electric vehicles reduce the emission of air pollutants and greenhouse gases in developing countries?", Transport Res. Part D: Transport and Environ., 51, Pages 129-145, 2017.
26. Doucette R.T., McCulloch M.D., "Modeling the CO_2 emissions from battery electric vehicles given the power generation mixes of different countries", Energy Pol., 39, 2, Pages 803-811, 2011.
27. Kucukvar M., Onat N.C., Kutty A.A., Abdella G.M., Bulak M.E., Ansari F., Kumbaroglu G., "Environmental efficiency of electric vehicles in Europe under various electricity production mix scenarios", J. Clean Prod., 335, 130291, 2022.
28. Sheng M.S., Sreenivasan A.V., Sharp B., Du B., "Well-to-wheel analysis of greenhouse gas emissions and energy consumption for electric vehicles: A comparative study in Oceania", Energy Policy, 158, 112552, 2021.
29. García A., Monsalve-Serrano J., Martinez-Boggio S., Soria Alcaide R., "Carbon Footprint of Battery Electric Vehicles Considering Average and Marginal Electricity Mix", Energy, 268, 126691, 2023.
30. Xia X., Li P., Xia Z., Wu R., Cheng Y., "Life cycle carbon footprint of electric vehicles in different countries: a review", Separation and Purification Technology, 301, 122063, 2022.
31. Garcia R., Freire F., "A review of fleet-based life-cycle approaches focusing on energy and environmental impacts of vehicles", Renew. Sust. Energ. Rev., 79, Pages 935–945, 2017.
32. Wang N., Tang G., "A review on environmental efficiency evaluation of new energy vehicles using life cycle analysis", Sustainability, 14, 3371, 2022. https://ourworldindata.org/electricity-mix.2021, 24/03/2023.
33. Wang M.Q., "GREET 1.5 - Transportation Fuel-Cycle Model. Volume 1: Methodology, Development, Use, and Results", 1999.