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Original Article

Studying the Carbon Footprint of Carbon Dioxide Gas Coming Out of Chimneys and Electricity Production of Zahedan Gas Power Plant

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Abstract

Background & Aims: The carbon footprint is one of the parameters that can be used to estimate the amount of pollution caused by carbon dioxide compounds. This research was conducted to evaluate and estimate the carbon footprint resulting from the carbon dioxide emissions of the Zahedan Gas Power Plant due to the consumption of fossil fuels and electricity production.

Materials and Methods: Carbon dioxide was read directly in the vicinity of the exhaust chimneys. In each studied season (spring, summer, or autumn), carbon dioxide was measured with 3 repetitions. TESTO (model 350, Germany) was utilized to measure carbon dioxide gas. The carbon footprint was estimated and evaluated by the IPCC method. To calculate the per capita carbon footprint, the population of Zahedan was considered based on the last census in 2021, which was 770 800 people.

Results: The total carbon dioxide emissions in the spring and summer of 2021 were 15.22 and 9.41 ppm, respectively. It was 12.44 and 20.37 ppm in the spring and autumn of 2022, and 21.49 ppm in the summer of 2023. The highest per capita carbon dioxide emission and intensity of carbon dioxide emission (2240.89 and 288.73, respectively) were obtained from the consumption of oil and gas in the year 2021 for electricity generation in the Zahedan Gas Power Plant.

Conclusion: Zahedan Power Plant has used oil and natural gas to produce electricity, and the consumption of natural gas was higher than that of oil gas in the two years under study. The amount of carbon dioxide emissions in 2021 from the consumption of natural gas was higher than that of oil gas. In addition, the amount of carbon dioxide emissions in 2021 was higher than in 2022. According to the results, carbon dioxide emissions increased in 2023 and 2022 compared to 2021.

Keywords: Air pollution, Carbon footprint, Carbon dioxide, Fossil fuels, Gas power plant

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1. Introduction

Power plants that use fossil fuels for their processes [1] produce various pollutants, such as sulfur dioxide, nitrogen oxides, carbon dioxide, carbon monoxide, lead, cadmium, and particulate matter [2].

More than 40% of carbon dioxide emissions from fossil fuels are generated by power plants that burn fuel for electricity production [3]. Carbon compounds are one of the common pollutants in power plants that are considered greenhouse gases (GHG) and cause climate change and global warming [4].

One of the most dangerous and harmful effects of fossil-fuel power plants is global warming, which is mainly due to GHG emissions, causing widespread climate change and global warming [5,6], the details of which are provided in Table 1.

The consequences of rising GHGs and global warming include rising air temperatures, rising sea and ocean levels, severe rainstorms, drought, and loss of animal and plant species [4].

In addition to the threat of climate change and global warming, GHGs also endanger the health of humans and living organisms [7].

Various studies have reported the harmful and adverse effects of air pollutants caused by power plants on human health, ultimately causing asthma, allergies, carcinogenicity, and, in chronic cases, premature death in humans [8-10].

Carbon footprint is a term used to estimate air pollution based on the emissions of carbon compounds such as carbon dioxide, carbon monoxide, and methane [11].

The term carbon footprint actually derives from the term ecological footprint utilized in the 1990s and is a measure of the total amount of carbon compound output associated with a given population, system, or activity, taking into account all resources, subsides, and storage within the time and place of that population, system, or activity [12].

Carbon footprint is an indicator that shows the effect of activities on the production of carbon dioxide produced by the consumption of fossil fuels and is expressed as the weight of carbon dioxide produced per tonne [13]. It has

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one of the most important and dangerous impacts on the environment, safety, and health of the human environment [14]. The main contributor to global warming is the carbon dioxide emissions from the combustion of fossil fuels, producing approximately 4 g of carbon dioxide for every g of combusted carbon and can contain 60%–80% carbon, depending on the fuel [15].

Gas fuel is now known as one of the cleanest types of fuel. This type of fuel is available as natural gas in the vicinity of crude oil tanks or gases produced in refineries or chemical processes. Natural gas is the best fuel ready to use, with a mixture of 80–90% methane, and the remaining 20–10% is mainly ethane and other gases such as propane/butane and nitrogen. Impurities, such as carbon dioxide and sulfur hydrogen dioxide, and organic sulfur compounds of 1% are also present in natural gas. The gas consumed by the power plants is transferred to the site through pressurized gas pipes, and after reducing the gas pressure and passing through the cyclones, it is directly transferred to the burners [16].

Several studies have been conducted on carbon footprints in different countries around the world [3,7,11-13]. Moreover, many studies have been performed in Iran in this regard, which can be mentioned from this research group to estimate the carbon emissions from fossil fuel consumption during the years 1927–2015 in Iran (16), due to electricity consumption and fossil fuels during the years 2010–2015 in Ahvaz [17,18], and evaluate the carbon footprint and its relationship with energy consumption in the Yadavaran oil field of Khuzestan province [19-21]. The issue of pollution and increased carbon dioxide emissions has become a global concern, and natural and human resources are causing carbon dioxide emissions. Natural resources include decomposition, release from the oceans, respiration, and photosynthesis. Respiration is a process in which organisms release energy from food and emit carbon dioxide. Photosynthesis, the biochemical process by which plants and some microbes produce food, acts as a natural counterpart to breathing by absorbing carbon dioxide from the atmosphere. Carbon dioxide emissions from human activities are also a major factor, as they change global average temperatures [22]. Therefore, this study aimed to evaluate and estimate the carbon footprint of the Zahedan Gas Power Plant due to fossil fuel consumption and electricity generation and compare it with the total costs of power plants in the country.

Table 1. Global warming potential value of greenhouse gases

Gas	Chemical	Global warming potential
Carbon dioxide	CO_2	1
Methane	CH_4	25
Nitrogen oxides	N_2O	298
Hydro chlorofluorocarbons	HCFCs	124-14800
Chlorofluorocarbons	CFCs	4760-14400

Materials and Methods

This study was performed at the Zahedan Gas Power Plant in 2021, 2022, and 2023. This plant is located in Sistan and Baluchestan Province, 5 km from Zahedan Gloorband Road, which was first put into operation in 1986 (Figure 1). One of Iran's power plants is gas-fired with a production capacity of 2262 MW, which includes 9 units of the Frame 5 model. Zahedan Power Plant is a construction of Hitachi, Brown Bowery, and AEG, and its fuel type is natural gas and oil gas.

Gas exhaust chimneys were sampled according to the US Environmental Protection Agency method [24] per day with a calm and sunny climate at an altitude of 4 meters above the ground (Table 2). The dioxide crane was read directly in the exhaust chimneys. In each study season (spring, summer, or autumn), CO_2 was estimated with 3 replications.

TESTO (model 350, Germany) was employed to measure carbon dioxide gas. For measurement, the device was controlled from every point of view, and it was ensured that the device was perfect for battery-charging and calibration. By asking the corresponding person responsible for the temperature of the chimney outlet, it was ensured that its temperature was not higher than the temperature tolerance range of the probe of the device and did not cause damage to the temperature sensor, or filter probes were used if the flue dust was high.

After the reliability and lack of a problem for measurement, the probe was connected to the device, and the device was turned on. After the Auto Zero stage, which may last from 30 seconds to several minutes, the probe was placed in the standard position, and the pump of the device was started. The results were saved after waiting for the numbers to be fixed and the measurements to be completed. To re-measure, it is necessary to zero in the next stations to obtain more accurate numbers.

The amounts of fuel consumed and power generated by Zahedan and the country's power plants were collected using statistical yearbooks [25,26]. The carbon footprint of fossil fuel consumption is an indirect emission; therefore, carbon dioxide emissions from oil and natural

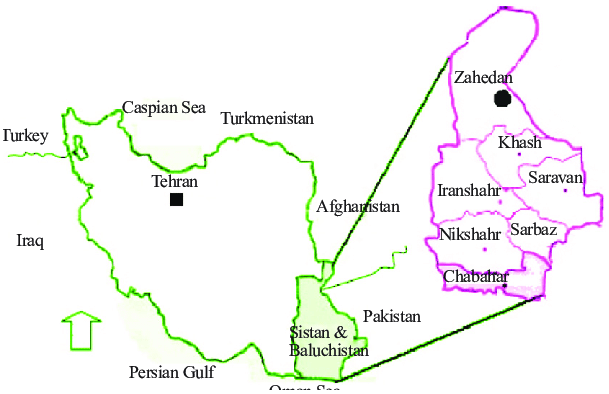

Figure 1. Geographical Location of Zahedan. *Source*. Mahjoob et al [23]

gas consumption were calculated from relation 1 [27]:

$$CO_2\ Emissions = Activity\ Data\ (AD) \times Emission\ Factor\ (EF) \quad (1)$$

This relationship represents the amount of fossil fuel consumption collected from the statistical yearbooks [25,26], as well as the emission coefficient presented in Table 3 [28].

Considering the total carbon footprint emissions from the Carbon dioxide from electricity production per year was obtained based on relation 2 [28]:

$$C_t = \sum_j \frac{C_{it}}{G_{it}} \frac{G_{it}}{G_t} \frac{G_t}{Y_t} Y_t \quad (2)$$

In this regard, *Ct* is the total CO_2 emissions of the power industry in year C_{it}, and *t* denotes the CO_2 emissions of power plant *i* in year C_{it}. In addition, *t* represents electricity generation *i* in year *Yt*, and *t* is the added value of the electricity industry in year *Cit/Git*. Further, *t* indicates the intensity of the CO_2 generation of electricity, and *Git/Gt* is the share of power generation of power plant *i*. Finally, *Gt/Yt* denotes the intensity of electricity in year *t* [28].

Per capita carbon footprint and CO_2 emissions were obtained from relations 3 and 4 [27]:

$$Carbon\ Emission = Total\ Carbon\ Emission \div Total\ Number\ of\ Staff \quad (3)$$

Table 2. Specifications of the sampling location of exhaust gases at the Zahedan Power Plant

Chimney	Chimney height	Sampling height	Longitude	Latitude
1	6 m	4 m	60.48° 22′ 67″	29.28° 32′ 12″
2	6 m	4 m	60.48° 19′ 20″	29.28° 32′ 50″
3	6 m	4 m	60.48° 20′ 89″	29.28° 31′ 59″
4	6 m	4 m	60.48° 19′ 93″	29.28° 32′ 80″
5	6 m	4 m	60.48° 23′ 18″	29.28° 32′ 34″
6	6 m	4 m	60.48° 23′ 45″	29.28° 32′ 10″
7	6 m	4 m	60.48° 23′ 45″	29.28° 32′ 10″
8	6 m	4 m	60.48° 24′ 72″	29.28° 32′ 28″
9	6 m	4 m	60.48° 24′ 74″	29.28° 32′ 52″

Table 3. Carbon dioxide emission coefficient from natural gas consumption in power plants

Release Source	diffusion Coefficient	Unit	
Natural gas	0.0556	Ton CO_2/MMBTU	API/DEFRA
Natural gas	0.0542	Ton CO_2/MMBTU	AGO
Natural gas	0.0532	Ton CO_2/MMBTU	IPCC
Gas oil	2.68	Kg CH_4/L fuel	CAPP

API, American Petroleum Institute; DEFRA, Department for Environment, Food, and Rural Affairs; AGO, Automotive Gas Oil; IPCC, Intergovernmental Panel on Climate Change; CAPP, Canadian Association of Petroleum Producers.
Source. Ahmadi Moghadam et al [28].

$$The\ Intensity\ of\ CO_2 = CO_2\ Emissions \div Energy\ Consumption \quad (4)$$

In this regard, carbon emissions per capita, total carbon emissions, total number of staff, intensity of CO_2, CO_2 emissions, and energy consumption [27].

Total energy consumption was obtained from relation (5), in which Total Energy Consumption TEC in terms of GJ. Moreover, *ei* is the actual amount of energy consumption, and *pi* represents the factor of the type of energy consumed [29]:

$$Total\ Energy\ Consumption = £\ e_i \times p_i \quad (5)$$

To calculate the ecological footprint, first, the annual consumption per capita of the main consumables was obtained based on the total data and divided by total consumption by population. Then, the average of the total ecological footprint of each person was computed by collecting all the ecosystem areas assigned to each person, and finally, the ecological footprint for the population of each planned area was calculated based on relation 6 [29]:

$$EF_P = EF \times N \quad (6)$$

The data were analyzed, and carbon footprint relationships were computed using Excel 2007 software. The tables were also drawn with the help of this software.

Results

The CO_2 emissions from the fumes of Zahedan Gas Power Plant in 2021, 2022, and 2023 are presented in Table 4. The highest emission in 2023 came from chimney No. 4 at 3/20 ppm.

Total CO_2 emissions during one day in the spring and summer of 2021 were 15.22 ppm and 9.41 ppm, respectively. The corresponding values were 12.44 ppm in spring and autumn 2022 and 20.37 ppm in the summer of 2023, respectively. In addition, it was 21.49 ppm in the

Table 4. Carbon Dioxide Emissions (ppm) From the Chimneys of Zahedan Power Plant

Chimney	2021		2022		2023
	Spring	Summer	Spring	Autumn	Summer
1	1.63	1.41	0.94	2.46	2.63
2	1.47	0.59	0.92	2.50	2.62
3	1.67	1.06	1.42	2.45	2.56
4	1.17	0.74	3.03	3.02	3.20
5	2.34	1.21	1.29	2.45	2.60
6	2.40	1.51	1.35	2.50	2.61
7	2.08	2.04	1.19	2.46	2.62
8	1.46	0.85	2.30	2.53	2.65
9	1	0.80	1.99	2.54	2.66
Total	1998.57	1833.30	1156.92	875.13	1415.46

summer of 2023, which is for 3 months in each period. According to the results, carbon dioxide emissions increased in 2023 and 2022 compared to 2021.

In this study, to measure the per capita carbon footprint, the population of Zahedan was considered based on the last census in 2021, which was 770 800. The total CO_2 emissions for one year were calculated. Fossil fuel consumption and electricity generation at the Zahedan Gas Power Plant are presented for 2021 and 2022. Zahedan Power Plant used two fuels (i.e., oil and natural gases) to generate electricity, which consumed more natural gas than oil gas in the two studied years (Table 5).

CO_2 emissions in 2021 from natural gas consumption were higher than oil. CO_2 emissions in 2021 were higher than in 2022. The highest CO_2 emissions per capita and CO_2 emissions were 1742.58 and 288.73, respectively, from oil consumption in 2021 for electricity generation at Zahedan Gas Power Plant (Table 6).

Discussion

Carbon dioxide is one of the compounds in the exhaust gases of industrial and manufacturing plants and is probably the most important pollutant of air and GHGs from human activities. Different amounts of carbon dioxide (0.3–5.20 ppm) obtained from the chimneys of the Zahedan Gas Power Plant were measured and determined in this study. Researchers reported CO_2 emissions from power plants such as Ramin Power Plant (12 600 tons per day), Abadan Gas Power Plant (4.26 μg/m^3), Genaveh Combined Cycle Power Plant (CO_2 466 kW/eq), coal-fired power plants (968 g/kWh), and combined cycle sites (579 g/kWh) [30-33]. Power plants discharge a large amount of carbon dioxide and carbon monoxide into the air in different parts of the country due to the factors of pollution from fossil fuels, which have been measured practically and theoretically. Other studies have reported carbon dioxide emissions from the chimneys of the food industry, as well as rubber and chemical production [34-37]. According to the results, carbon dioxide emissions increased in 2023 and 2022 compared to 2021. One study reported that CO_2 emissions from oil consumption were higher compared to other fossil fuels [16].

After petroleum, gasoline had the highest carbon dioxide emissions. The amount of fuel oil and kerosene was followed by carbon dioxide emissions. Considering the increasing consumption of fossil fuels and increasing carbon emissions, air pollution, and global warming, it is recommended that management strategies are provided for the optimal use of fossil fuels, and clean and renewable energies such as wind and solar energies are replaced with the existing ones [16]. One of the most important pollutants in the energy consumption sector is air pollution due to emissions and leakage of pollutant gases caused by burning fossil fuels [17]. Regarding the effect of hydroelectric energy consumption on CO_2 emissions, ecological footprint, and carbon footprint in Iran, the estimation of the models indicated that there is a long-term relationship between the variables considered in these models. It demonstrates that there is a significant negative relationship between hydroelectric energy consumption and carbon dioxide emissions and carbon footprints in the short and long term. In other words, the use of hydroelectric power in the short- and long-term leads to a reduction in carbon footprint and carbon dioxide emissions. Moreover, hydroelectric power has an impact on the ecological footprint in the short term [38]. Another study reported higher carbon dioxide emissions from oil consumption than from other fossil fuels [39], confirming the results of this research.

The CO_2 emissions from electricity generation in 2022 at Zahedan Gas Power Plant were 1 343 183 554.98 tons per year. The researchers reported that about 40% of carbon dioxide emissions were attributed to power generation in power plants [40,41].

Currently, the electricity industry, with about 30% of the country's GHG emissions, is the most serious cause of the production of these gases; thus, reducing the amount of emissions in the electricity sector can have a significant impact on reducing the country's overall emissions [42].

Considering that the power generation industry is a

Table 5. Fuel Consumption and Electricity Production of the Zahedan Gas Power Plant

Fuel Type	Unit	2022	2023
Gas/oil consumption	L	4561394	3406860
Electricity production	MW	11057	7916
Consumption of natural gas	M^3	491432590	527864110
Electricity production	MW	1212481	1306999
Total of electricity production	MW	1223538	1314915

Table 6. Evaluation of the carbon footprint (tons/year) of energy consumption and electricity production of zahedan gas power plant

Parameter	Years	Gas oil	Natural gas	Electricity production
Emission of carbon dioxide	2021	1317039341.2	26144213.78	1343183554.98
	2022	9130384.8	28082370.65	37212755.45
Carbon dioxide emissions per capita	2021	1708.66	33.91	1742.58
	2022	11.84	36.43	48.27
The intensity of carbon dioxide emissions	2021	288.73	0.053	1097.78
	2022	2.68	0.053	28.30

major polluting industry, it is important to examine the carbon footprint in this sector, as fossil fuels continue to be the number one source of energy for generating electricity. Coal-fired power plants, which have the highest GHG emissions, will occupy the first place in this field and will even have a large share in the coming years [32].

The study of the carbon footprint in the electricity industry in Pakistan showed that the average weighted GHG emission factor in Pakistan's electricity sector was 0.566 tons of carbon per cubic meter (tons of carbon dioxide per megawatt hour) for wind and solar energy projects and 0.478 tons of carbon per cubic meter for hydropower projects. Pakistan's electricity industry is one of the major sources of GHG emissions in the country. Pakistan's national electricity is dominated by thermal energy projects that emit large amounts of carbon dioxide [43].

Between 1995 and 2014, carbon dioxide emissions from the electricity industry fluctuated in the Beijing Tianjin region of Hebei, China, and the overall annual growth was 5.93%. Factors affecting the growth of CO_2 gas production from the electricity industry in the Beijing Tianjin Hebei region were the economic scale, population, transmission and distribution losses, and industrial structure, with a share rate of 150.70%, 20.80%, 8.86%, and 8.83%, respectively.

The effective factors in reducing CO_2 production were power consumption of generators, coal consumption, electricity consumption ratio, household electricity consumption, power generation structure, and fuel mixture, with interest rates of -45.97%, -22.38%, -19.41%, -0.62%, -0.49%, and -0.32%, respectively [44]. Grilo et al analyzed and compared the carbon footprint of solar power supply and thermal power grid in Brazil. Carbon footprints were calculated from two different scenarios for electricity supply. The first scenario used the national electricity grid (a combination of Brazilians), and the second scenario utilized a solar power system connected to the power grid. Solar energy provided significant environmental benefits in comparison to the direct use of electricity from the grid, which was associated with a reduction of around 207/88 CO_2-eq/year. The use of clean energy sources, such as solar sources, could significantly reduce the carbon footprint [45]. Electricity is one of the most widely used and high-level energy carriers that plays a significant role in the development process, but electricity production depends on other energy sources, especially fossil fuels. Fossil fuels are an important source of GHG emissions and the main cause of global warming, with 95% of Iran's electricity generated from these sources. Each kWh of electricity generation from thermal power plants emits 817 g of carbon dioxide, which is the main GHG [46]. In another study, the CO_2 emission index from electricity generation in Malaysia was calculated at 0.329 t/m^2, and the amount of CO_2 accumulation was 1825.96 million tons of CO_2-eq [47].

A draft on carbon emissions and GHGs was presented in the Kyoto Protocol. Carbon emissions can be reduced through the use of solar, wind, farms, and more. There are actually several ways to decrease GHGs. With several simple and practical steps, one can successfully reduce their personal carbon footprint and cause environmental change. Reducing the carbon footprint can be brought about through the economic use of electricity in the home. Using fluorescent or low-energy lamps can reduce about 70 kg of carbon dioxide per household in a year.

Another way to reduce carbon dioxide is to plant trees. A tree absorbs a ton of carbon dioxide during its lifetime and saves as much energy as possible. An effective way to decrease the carbon footprint is to use energy star-rated products. Energy-efficient devices save up to 15% on electricity consumption, reducing your extra cost savings as well [48].

Conclusion

Zahedan Power Plant has used two fuels, namely, oil and natural gases, to generate electricity, which was more than the oil gas in the two years under study. CO_2 emissions from natural gas consumption were higher in 2021 than in 2022.

According to the results, CO_2 emissions increased in 2023 and 2022 compared to 2021. One of the limitations of this study was the lack of data needed about other power plants in each province and city. It seems that by collecting power generation data from the existing power plants in the country, the contribution of each of these plants to the carbon footprint can be assessed equally and simultaneously.

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Authors' Contribution

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Investigation: Mohammad Reza Moudi, Mohammad Velayatzadeh, Tayebeh Dadras Moghadam, Mahnaz Nasr Abadi.
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References
1. Vig N, Ravindra K, Mor S. Environmental impacts of Indian coal thermal power plants and associated human health risk to the nearby residential communities: a potential review. Chemosphere. 2023;341:140103. doi: 10.1016/j.chemosphere.2023.140103.
2. Reddy MS, Basha S, Joshi HV, Jha B. Evaluation of the emission characteristics of trace metals from coal and fuel oil fired power plants and their fate during combustion. J Hazard Mater. 2005;123(1-3):242-9. doi: 10.1016/j.jhazmat.2005.04.008.
3. Crippa M, Guizzardi D, Banja M, Solazzo E, Muntean M, Schaaf E, et al. CO2 Emissions of All World Countries, EUR 31182 EN. Luxembourg: Publications Office of the European Union; 2022. doi: 10.2760/730164.
4. Jozi SA, Saffarian S, Shafiee M. Environmental risk assessment of a gas power plant exploitation unit using integrated TOP-EFMEA method. Pol J Environ Stud. 2012;21(1):95-105.
5. Roelfsema M, Fekete H, Höhne N, den Elzen M, Forsell N, Kuramochi T, et al. Reducing global GHG emissions by replicating successful sector examples: the 'good practice policies' scenario. Clim Policy. 2018;18(9):1103-13. doi: 10.1080/14693062.2018.1481356.
6. Alaa Abbass R, Kumar P, El-Gendy A. An overview of monitoring and reduction strategies for health and climate change related emissions in the Middle East and North Africa region. Atmos Environ. 2018;175:33-43. doi: 10.1016/j.atmosenv.2017.11.061.
7. Guevara M, Enciso S, Tena C, Jorba O, Dellaert S, Denier van der Gon H, et al. A global catalogue of CO2 emissions and co-emitted species from power plants, including high-resolution vertical and temporal profiles. Earth Syst Sci Data. 2024;16(1):337-73. doi: 10.5194/essd-16-337-2024.
8. Skorek-Osikowska A, Bartela Ł, Kotowicz J. Thermodynamic and ecological assessment of selected coal-fired power plants integrated with carbon dioxide capture. Appl Energy. 2017;200:73-88. doi: 10.1016/j.apenergy.2017.05.055.
9. Cushing LJ, Li S, Steiger BB, Casey JA. Historical red-lining is associated with fossil fuel power plant siting and present-day inequalities in air pollutant emissions. Nat Energy. 2023;8(1):52-61. doi: 10.1038/s41560-022-01162-y.
10. Tiwari MK, Bajpai S, Dewangan UK. Environmental issues in thermal power plants–review in Chhattisgarh context. J Mater Environ Sci. 2019;10(11):1123-34.
11. Müller LJ, Kätelhön A, Bringezu S, McCoy S, Suh S, Edwards R, et al. The carbon footprint of the carbon feedstock CO2. Energy Environ Sci. 2020;13(9):2979-92. doi: 10.1039/d0ee01530j.
12. Fenner AE, Kibert CJ, Woo J, Morque S, Razkenari M, Hakim H, et al. The carbon footprint of buildings: a review of methodologies and applications. Renew Sustain Energy Rev. 2018;94:1142-52. doi: 10.1016/j.rser.2018.07.012.
13. Lenzen M, Sun YY, Faturay F, Ting YP, Geschke A, Malik A. The carbon footprint of global tourism. Nat Clim Chang. 2018;8(6):522-8. doi: 10.1038/s41558-018-0141-x.
14. Aichele R, Felbermayr G. Kyoto and the carbon footprint of nations. J Environ Econ Manage. 2012;63(3):336-54. doi: 10.1016/j.jeem.2011.10.005.
15. Mancini MS, Galli A, Niccolucci V, Lin D, Bastianoni S, Wackernagel M, et al. Ecological footprint: refining the carbon footprint calculation. Ecol Indic. 2016;61(Pt 2):390-403. doi: 10.1016/j.ecolind.2015.09.040.
16. Velayatzadeh M. The estimated carbon emissions from fossil fuel consumption in the period 1306-1394 in Iran. J Res Environ Health. 2018;4(3):237-46. doi: 10.22038/jreh.2018.33883.1234. [Persian].
17. Velayatzadeh M. Evaluation of the carbon footprint caused by the consumption of electricity and fossil fuels in the city of Ahvaz during the years 2010-2015. Torang Journal. 2019;1(1):16-22. [Persian].
18. Mansoori ST, Zarghami E. Ecological footprint assessment of the use of fossil fuels in the city of Ahvaz. J Environ Sci Technol. 2021;23(7):281-90. doi: 10.30495/jest.2022.55251.5156. [Persian].
19. Velayatzadeh M, Davazdah Emami S. Carbon footprint emissions and their relationship with energy consumption in Yadavaran oil field in Khuzestan province, Iran. Journal of School of Public Health and Institute of Public Health Research. 2019;17(1):47-60. [Persian].
20. Velayatzadeh M, Davazdah Emami S. Investigating the effect of vegetation on the absorption of carbon dioxide (case study: Yadavaran oil field). Journal of Air Pollution and Health. 2019;4(3):147-54. doi: 10.18502/japh.v4i3.1544.
21. Velayatzadeh M, Mansouri Moghadam S. Relationship between temperature, humidity, oxygen and carbon dioxide in the air of Yadavaran oil field and neighboring cities (Ahvaz and Azadegan plain). Environ Pollut Climate Change. 2022;6(10):302. doi: 10.4172/2573-458x.1000302.
22. Velayatzadeh M, Ahmadi Heydari H. The Role of Carbon and the Effects of Carbon Dioxide on Air Pollution and Human Health. The Second International Research Conference on Agriculture and Environment; 2023. p. 7. [Persian].
23. Mahjoob M, Heydarian S, Nejati J, Ansari-Moghaddam A, Ravandeh N. Prevalence of refractive errors among primary school children in a tropical area, Southeastern Iran. Asian Pac J Trop Biomed. 2016;6(2):181-4. doi: 10.1016/j.apjtb.2015.10.008.
24. U.S. Environmental Protection Agency (USEPA). EMC Conditional Test Method (CTM-030). Determination of Nitrogen Oxides, Carbon Monoxide, and Oxygen Emissions from Natural Gas-Fired Engines, Boilers and Process Heaters Using Portable Analyzers. USEPA; 1997.
25. Statistical Centre of Iran (SCI). Statistical Yearbook of 1400. Program and Budget Organization of the Country. Office of the President, Public Relations and International Cooperation. 1st ed. Tehran: SCI; 2023. p. 926. [Persian].
26. Domestic statistical monthly of thermal power generation industry. Functional information until the end of March 2023. 2023;2(18). [Persian].
27. Lin B, Ahmad I. Analysis of energy related carbon dioxide emission and reduction potential in Pakistan. J Clean Prod. 2017;143:278-87. doi: 10.1016/j.jclepro.2016.12.113.
28. Ahmadi Moghadam M, Ghodrati S, Jaafarzadeh Haghighifard N. CO2 and CH4 emission estimation using emission factors from Sugarcane Development Company. Jentashapir Science

Medicine Journal. 2013;Special Issue:9-17. [Persian].
29. Rees W, Wackernagel M. Urban ecological footprints: why cities cannot be sustainable—and why they are a key to sustainability. In: Marzluff JM, Shulenberger E, Endlicher W, Alberti M, Bradley G, Ryan C, et al, eds. Urban Ecology: An International Perspective on the Interaction Between Humans and Nature. Boston, MA: Springer; 2008. p. 537-55. doi: 10.1007/978-0-387-73412-5_35.
30. Seydi Abdolli MB. Feasibility of reducing carbon dioxide emissions of Ramin power plant by injecting this gas into Ramshir field. Scientific Monthly Oil and Gas Exploration and Production. 2013;(103):50-57. [Persian].
31. Jozi SA, Saffarian S. Environmental risk analysis of Abadan gas power plant using TOPSIS method. J Environ Stud. 2011;37(58):53-66. [Persian].
32. Moosavian SF, Hajinezhad A, Hashemi Zonouzi S, Borzuei D. Evaluation of carbon footprint in steam and combined cycle power plants and comparison with coal-fired power plants. Journal of Sustainable Energy Systems. 2022;1(2):97-110. [Persian].
33. Dalir F, Shabani A, Radmehr H. Estimating the carbon footprint of Ganave combined cycle power plant in the operation phase of its life cycle. The 29th Annual International Conference of the Mechanical Engineers Association of Iran and the 8th Conference of the Thermal Power Plant Industry; 2021; Tehran. [Persian].
34. Ahmadi Shahrivar N, Alimohammadi M, Moattar F, Dehghanifard E, Askari M. Evaluation of pollutants emission from stack vegetable oil factory in north of Iran. J Environ Health Eng. 2017;4(3):184-77. [Persian].
35. Razi Abadi M, Hassani F. Estimation of emission of pollutants from chimneys of rubber mills (case study of Iran Yasa Tire and Rubber). J Environ Sci Stud. 2019;4(1):945-53.
36. Omidi Khaniabadi Y, Rashidi R, Godarzi G, Zare S. Measurement of mass emission values of gaseous pollutants from the stack of Doroud cement plant. Journal of Health in the Field. 2014;2(2):36-42. [Persian].
37. Joshani G, Motesaddi Zarandi S, Pirasteh MH, Momayezi MH, Aghayani E, Taghavi M. Evaluation of carbon footprint and its influencing factors in the cement factory of Abyek. Hozan j Environ Sci. 2016;1(2):38-44. [Persian].
38. Safarzadeh E, Shad Ostanjin E. The effect of hydro-power energy consumption on carbon dioxide emissions, ecological footprint, and carbon footprint in Iran. Iranian Energy Economics. 2021;10(40):39-61. doi: 10.22054/jiee.2022.67134.1901. [Persian].
39. Lau J, Dey G, Licht S. Thermodynamic assessment of CO2 to carbon nanofiber transformation for carbon sequestration in a combined cycle gas or a coal power plant. Energy Convers Manag. 2016;122:400-10. doi: 10.1016/j.enconman.2016.06.007.
40. Delir F, Shafipourmutlaq M, Rouhi K. Reducing the carbon footprint in the electricity industry to deal with climate change (by examining the waste incineration plant). International Conference on Climate Change, Consequences, Adaptation and Adjustment; 2019; Tehran. [Persian].
41. Roy S, Lam YF, Hossain MU, Chan JCL. Comprehensive evaluation of electricity generation and emission reduction potential in the power sector using renewable alternatives in Vietnam. Renew Sustain Energy Rev. 2022;157:112009. doi: 10.1016/j.rser.2021.112009.
42. Anani Y, Delir F, Gamar Z. Reducing the carbon footprint of Iran's electricity grid from the perspective of increasing the energy efficiency of thermal power plants. The 29th Annual International Conference of the Mechanical Engineers Association of Iran and the 8th Conference of the Thermal Power Plant Industry; 2021; Tehran. [Persian].
43. Yousuf I, Ghumman AR, Hashmi HN, Kamal MA. Carbon emissions from power sector in Pakistan and opportunities to mitigate those. Renew Sustain Energy Rev. 2014;34:71-7. doi: 10.1016/j.rser.2014.03.003.
44. Zhang C, Zhang M, Zhang N. CO2 emissions from the power industry in the China's Beijing-Tianjin-Hebei region: decomposition and policy analysis. Pol J Environ Stud. 2017;26(2):903-16. doi: 10.15244/pjoes/66718.
45. de Souza Grilo MM, Fortes AF, de Souza RP, Silva JA, Carvalho M. Carbon footprints for the supply of electricity to a heat pump: solar energy vs. electric grid. J Renew Sustain Energy. 2018;10(2):023701. doi: 10.1063/1.4997306.
46. Sadeghi H, Nouri-Shirazi M, Biabani Khameneh K. The role of electricity generation from renewable sources in reducing greenhouse gases: an econometric approach. Iranian Journal of Energy. 2014;17(3):23-38. [Persian].
47. Fairuz SM, Sulaiman MY, Lim CH, Mat S, Ali B, Saadatian O, et al. Long-term strategy for electricity generation in Peninsular Malaysia – analysis of cost and carbon footprint using MESSAGE. Energy Policy. 2013;62:493-502. doi: 10.1016/j.enpol.2013.08.005.
48. Velayatzadeh M, Ahmadi Heydari H. Principles and Basics of Carbon Footprint. Simorgh Aseman Azargan Publications; 2024. p. 111. [Persian].