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Analysis of CO_2 Mitigation Strategies for Iran's Thermal Power Plants Using Modified STIRPAT Model

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ABSTRACT

Thermal power plants are one of the main sources of CO_2 emissions in the world. On the other hand, increasing carbon dioxide emissions as a greenhouse gas is led to global warming and climate change. In this study, CO_2 mitigation strategies for Iran's thermal power plants regarding Intended Nationally Determined Contributions submitted by Iran using modified STIRPAT model examines are presented. In the first step of this research, CO_2 emissions from Iran's power sector are predicted with respect to the parameters including, population, GDP, and electricity generation. In the second step of this research, CO_2 mitigation strategies including, using the renewable sources and increasing energy saving as well as power generation efficiency during the years of 2020 to 2025 are analyzed using modified STIRPAT model to reduce carbon dioxide emissions in accordance with Iran's INDCs. The prediction of carbon dioxide emissions by 2025 represents an increase of 26.5% in carbon dioxide emissions compared to 2017 while estimating carbon dioxide emissions in accordance with Iran's INDCs allows a maximum increase of 21.4% compared to 2017. In order to reduce carbon dioxide emissions, the average efficiency of power plants by 2025 should be 1.542% higher than in 2017, or 3.086% of the energy savings should be implemented compared to total electricity generation output projected in 2025, or more than 36.22% increment of electricity generation output from renewable energy is expected compared to the projected level in 2025, or a combination of these three solutions.

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INTRODUCTION

The World Bank introduced Iran as one of six countries that emitted 745 million tons of carbon dioxide to the atmosphere, in 2020. The use of fossil fuels as the main source of electric power generation, low energy prices and energy losses in the form of thermal energy, low thermal energy conversion efficiency, energy losses in transmission and distribution networks, and inappropriate implementation of renewable energy in Iran cause carbon dioxide emissions increment from the power sector (Amiri and Eslamian, 2010; Bagheri, 2020; Solaymani, 2020). The Iranian government registered national regulations for the implementation of the Kyoto Protocol in 2005. Also, according to Iran's INDCs, the Iranian unconditional contributions to reduce carbon dioxide emissions by 4% by 2030 have been submitted in November 2015, thus, understanding the factors which have the most important implication on carbon dioxide emissions mitigation especially from thermal power plants is essential. Some research have been done on the carbon dioxide emissions from various sectors in Iran (Lotfalipour et al.,

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2010; Avami and Farahmandpour, 2008; Mousavi et al., 2017). However, carbon dioxide emissions from thermal power plants have not been specifically investigated and its impact factors have not been studied simultaneously. Along with the domestic studies mentioned, various foreign studies recently investigate the impact of population, Affluence, and technology on carbon dioxide emissions in various sector of OECD countries and China. These studies are modeled by the STIRPAT model. In the mentioned studies, the impact of following variables on carbon dioxide emissions have been investigated: population, per capita GDP, the energy structure, Energy efficiency, energy intensity, renewable energy consumption (Bargaoui et al., 2014; de Mattos et al., 2014; Guan et al., 2017; Liddle et al., 2015, Lin et al., 2016; Lv, 2017; Shafiei et al., 2014; Shi et al., 2003; Shuai et al., 2017; Tan et al., 2016; Wang et al., 2013; Wang et al., 2016; Wang and Zhao,2015; Xu and Lin, 2017; Yang et al., 2015; Zhang and Tan, 2016; Zhang and Zhou, 2016; Zhou, 2015; Zhou and Liu, 2016; Zoundi, 2017; Wang et al., 2015). Considering the low range of variables affecting carbon dioxide emissions have been investigated in domestic research, as well as the fact that the variables affecting carbon dioxide emissions in foreign research indicate different and contradictory behavior of these spatial and temporal variables, so, in this study factors affecting on carbon dioxide emissions mitigation for Iran's thermal power plants regarding the Iranian unconditional contributions using modified STIRPAT model has been investigated.

MATERIALS AND METHODS

IPAT and STIRPAT models

The IPAT model was introduced by Erik & Holden in the early 1970s. IPAT is widely used as a model that is easy to understand. This model serves as a framework for measuring the pressure which imposed on the environment by the driving forces, that is described by the following equation (York et al., 2003a; York et al., 2003b).

$$I=P\times A\times T$$

Where, "I" is impact index on the environment, P is a function of population, A is a function of affluence, and T is a function of technology level.

In the IPAT model, it is assumed that "I" is affected by three driving forces, namely P, A, and T. Hence, the IPAT model has limitations due to the direct proportion between the impact on the environment and its driving forces. Therefore, York and his colleagues establish the STIRPAT model with a stochastic form based on the IPAT framework, which resolved the previous model's limitations (York et al., 2003a; York et al., 2003b). The IPAT model cannot be a suitable pattern for non-proportional and non-monotonic driving forces. To overcome these issues, York and colleagues (York et al., 2003a; York et al., 2003b) rearranged the IPAT equation as a stochastic model. The application of this model has been successful in analyzing the driving factors impacts on the environment on several studies as the following equation (York et al., 2003a; York et al., 2003b).

$$I=a.P^{b}.A^{c}.T^{d}.e$$

In the above equation, I is the impact on the environment, P is a function of the population, A is a function of the affluence, T is a function of the technology level, a is the coefficient of the model, b, c and d are the power of independent variables, and e is the model error. By applying a natural logarithm to both sides of the above equation, a nonlinear multivariate model has been obtained as follow:

$I=a+b.Ln\ (P)\ +c.Ln\ (A)\ +d.Ln\ (T)\ +e.Ln\ (e)$

Due to the ability of STIRPAT to expand the model and contribute to additional factors, this model has been used to calculate the pollutants emissions on several studies. In this study, carbon dioxide emissions from Iran's power plants are modeled using general variables of population, affluence, and technology. Considering previous studies and power plants data availability, the variables of population, affluence and technology, each, in turn, have been subdivided into more detailed variables, which are described in Table 1.

Finally, the equation of the STIRPAT model was rewritten as follows:

$$Ln\left(CO_2\right)=C_0+C_1\,Ln\left(P\right)+\ C_2\,Ln\left(pGDP\right)+$$
$$C_3\,Ln\left(EF\right)+C_4\,Ln\left(FC\right)+\ C_5\,Ln\left(H\right)+\ C_6\,Ln\left(R\right)+\ C_7\,Ln\left(A\right)$$

Data Forecasting

In this paper, the data needed for the STIRPAT model factors to estimate carbon dioxide emissions in the period of 2016 to 2025 were used from "Power Plants Development Strategy by1420" project, which was conducted at Niroo Research Institute.

Population prediction by 2025

The Statistical Center of Iran, by carrying out extensive studies and utilizing the knowledge of experts and scholars, has predicted population growth during the five-year periods up to 2031 with four fertility assumptions. The information related to this prediction, which in fact includes 4 scenarios, is presented in Table 2. The population growth rate is positive in the country, but this rate is declining as shown in Table 2.

The fertility reduction scenario is presented as the possible scenario, and the total population size in 2016 was 79,926,270. (According to the latest Population and Housing Censuses). According to these assumptions and information, the forecast of population size by 2025 presented in Table 3.

Table 1. Definitions of the variables in the STIRPAT model

Variable	Symbol	Definition
Carbon dioxide emissions	CO_2	The amount of carbon dioxide emissions from power plants per year
Population	P	The population size of Iran per year
Per capita gross domestic product	$pGDP$	The total value of final products produced by the economic units
Energy Efficiency	EF	The ratio of gross domestic product to the total gross electricity generation output
Fuel Composition	FC	The ratio of the gross electricity generation output from natural gas to the gross electricity generation output generated from mazut and diesel
The share of renewable energies	R	The ratio of the gross electricity generation output from renewable, hydroelectric, and nuclear sources to the total gross electric output
The share of household consumption	H	The ratio of the electric energy consumed in the domestic sector to the total gross electricity generation output
Electricity added value	A	The ratio of the electricity generation added value to the electricity generation total value

Table 2. Forecast of the population growth by 2051

Period	Decrease fertility (1.3 children)	Fertility consolidation (1.8 children)	Increase up to substitution level (2.1 children)	Increase above substitution level (2.5 children)
2011-2016	1.11	1.15	1.17	1.2
2016-2021	0.87	0.95	1	1.07
2021-2026	0.61	0.71	0.79	0.88
2026-2031	0.42	0.55	0.65	0.76
2031-2036	0.28	0.45	0.58	0.72
2036-2041	0.13	0.35	0.52	0.7
2041-2046	-0.06	0.21	0.42	0.65
2046-2051	-0.3	0.03	0.28	0.56

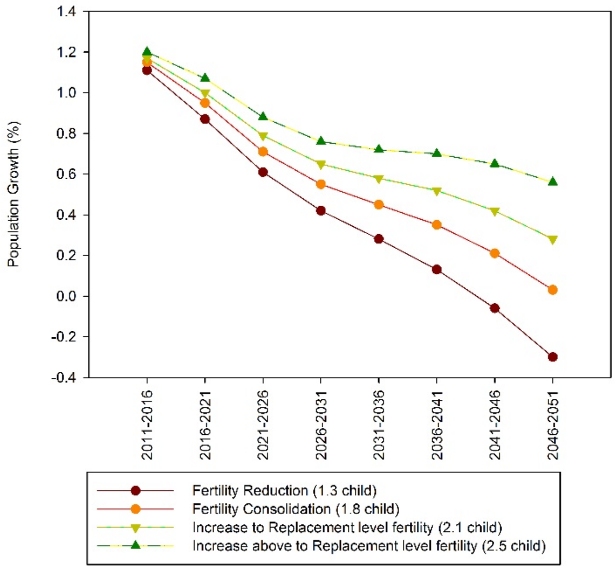

Fig. 1. Different scenarios of population growth by 2051

Gross domestic product by 2025

Energy Conservation and Consumption Management Group of the Niroo Research Institute in 2010 conducted comprehensive studies on how the country's gross domestic product changed over the past years and projected by 2041. In this regard, factors affecting gross domestic product have been identified in Iran and the trend of this variable has been predicted for the next 30 years in Iran. The results of mentioned project, based on economic theories and using econometric techniques and with the help of Eviews and Microfit software, are presented in the project "Power Plants Development Strategy by 2041" in the form of three scenarios: reference, optimistic and pessimistic, The average gross domestic product growth rate in these scenarios is 3.6%, 4.6%, and 2.6%, respectively, in the range of 2011 to 2041. According to World Bank data, based on 2016, Iran's gross domestic product was 425.326 million dollars in 2014. Considering gross domestic product growth rate at 3.6%, the forecast for the gross domestic product by 2025 are presented Table 4.

Prediction of power generation from different sources of energy carriers in Iran by 2025

In 2015, the total nominal capacity of the Iran's power plants was 72,236 MW, and the average practical capacity was 64,536 MW, which, 15197 MW were assigned to the thermal

Table 3. Forecasting of the population by 2025

Year	Population			
	decrease fertility	Fertility consolidation	Increase up to substitution level	Increase above substitution level
2016	79,926,270	79,926,270	79,926,270	79,926,270
2017	80,621,629	80,685,570	80,725,533	80,781,481
2018	81,323,037	81,452,082	81,532,788	81,645,843
2019	82,030,547	82,225,877	82,348,116	82,519,453
2020	82,744,213	83,007,023	83,171,597	83,402,412
2021	83,464,088	83,795,590	84,003,313	84,294,817
2022	83,973,218	84,390,539	84,666,939	85,036,612
2023	84,485,455	84,989,711	85,335,808	85,784,934
2024	85,000,816	85,593,138	86,009,961	86,539,841
2025	85,519,321	86,200,850	86,689,440	87,301,392

Table 4. Forecasting of GDP by 2025

Year	Gross domestic product (Million U.S. dollars)
2015	440638
2016	456501
2017	472935
2018	489960
2019	507599
2020	525873
2021	544804
2022	564417
2023	584736
2024	605786
2025	627595

units (24%), 21495 MW to the gas units (33%), 15112 MW to the combined cyclic units (23%), 11275 MW to the hydroelectric units (18%), 1193 MW to the nuclear and renewable units (2%) and 263 MW are dedicated to diesel units. According to the results of the project "Power Plants Development Strategy by 2041", the electricity generation from various sources and energy carriers will be in accordance with Table 5. The installed capacity of the power plant in Iran will be 123,840 megawatts. To achieve mentioned capacity, it is necessary to invest 55.2 billion dollars in the range of 2016 to 2025.

The prediction of household power consumption by 2025

Electricity consumption has been rising over the two past decades, but the power structure in these two recent decades has been swinging among different consumer sectors. During this time, the share of domestic and agricultural consumption has increased and the share of industrial consumption has decreased slightly in recent years. Therefore, the consumption of domestic and agricultural sectors during this period has increased to the detriment of industrial and commercial sectors, which has been driven by the government's view of providing electricity to households, especially villagers and the agricultural sector. According to the results of the project "Power Plants Development Strategy by 2041", domestic electricity consumption will grow by an average of 5 percent per year. The electricity consumption in the household sector

Table 5. Forecasting of power generation from various energy sources by 2025

Year	Electricity generation output from natural gas (GWh)	Electricity generation output from diesel (GWh)	Electricity generation output from mazut (GWh)	Electricity generation output from coal (GWh)	Electricity generation output from coal (GWh)	Electricity generation output (GWh)
2016	221,423	16,127	27,661	-	22,555	287,766
2017	229,855	22,190	23,928	-	23,322	299,294
2018	209,660	25,089	25,632	27,180	23,774	311,335
2019	213,967	31,841	26,475	27,526	24,106	323,915
2020	226,979	32,433	25,173	27,382	25,090	337,057
2021	244,211	29,678	18,313	29,105	26,075	347,382
2022	265,412	25,791	16,474	18,356	32,032	358,064
2023	284,434	15,629	19,931	14,443	34,681	369,118
2024	284,219	27,766	26,977	4,267	37,326	380,556
2025	280,040	35,536	26,665	11,124	39,029	392,394

Table 6. Forecasting of power consumption in the household sector by 2025

Year	Power consumption (GWh)	Domestic share of total consumption (%)
2016	79,908	33.8
2017	83,904	33.9
2018	88,099	34.1
2019	92,504	34.3
2020	97,129	34.4
2021	101,985	35.0
2022	107,085	35.5
2023	112,439	36.1
2024	118,061	36.6
2025	123,964	37.1

in the range of 2016 to 2025 is presented in Table 6.

The forecast of the electricity generation added value and the forecast of the electricity generation total value

According to the information extracted from the time series of the national accounts of the Central Bank of the Islamic Republic of Iran, the ratio of the electricity generation added value to total electricity generation value remains constant in the period of 2001 to 2013. According to the results of the project, "Power Plants Development Strategy by 2041", this parameter is projected to increase by an average of 7.9% per year from 2017 to 2025.

Carbon dioxide emissions mitigation according to Iran's INDCs

Intended Nationally Determined Contributions (INDCs) submitted by the Islamic Republic of Iran to mitigate its carbon dioxide emissions by 4% based on BAU scenario in unconditional contributions. According to this scenario, Iran must reduce its greenhouse gas emissions by 4% by 2030 compared to the BAU scenario.

It is assumed in this research that the reduction of carbon dioxide emissions from a power plant is considered to be 4%. To meet the Iranian unconditional contributions, by 2030 it is necessary to reduce the carbon dioxide emissions by at least 4% relative to the base scenario (BAU). In this research, it has been assumed also, that the carbon dioxide emission estimation by the STIRPAT model, as an imagined future, supposed to be BAU scenario. Therefore, carbon dioxide emissions should be 4% lower than its estimated value by the STIRPAT model.

Model Modification

Model modification by the increment of electricity generation output from renewable sources

In this section, the carbon dioxide emission model has been modified with the assumption of electricity generation output increment from renewable sources compared to the reference scenario. It is also assumed that other factors involved in the model, which are not related to the gross electricity generation output from renewable sources, such as population, per capita GDP, fuel composition, household consumption, and electricity generation added value, are unchanged, and the ratio of electricity generation output from renewable sources to total electricity generation output, as a related variable, is changed.

By assuming that the gross electricity generation output increment from renewable energies replaces gross thermal electricity generation output, the overall electricity generation output remains constant and carbon dioxide emissions from thermal electricity generation output also reduced. Due to the consolidation of the total gross electricity generation output, the increased fraction of R variable will be equal to the increased fraction of the electricity generation output from renewable sources. Therefore, if the increased fraction of the electricity generation output from renewable sources is equal to m, then:

$R_2 = (1+m) \times R_1$

By placing the variable R_2, the STIRPAT model will be rearranged as follows:

$$Ln\left(CO_2\right) = C_0 + C_1\, Ln\left(P\right) + C_2\, Ln\left(pGDP\right) + C_3\, Ln\left(EF\right) + C_4\, Ln\left(FC\right)$$
$$+ C_5\, Ln\left(H\right) + C_6\, Ln\left(\left(1+m\right)\times R\right) + C_7\, Ln\left(A\right)$$

In the STIRPAT model, the ratio of electricity generation output from renewable sources to total electricity generation output (R) is in the range of 7.36% to 9.95%. Therefore, the increment of electricity generation output from renewable energy may cause the R variable to locate out of range that used to fit the model, In that case, the STIRPAT model should be modified.

If carbon dioxide emission showed by CO_2, and the carbon dioxide for the increased ratio of electricity generation output from renewable energies to total electricity generation output, R, showed by CO_2', and other variables will remain unchanged in both cases, then:

$$Ln\left(CO_2^{'}\right) = C_0 + C_1\, Ln\left(P\right) + C_2\, Ln\left(pGDP\right) + C_3\, Ln\left(EF\right) +$$
$$C_4\, Ln\left(FC\right) + C_5\, Ln\left(H\right) + C_6\, Ln\left(\left(1+m\right)\times R\right) + C_7\, Ln\left(A\right) + \mathrm{Ln}\left(Z\right)$$

Which, Ln (z) is the term of the model correction. The difference in the increase in emissions is presented by the following equation:

$$Ln\left(CO_2^{'}\right) - Ln\left(CO_2\right) = +C_6\, Ln\left(\left(1+m\right)\times R\right) - C_6\, Ln\left(R\right) + \mathrm{Ln}\left(Z\right)$$

Consequently, carbon dioxide emissions in the mode of increasing the electricity generation output from renewable energy are equal to:

$$CO_2^{'} = CO_2 \times (1+m)^{C_6} \times z$$

On the other hand, carbon dioxide emission in the condition of no change in the fuel composition in proportion to the amount of electricity generation output from thermal power plants, then:

$$\frac{CO_2^{'}}{CO_2} = \frac{(1-R')}{1-R} = 1 - \frac{m \times R}{1-R}$$

The correction term of the STIRPAT model is equal to:

$$Ln(z) = Ln\left[\frac{\left(1-\frac{m \times R}{1-R}\right)}{(1+m)^{C_6}}\right]$$

By inserting the above correction, the modified model will be rearranged as follows:

$$Ln(CO_2) = C_0 + C_1\,Ln(P) + C_2\,Ln(pGDP) + C_3\,Ln(EF) +$$
$$C_4\,Ln(FC) + C_5\,Ln(H) + C_6\,Ln((1+m) \times R) + C_7\,Ln(A) + \mathrm{Ln}\left[\frac{\left(1-\frac{m \times R}{1-R}\right)}{(1+m)^{C_6}}\right]$$

Model modification with energy saving on the user's side

In this section, the carbon dioxide emission model has been modified with the assumption of energy savings. For this, it is assumed that other factors involved in the model that are not related to energy consumption, such as population, per capita GDP, fuel composition, household consumption share and electricity added value are unchanged, and factors such as energy efficiency, and The ratio of electricity generation output from renewable energies to total electricity generation output are changed. It is assumed that energy savings do not reduce GDP. In other words, the energy efficiency variable in which the ratio of GDP to the amount of energy consumption, is changed in a way that GDP remains constant for less energy consumption. Therefore, energy efficiency will increase with energy saving. If the reduced fraction of the electric energy consumed is assumed to be α, the productivity variable will be changed according to the following equation:

$$EF_2 = EF_1 \times \frac{1}{1-\alpha}$$

In addition to energy efficiency, energy savings will change the ratio of electricity generation output from renewable energy to total electricity generation output. Since energy savings have been made to reduce carbon dioxide emissions, it is clear that energy saving is assumed to mitigate electricity generation output from fossil fuels and the electricity generation output from renewable energy remains unchanged. Therefore, by saving energy, the ratio of electricity generation output from renewable sources to total electricity generation output will be decreased. If the reduced fraction of the electric energy consumed is assumed to be α, the ratio of electricity generation output from renewable sources to total electricity generation output is varied according to the following equation:

$$R_2 = R_1 \times \frac{1}{1-\alpha}$$

By replacing the modified energy efficiency and the modified ratio of electricity generation output from renewable sources to total electricity generation output in above equations, then:

$$Ln\left(CO_2^{"}\right) = C_1\, Ln\left(P\right) + C_2\, Ln\left(pGDP\right) + C_3\, Ln\left(EF \times \frac{1}{1-\alpha}\right)$$

$$+C_4\, Ln\left(FC\right) + C_5\, Ln\left(H\right) + C_6\, Ln\left(R \times \frac{1}{1-\alpha}\right) + C_7\, Ln\left(A\right)$$

As a result, the STIRPAT model for carbon dioxide emissions with the α-energy saving fraction is rearranged as follows:

$$Ln\left(CO_2^{"}\right) = C_1\, Ln\left(P\right) + C_2\, Ln\left(pGDP\right) + C_3\, Ln\left(EF\right) + C_4\, Ln\left(FC\right)$$

$$+\, C_5\; Ln(H) +\; C_6\; Ln(R) +\; C_7\; Ln(A) - (C_3 + C_6) \times \mathrm{Ln}(1-\alpha)$$

Modification of the STIRPAT model by increasing the efficiency of the power plants

By increasing the thermal-electric energy conversion efficiency at power plants, the amount of fuel consumed decreases to produce a certain amount of electrical energy. Therefore, the amount of carbon dioxide emissions calculated in the STIRPAT model will change. If the fuel consumption of the power plants remains constant, the change in fuel consumption will not change the variables of the model. Therefore, it is necessary to modify the STIRPAT model by assuming an increase in the efficiency of the power plants.

In order to generate a certain amount of electricity generation output, increasing the power plant's efficiency reduces the required heat value and consequently reduces the amount of primary fuel consumed. Assuming that the initial efficiency of the power plant is equal to η and increasing the power plant's efficiency equal to ε, the secondary efficiency is equal to:

$$\eta_2 = \eta + \varepsilon$$

If the heat value necessary to generate a certain amount of electricity generation output(E) with η efficiency is equal to A and the heat value necessary to generate the same electrical energy output in case of efficiency increment is equal to A', then:

$$E = A \times \eta$$

$$E = A' \times \left(\eta + \varepsilon\right)$$

$$\therefore A' = A \times \frac{\eta}{\eta + \varepsilon}$$

In order to produce a certain amount of heat value, with the constant rate of heat value to consumed fuel, the heat value generated was proportional to fuel consumed, in other words, if generated heat value by the consumption fuel of F is equal to A, then A' heat value is generated as follows:

$$F \times calorific\, value = A$$
$$F' \times caorific\, value = A'$$
$$\therefore F' = F \times \frac{\eta}{\eta + \varepsilon}$$

Given that carbon dioxide emissions are proportional to fuel consumption, then:

$$CO_2' = CO_2 \times \frac{\eta}{\eta + \varepsilon}$$

Finally, the STIRPAT model for carbon dioxide emissions by increasing power plant efficiency rearranged as follows:

$$Ln\left(CO_2'\right) = Ln\left(\frac{\eta}{\eta + \varepsilon}\right) + C_1\, Ln\left(P\right) + C_2\, Ln\left(pGDP\right) + C_3\, Ln\left(EF\right)$$
$$+ C_4\, Ln\left(FC\right) + C_5\, Ln\left(H\right) + C_6\, Ln\left(R\right) + C_7\, Ln\left(A\right)$$

Calculation of emissions reduction parameters regarding Iran's INDCs

In this section, the relationship between the carbon dioxide emission reduction parameters, such as the increase in ratio of electricity generation output from renewable sources to total electricity generation output, the increase in energy efficiency through the consumption management, and the increase in average efficiency of the power plants to achieve emission reductions according to the Iranian unconditional contributions has been studied. For this purpose, the modified models are combined as follows:

$$Ln\left(CO_2\right) = C_0 + C_1\, Ln\left(P\right) + C_2\, Ln\left(pGDP\right) + C_3\, Ln\left(EF\right) + C_4\, Ln\left(FC\right)$$
$$+ C_5\, Ln(H) + C_6\, Ln(R) + C_7\, Ln(A) + Ln\left[\frac{\left(1 - \frac{m \times R}{1 - R}\right)}{(1+m)^{C_6}}\right] + C_6\, Ln(1+m)$$
$$+ Ln\left(\frac{\eta}{\eta + \varepsilon}\right) - (C_3 + C_6) \times \mathrm{Ln}(1 - \alpha)$$

If, on the right side of the above equation, population, per capita GDP, energy efficiency, fuel composition, renewable energy ratio and the ratio of electricity generation added value of corresponding to each year have been located, and the carbon dioxide emissions would be in accordance with the Iranian unconditional contributions, then the resulting equation Indicates the relationship between: increasing the ratio of electricity generation output of renewable sources to the total electricity generation output, increasing energy efficiency through consumption management, and also increasing the average efficiency of power plants in terms of emission reductions.

$$\alpha = e^{\frac{Ln\left(CO_2^{model}\right) - Ln\left(CO_2^{Paris}\right) + Ln\left[\frac{\left(1 - \frac{m \times R}{1-R}\right)}{(1+m)^{C_6}}\right] + C_6\, Ln(1+m) + Ln\left(\frac{\eta}{\eta+\varepsilon}\right)}{C_3 + C_6}}$$

Where $Ln\left(CO_2^{model}\right)$ has represented carbon dioxide emissions before emission mitigation and $Ln\left(CO_2^{Paris}\right)$ is referring to the reduced carbon dioxide emissions in accordance with the Iranian unconditional contributions.

RESULTS AND DISCUSSION

Carbon dioxide emissions forecast by 2025

By putting the predicted data values (Table 7), the carbon dioxide emissions from the power plants in the period of 2013 to 2025 will be according to Table 7. The carbon dioxide emissions for 2017-2025 are shown in Fig.2.

Using the predicted data and carbon dioxide emissions from power plants, the following points can be concluded:

1. The amount of carbon dioxide emissions from the power plants will increase from the beginning and end of the period of 2017 to 2025 and remain relatively constant in the middle years (2020-2022).

2. The amount of carbon dioxide emissions from the country's power plants will be equal to 206.198 million tons by 2025, which is 26 percent higher than 2017. The average annual growth

Table 7. Forecasting of STIRPPAT Model impact factors and carbon dioxide emissions from power plants by 2025

Year	Population	Per capita GDP (Dollars per person)	Energy Efficiency (Dollars per Kilowatt-hour)	Ratio of household consumption to total electricity generation output	The ratio of value added of electricity generation to total electricity generation value	Ratio of electricity generation output from renewable energy to total electricity generation output	Fuel composition	Carbon dioxide emissions (million tons per year)
2013	76,942,000	6631	1.952	0.251	0.1331	0.0736	1.316	154.606
2014	77,856,747	5443	1.550	0.259	0.1331	0.0678	2.615	155.661
2015	78,782,370	5593	1.570	0.271	0.1331	0.0616	4.489	155.679
2016	79,926,270	5712	1.586	0.278	0.1331	0.0784	5.057	155.803
2017	80,621,629	5866	1.580	0.280	0.1331	0.0779	4.984	163.057
2018	81,323,037	6025	1.574	0.283	0.1437	0.0764	2.691	178.342
2019	82,030,547	6188	1.567	0.286	0.1551	0.0744	2.493	185.552
2020	82,744,213	6355	1.560	0.288	0.1674	0.0744	2.671	190.124
2021	83,464,088	6527	1.568	0.294	0.1806	0.0751	3.168	191.642
2022	83,973,218	6721	1.576	0.299	0.195	0.0895	4.378	188.821
2023	84,485,455	6921	1.584	0.305	0.2104	0.0940	5.688	188.745
2024	85,000,816	7127	1.592	0.310	0.2271	0.0981	4.816	196.474
2025	85,519,321	7339	1.599	0.316	0.2452	0.0995	3.819	206.198

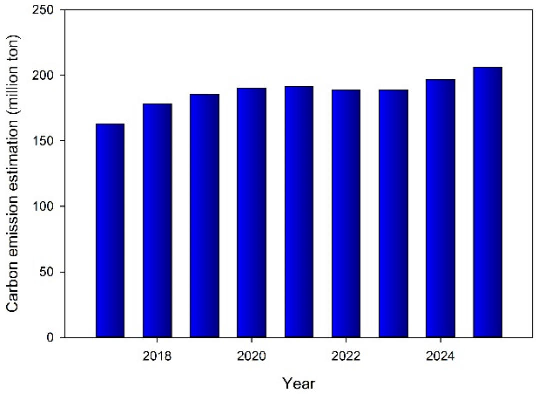

Fig. 2. Carbon dioxide emissions from power plants in the period of 2017-2025

Table 8. The carbon dioxide emissions from Iran's thermal power plants based on the modified STIRPAT model with respect to the Iranian unconditional contributions

Year	**Forecasted emissions** (Million tons of CO_2)	**Emissions regarding the Iranian unconditional contributions** (Million tons of CO_2) (million kg of CO_2)	**Emission reduction** (Million tons of CO_2)
2017	163.057	-	-
2018	178.342	-	-
2019	185.552	-	-
2020	190.124	182.519	7.605
2021	191.642	183.976	7.666
2022	188.821	181.268	7.553
2023	188.745	181.195	7.550
2024	196.474	188.615	7.859
2025	206.198	197.950	8.248

rate is 3%.

3. 3. 1,688,954 million tons of carbon dioxide will be released by the country's power plants in the range of 2017 to 2025. The share of each year will be 187.662 million tons.

The results of applying the model to predict carbon dioxide emissions showed that if the power generation policies followed in accordance with the project "power development strategy by 2041", the carbon dioxide emissions from power plants increased more than 26% by 2025, compared to 2017. These statistics show the Necessity of careful policy-making and correct development of the power sector.

Results of carbon dioxide emissions mitigation based on the Iranian unconditional contributions

Based on forecasted emission's data in the period of 2017 to 2025, carbon dioxide emissions have been estimated regarding the Iranian unconditional contributions in the range of 2020 and 2025, which can be seen in Fig.3. To meet the objectives of the Iranian unconditional contributions, carbon dioxide emissions should be 182.519 million tons at 2020 and increase to 197.950 million tons by 2025, equivalent to 4% mitigation compared to BAU scenario.

In order to reduce carbon dioxide emissions from 2020 to 2025, increasing the electricity generation output from renewable sources, increasing the average efficiency of power plants and increasing the energy efficiency on the consumer side by relying on lower electricity consumption in the constant level of GDP is recommended. The relationship between increasing the electricity generation output from renewable sources, increasing the average efficiency of power plants, and saving electric energy to reach the Iranian unconditional contributions are shown in the graphs of Figs 4 to 9 for each individual year. The horizontal axis of these graphs shows the average increase in power plants efficiency from the current value of 37% and the vertical axis represents the amount of electrical energy savings, corresponding to increasing efficiency, to meet the objectives of the Iranian unconditional contributions. For example,

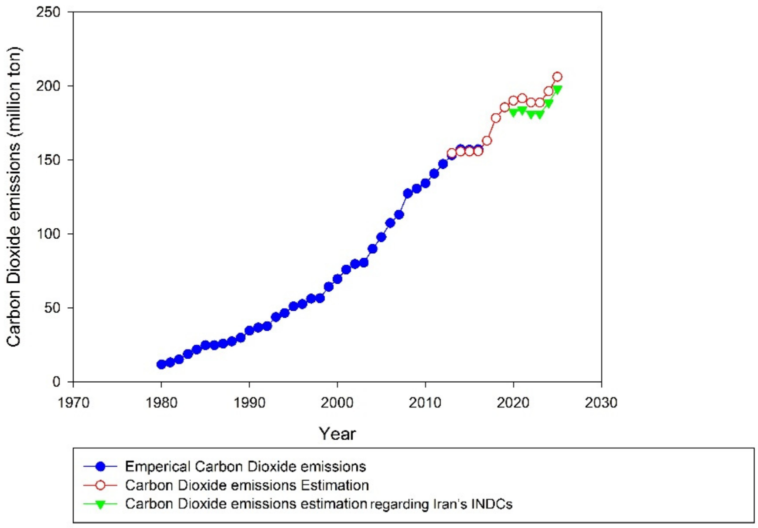

Fig. 3. The comparison of carbon dioxide emissions from Iran's thermal power plants based on the STIRPAT model with respect to the Iranian unconditional contributions

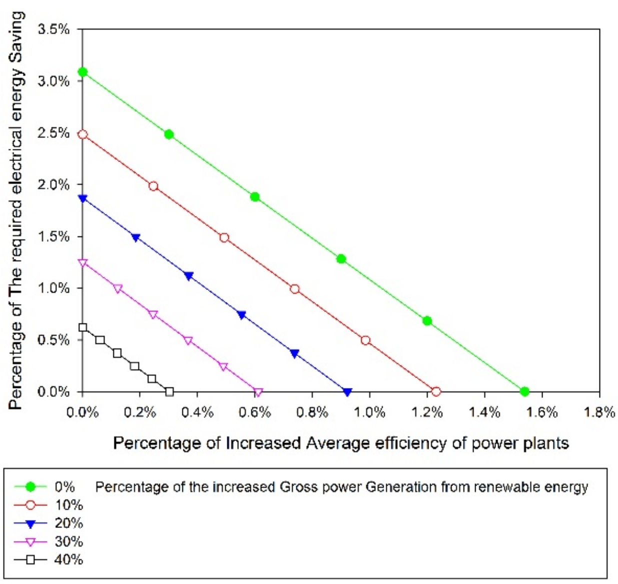

Fig. 4. Relationship between increased gross power generation from renewable energy, increased average efficiency, and energy saving by 2020 to achieve carbon dioxide emission mitigation in accordance with the Iranian unconditional contributions

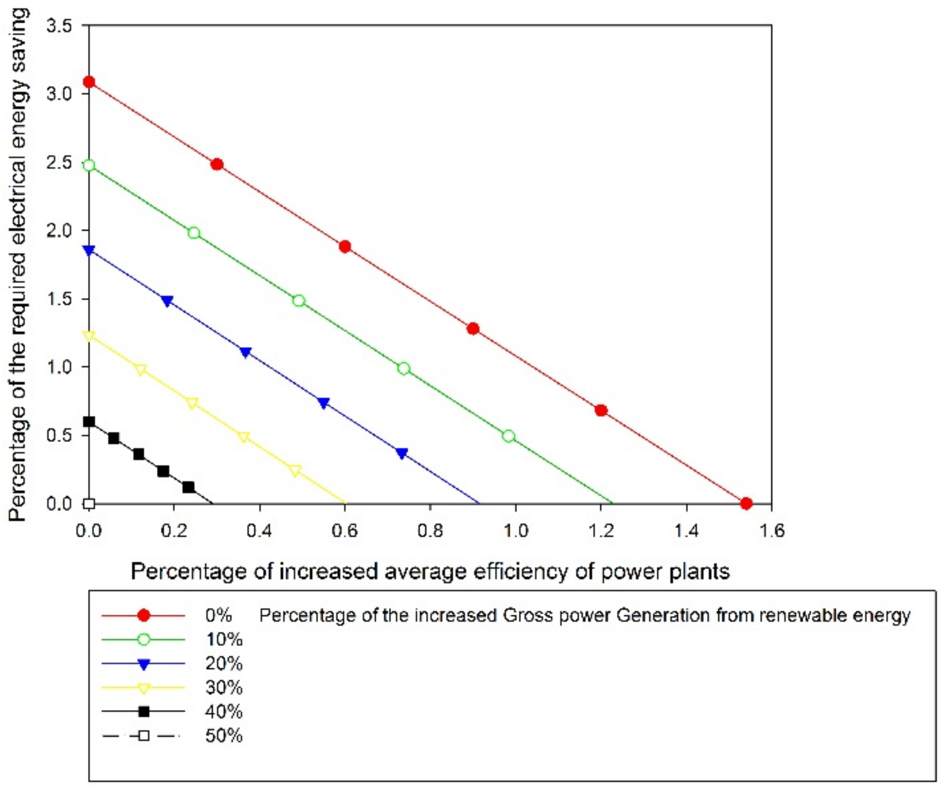

Fig. 5. Relationship between increased gross power generation from renewable energy, increased average efficiency, and energy saving by 2021 to achieve carbon dioxide emission mitigation in accordance with the Iranian unconditional contributions

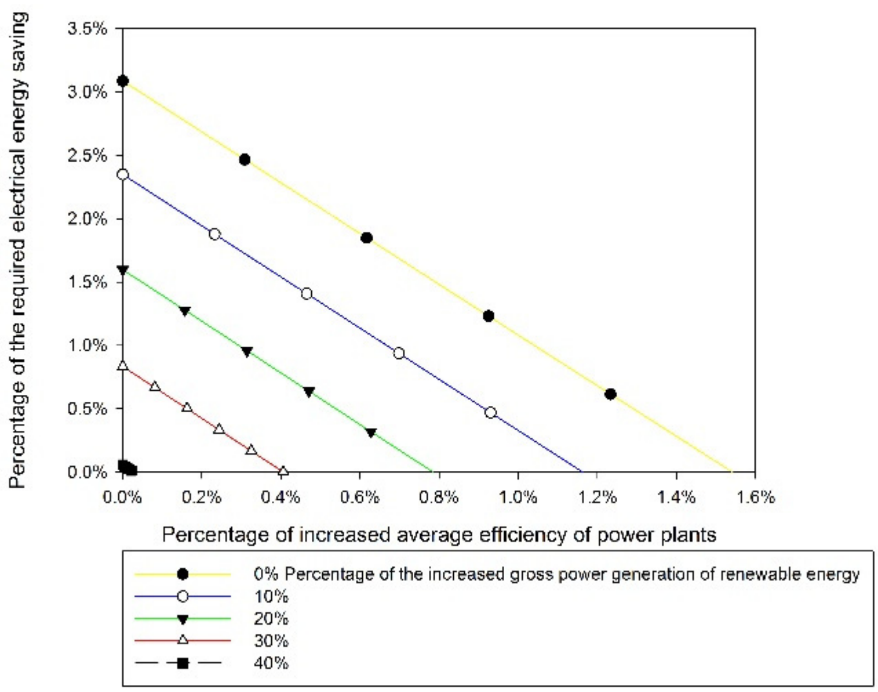

Fig. 6. Relationship between increased gross power generation from renewable energy, increased average efficiency, and energy saving by 2022 to achieve carbon dioxide emission mitigation in accordance with the Iranian unconditional contributions

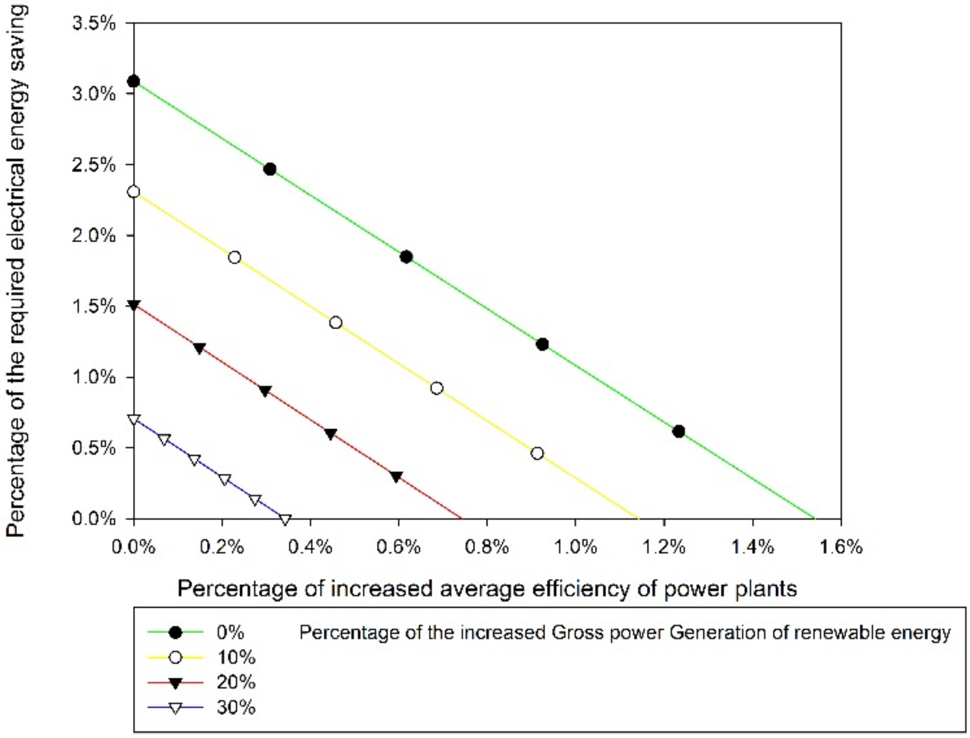

Fig. 7. Relationship between increased gross power generation from renewable energy, increased average efficiency, and energy saving by 2023 to achieve carbon dioxide emission mitigation in accordance with the Iranian unconditional contributions

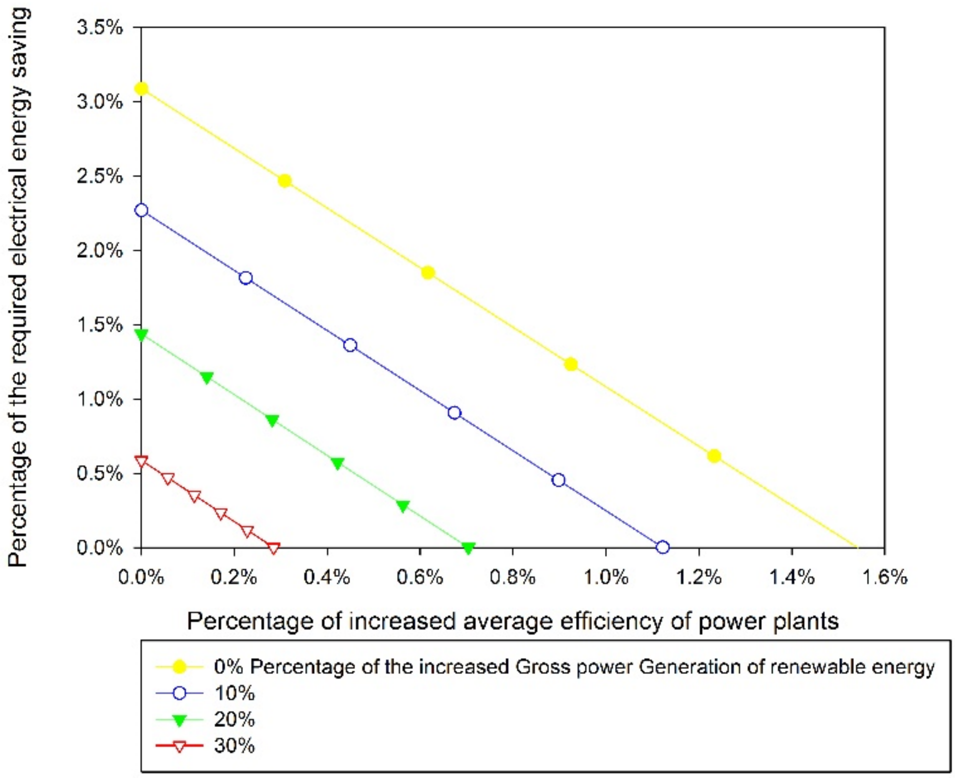

Fig. 8. the relationship between increased gross power generation from renewable energy, increased average efficiency, and energy saving by 2024 to achieve carbon dioxide emission mitigation in accordance with the Iranian unconditional contributions

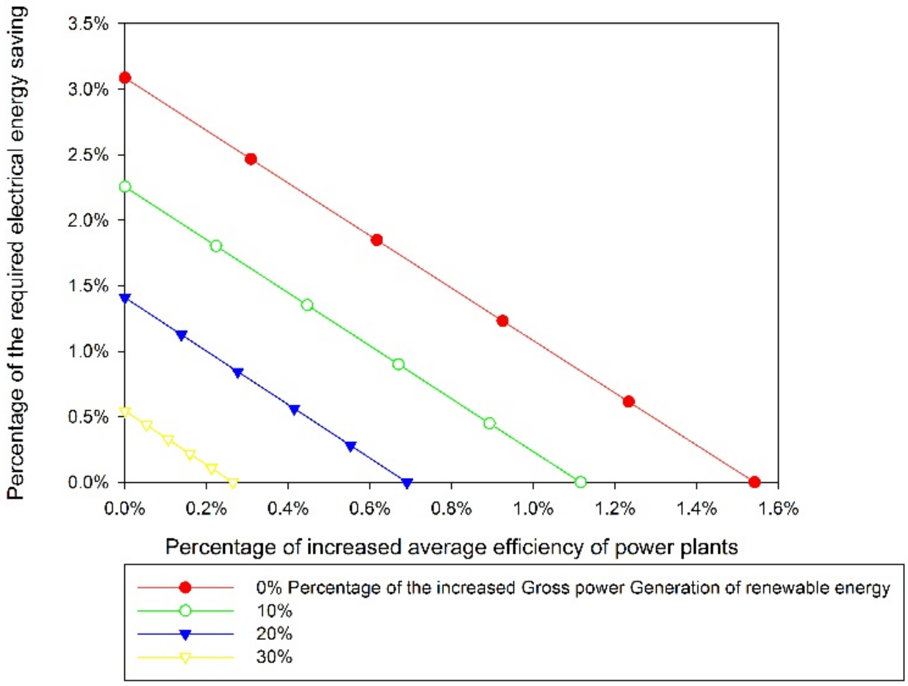

Fig. 9. the relationship between increased gross power generation from renewable energy, increased average efficiency, and energy saving by 2025 to achieve carbon dioxide emission mitigation in accordance with the Iranian unconditional contributions

according to Fig.4, if the production of electric output from renewable sources does not increase, in order to achieve the objectives of the Iranian unconditional contributions in 2020, the average efficiency of power plants should be increased by 1.54% or electricity consumption should be decreased 3.09% compared to their forecasted value in table 7. If the increase in electricity generation output from renewable energy sources increases by 10% compared to the projected level, in order to meet the objectives of the Iranian unconditional contributions, the average efficiency of power plants should increase by 0.5% and save 1.5% of the electric energy consumption. However, In order to achieve the objectives of the Iranian unconditional contributions in the mentioned range, the highest average increment in power efficiency should be 1.542% compared to current efficiency and the highest amount of electrical energy saving is 3.086% compared to the projected electricity generation output. The presented diagrams contain important information for policymakers to reduce carbon dioxide emissions. However, economic studies should also be undertaken to adopt the best solution for mitigating carbon dioxide emissions.

CONCLUSION

The prediction of carbon dioxide emissions by 2025 represents an increase of 26.5% in carbon dioxide emissions compared to 2017 while estimating carbon dioxide emissions regarding the Iranian unconditional contributions allows a maximum increase of 21.4% compared to 2017. Therefore, the necessity of using the carbon dioxide mitigation strategies is serious. In order to reduce carbon dioxide emissions, the average efficiency of power plants by 2025 should be 1.542% higher than in 2017, or 3.086% of the energy savings should be implemented compared to total electricity generation output projected in 2025, or more than 36.22% increment of electricity generation output from renewable energy is expected compared to the projected level in 2025, or a combination of these three solutions.

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CONFLICT OF INTEREST

The authors declare that there is not any conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

REFERENCES

Amiri, M. J., & Eslamian, S. S. (2010). Investigation of climate change in Iran. J. Environ. Sci. Technol., 3(4), 208-216.

Avami, A., & Farahmandpour, B. (2008). Analysis of environmental emissions and greenhouse gases in Islamic Republic of Iran. WSEAS Trans. Environ. Dev., 4(4), 303-312.

Bargaoui, S. A., Liouane, N., & Nouri, F. Z. (2014). Environmental impact determinants: An empirical analysis based on the STIRPAT model. Procedia Soc. Behav. Sci., 109, 449-458.

Bagheri, S. (2022). Analysing the CO_2 Emission Function in Iran. Environment and Interdisciplinary Development, 7(76), 61-73.

de Mattos, E. J., & Filippi, E. E. (2014). Drivers of environmental impact: A proposal for nonlinear scenario designing. Environ. Model. Softw. , 62, 22-32.

Guan, Y., Kang, L., Shao, C., Wang, P., & Ju, M. (2017). Measuring county-level heterogeneity of CO_2 emissions attributed to energy consumption: A case study in Ningxia Hui Autonomous Region, China. J. Clean. Prod., 142, 3471-3481.

Lotfalipour, M. R., Falahi, M. A., & Ashena, M. (2010). Economic growth, CO_2 emissions, and fossil fuels consumption in Iran. Energy, 35(12), 5115-5120.

Liddle, B. (2015). What are the carbon emissions elasticities for income and population? Bridging STIRPAT and EKC via robust heterogeneous panel estimates. Glob. Environ. Change. , 31, 62-73.

Lin, B., Omoju, O. E., Nwakeze, N. M., Okonkwo, J. U., & Megbowon, E. T. (2016). Is the environmental Kuznets curve hypothesis a sound basis for environmental policy in Africa? J. Clean. Prod., 133, 712-724.

Lv, Z. (2017). The effect of democracy on CO_2 emissions in emerging countries: does the level of income matter? Renew. Sustain. Energy Rev., 72, 900-906.

Mousavi, B., Lopez, N. S. A., Biona, J. B. M., Chiu, A. S., & Blesl, M. (2017). Driving forces of Iran's CO_2 emissions from energy consumption: an LMDI decomposition approach. Appl. Energy, 206, 804-814.

Shafiei, S., & Salim, R. A. (2014). Non-renewable and renewable energy consumption and CO_2 emissions in OECD countries: a comparative analysis. Energy Policy, 66, 547-556.

Shi, A. (2003). The impact of population pressure on global carbon dioxide emissions, 1975–1996: evidence from pooled cross-country data. Ecol. Econ., 44(1), 29-42.

Shuai, C., Shen, L., Jiao, L., Wu, Y., & Tan, Y. (2017). Identifying key impact factors on carbon emission: Evidences from panel and time-series data of 125 countries from 1990 to 2011. Appl. Energy, 187, 310-325.

Tan, X., Dong, L., Chen, D., Gu, B., & Zeng, Y. (2016). China's regional CO_2 emissions reduction potential: A study of Chongqing city. Appl. Energy, 162, 1345-1354.

Wang, C., Wang, F., Zhang, X., Yang, Y., Su, Y., Ye, Y., & Zhang, H. (2017). Examining the driving factors of energy related carbon emissions using the extended STIRPAT model based on IPAT identity in Xinjiang. Renew. Sustain. Energy Rev., 67, 51-61.

Wang, P., Wu, W., Zhu, B., & Wei, Y. (2013). Examining the impact factors of energy-related CO2 emissions using the STIRPAT model in Guangdong Province, China. Appl. Energy, 106, 65-71.

Wang, S., Fang, C., & Wang, Y. (2016). Spatiotemporal variations of energy-related CO_2 emissions in China and its influencing factors: An empirical analysis based on provincial panel data. Renew. Sustain. Energy Rev., *55*, 505-515.

Wang, Y., & Zhao, T. (2015). Impacts of energy-related CO_2 emissions: evidence from under developed, developing and highly developed regions in China. Ecol. Indic., 50, 186-195.

Xu, R., & Lin, B. (2017). Why are there large regional differences in CO_2 emissions? Evidence from China's manufacturing industry. J. Clean. Prod. , 140, 1330-1343.

Yang, Y., Zhao, T., Wang, Y., & Shi, Z. (2015). Research on impacts of population-related factors on carbon emissions in Beijing from 1984 to 2012. Environ. Impact Assess. Rev., 55, 45-53.

York, R., Rosa, E. A., & Dietz, T. (2003). Footprints on the earth: The environmental consequences of modernity. Am. Sociol. Rev., 279-300.

York, R., Rosa, E. A., & Dietz, T. (2003). STIRPAT, IPAT and ImPACT: analytic tools for unpacking the driving forces of environmental impacts. Ecol. Econ. , 46(3), 351-365.

Zhang, C., & Tan, Z. (2016). The relationships between population factors and China's carbon emissions: Does population aging matter? Renew. Sustain. Energy Rev., 65, 1018-1025.

Zhang, C., & Zhou, X. (2016). Does foreign direct investment lead to lower CO_2 emissions? Evidence from a regional analysis in China. Renew. Sustain. Energy Rev., 58, 943-951.

Zhou, Y., Liu, Y., Wu, W., & Li, Y. (2015). Effects of rural–urban development transformation on energy consumption and CO_2 emissions: A regional analysis in China. Renew. Sustain. Energy Rev., 52, 863-875.

Zhou, Y., & Liu, Y. (2016). Does population have a larger impact on carbon dioxide emissions than income? Evidence from a cross-regional panel analysis in China. Appl. Energy, 180, 800-809.

Zoundi, Z. (2017). CO_2 emissions, renewable energy and the Environmental Kuznets Curve, a panel cointegration approach. Renew. Sustain. Energy Rev., 72, 1067-1075.

Solaymani, S. (2020). A CO_2 emissions assessment of the green economy in Iran. Greenh. Gases: Sci., 10(2), 390-407.

Wang, Y., Zhang, X., Kubota, J., Zhu, X., & Lu, G. (2015). A semi-parametric panel data analysis on the urbanization-carbon emissions nexus for OECD countries. Renew. Sustain. Energy Rev., 48, 704-709.